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KAWASAKI TECHNICAL REVIEW

Special Issue on Motorcycle & Engine

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Fun to Ride for everyone

Kawasaki

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Bringing the Kawasaki brand to people around the world

Hiroshi Takata
Senior Executive Vice President

What is the place of the motorcycle & engine business within the Kawasaki Group?

Unlike our other businesses that are mainly directed at corporate customers, the motorcycle & engine business focuses on consumer products. Our business can be divided broadly into our two-wheel, four-wheel, and Jet Ski vehicle businesses that interact directly with consumers through our products, and our general-purpose engine business that provides products to OEM companies. In either case, the Kawasaki brand name is the selling point in these products.

Please talk to us about the Kawasaki brand

The Kawasaki brand is known worldwide for its motorcycle business, so I expect many people actually equate Kawasaki with motorcycle manufacturing.

As the vice president in charge of marketing, my goal is to leverage the strength of our motorcycle brand to enhance the Kawasaki group brand as a whole. To do that, of course, Kawasaki motorcycles need to be products worthy of the brand. As president of the Motorcycle & Engine Company, I challenged our engineers to "put products front and center." As senior executive vice president my role has shifted but my thinking remains unchanged. A strong brand depends on the development of strong products. A strong brand attracts customers and gives them a sense of joy and pride as owners of Kawasaki products. Which is why I believe we need to continue to strengthen our brand — to increase our non-price competitiveness.

We often hear mention of a "Kawasaki style."

For our motorcycle business, "Fun to Ride," "Ease of Riding," "environment," and "loyalty" have been the keywords that have guided our development efforts. The "Kawasaki style" means "strong models" that seek to deliver a "Fun to Ride" experience that appeals to all five senses so riders never want to stop riding with us. In the case of our general purpose engines, which are tools that our customers use for work, the focus of our development has been on "professional-use, high value-added engines."

Through our pursuit of "Kawasaki style," I believe we can contribute to our group mission of "Kawasaki, working as one for the good of the planet."

Speaking of the Kawasaki brand, the Ninja 250/300 has been very popular, hasn't it?

The Ninja 250/300 has become popular as an entry-level model in advanced countries, and as a premium model in emerging countries. Together with its sibling Z250, the series as a whole is predicted to exceed an annual production of 100,000 units. That will be the highest annual production in the history of our company's motorcycle business. My hope is that these new models will become a part of the legacy that was forged by their predecessors, such as the Z1/Z2 and Ninja 900R, as they continue to lead the Kawasaki brand into the future.

What is the future of our group's brand strategy?

Our goal is to further strengthen our brand in global markets. Although our group has some name recognition domestically, we feel that the brand is still weak globally, including in emerging countries. Luckily, people in many countries enjoy Kawasaki motorcycles. This means that our motorcycle business has an important role to play in strengthening recognition of the Kawasaki group.

Factors that support brand strength include quality, performance, and design. Another important factor in recent years has been environmental performance. Even in the motorcycle market, a growing number of customers are concerned with environmental performance. This is why we are actively involved in research and development to increase fuel efficiency and comply with environmental regulations.

Our group produces many products with advanced environmental technologies. I want customers around the world to know us as a brand that is committed to helping the environment.

Current status and future prospects of the motorcycle & engine business

Shigehiko Kiyama
Senior Vice President
President, Motorcycle & Engine Company

Preface

For over 50 years, our motorcycle & engine business has been centered on products developed and manufactured in Japan for export and sale in advanced countries. Since the Lehman Shock, however, the structure of our business has been changing in response to the new financial and economic environment. Today it is not just our sales activities that are important. Rather our product development, QDC (Quality, Delivery, Cost), and supply-chain balance must reflect the market so that our business is better attuned to market changes. The current status and future prospects of our business are discussed in this article.

1 Current status

(1) Two-wheel vehicle (motorcycle) business

(i) Advanced country markets

Our company refers to markets in the U.S., Canada, Europe, Australia, and Japan as advanced country markets. Since the sub-prime lending crisis of 2007, demand in these markets has shrunk considerably due to financial instability and its impact on the real economy. The added impact of the strong yen has also lowered cost competitiveness against European and American manufacturers, making it difficult for businesses to achieve high profitability.

Thanks to financial deregulation and economic stimulus actively undertaken by these countries, change became visible beginning in 2013. While recession continues to plague the European market, the U.S. market has bottomed out and is recovering, albeit modestly. In Japan, the market has been improving with the economic upswing, and there are now quantitatively hopeful signs. At the same, however, weak employment and asset contraction has driven consumer tastes toward low-price products, revealing a trend toward categories not previously seen in advanced countries.

Despite this, our company has retained a high market share through the ongoing introduction of new models and support of our sales network. At the same time, by optimizing development including in our Thai R&D division and transferring production to our Thai plant (KMT*) (Fig. 1(a)), we have increased our cost competitiveness, which has contributed significantly to sales, through low-cost procurement and manufacturing of our entry models.

*KMT: Kawasaki Motors Enterprise (Thailand) Co., Ltd.

(ii) Emerging country markets

Emerging country markets, which include ASEAN, China, India, and Central and South America, represent the largest chunk of global demand for two-wheel vehicles. Unlike our competitors, we are not known for low-price, mass-marketed products like mopeds and scooters. Rather, our sales are driven by the sports category focused on our Ninja Series and the recognition that Kawasaki stands for "high-performance premium motorcycles." While demand in advanced country markets has slumped, it has increased steadily with economic growth in emerging country markets. That said, as capital has flowed backwards into advanced countries and credit uncertainty has prevailed, growth has slowed in some markets recently. Despite all of this, demand for our premium products remains as solid as ever and sales continue to grow.

(2) Four-wheel business

In our main market, the U.S., we have seen a shift from ATVs (all-terrain vehicles) to two or four-seater SxS (Side by Side) utility vehicles and sport vehicles. This trend has become especially noticeable in recent years, with competitors actively continuing to enter the market. Kawasaki too has actively introduced new models for the growing SxS market and is engaged in initiatives to increase our recognition in the market and strengthen revenue.

(3) PWC (personal watercraft) business

Because the main market for our PWC business is the U.S., our U.S. plant (KMM*) (Fig. 1(b)) specializes in the production of Jet Ski personal watercraft developed in Japan. The market is dominated by large 1,500 cm^3 models. Like other companies, Kawasaki makes continuous improvements to its products to maintain product competitiveness.

*KMM: Kawasaki Motors Manufacturing Corp., U.S.A.

(4) General-purpose engine business

The main products in our general-purpose engine business are engines used in professional equipment such as lawnmowers and agricultural tractors. In contrast to our two-wheel vehicles, everyday consumers will rarely have direct contact with our general-purpose engines, yet we still provide highly reliable engines at a reasonable cost.

(a) Kawasaki Motors Enterprise (Thailand) Co., Ltd.

(b) Kawasaki Motors Manufacturing Corp., U.S.A.

Fig. 1 Global network

2 Near-term business operations

Our efforts are focused on improving business profitability in advanced countries, and on capturing demand and strengthening our business foundation in leisure motorcycle market in emerging countries. Sales of the Ninja 250 Series are very healthy and production has been partially transferred back to Japan as part of our strategy of “global production without lost opportunities.” Our current revenue sources lean toward emerging countries, but our goal is to build a business in which advanced and emerging countries are balanced.

Overseas production for our general-purpose engine business is centered on our U.S. and Chinese (CK&K*) plants, reflecting significant changes to our business structure over these past three years. Even with changes to our production system and the role of our “mother factory,” the Akashi Works in Japan, our operations will aim to strike a balance in QDC.

We are currently reorganizing the Akashi Works and reviewing its facilities in view of global production so that it will continue to be a factory where coming generations can work with confidence.

*CK&K: Changzhou Kawasaki and Kwang Yang Engine Co., Ltd.

3 New models for 2014

Our 2014 models, which were announced beginning summer of last year, have been extremely well received. The 2014 Ninja 250 makes minor changes that incorporate various improvements. Because our production capacity in 2013 was inadequate, we have also made improvements in production that enable us to make sales without lost opportunities. On the Ninja ZX-14R, Ninja 1000 (Fig. 2), and Z1000 (Fig. 3), we strengthened features to create products that reflect the “voice of customers” and offer them more attractive products. We also introduced the four-wheel Teryx4 SxS (Fig. 4) and Jet Ski ULTRA 310 Series (Fig. 5).

Fig. 2 Ninja 1000

Fig. 3 Z1000

Fig. 4 Teryx4

Fig. 5 Jet Ski ULTRA 310 Series

4 Future business prospects

Our first goal is "to further strengthen our brand." Even after the Lehman Shock, our company actively continued to introduce competitive new models in advanced country markets despite the recession. We also enlisted various marketing techniques (racing activities, new store designs) with the aim of strengthening our brand. It is fair to say these efforts elevated our brand image in emerging countries as well and contributed to increased sales. Looking ahead, we will continue to use our advanced craftsmanship to introduce "strong models" that strengthen our brand.

Our efforts will also stress "environmental compliance." Because noise and emissions regulations are getting stricter every year and an increasing number of customers are concerned with fuel efficiency and environmental performance, electric is one direction we are considering. Because this market is expected to grow with improved battery performance and advances in control technology, we will continue to concentrate our efforts on research and development.

5 Globalization

We no longer live in an age when the simple overseas export of domestically manufactured products from Japan is enough to generate profits. Under conditions of high yen appreciation, globalization was sometimes equated with overseas procurement. At present, we believe that "the proper path for globalization is optimally localized procurement and optimally localized production." The notion of "local production, local consumption" is fundamental to minimizing currency risk and reducing lead times. At the same time, an approach to supply chains that includes nearby production countries-an "Oobeya" approach-can strengthen network effects by limiting capital investment and lowering costs. Today is an age of global procurement, manufacturing, and sales. As such, our goal must be to optimize our business as a whole by solving complex equations daily to strike a balance in QDC.

Closing

Operations at the Motorcycle & Engine Company have been extremely challenging under recent financial and economic conditions, especially in the past five years, as has been the case for many Japanese export firms engaged in manufacturing. Despite the challenges, the experience has been invaluable. During this period, we have undertaken measures not only to increase profit ratios and constrain costs but also to strengthen our brand. As a result, we have increased profitability and will continue to do so in the future.

I express our sincere gratitude to the stakeholders who have believed in and supported our company, and reaffirm our commitment to being a strong company that delivers the Kawasaki brand to customers around the world as a top-class manufacturer.

Consumer-driven product development: strategies and execution

Kohei Yamada
General Manager, Research & Development Division,
Motorcycle & Engine Company at the time of writing

Preface

At Kawasaki Motorcycle & Engine Company, we are taking a new initiative, "voice of the customers," in order to raise profitability to its maximum potential. This article provides an overview of its customer-centered strategies and execution.

1 Vital role of the Customer Insight during product development for mature markets

The author proposes a unique definition of a "mature market" in this article. In the early stages of a consumer market, consumers have limited product knowledge, very limited brand relationship because of their lack of purchase experience, so when a company launches "new and improved" products, customers will buy the new products replacing the old ones. In a mature market, however, customers have deep product knowledge and brand preference as a result of their purchase experiences. And individual customers know exactly what they like and what they dislike, and this knowledge actively drives their own brand/product choice behavior. They already have their own consideration set before purchase. They are selective. A mature market is defined as a consumer-driven market.

Whether a country is emerging or already advanced, its markets always proceed from underdeveloped to mature. In a mature market, in which customers are the ones who best understand what they want, low prices are no longer a major motivation for making a purchase. If a product does not reflect the consumers' value system, they will never purchase it. When doing business in a mature market, or dealing with knowledgeable, experienced and brand-conscious consumers, it matters little how much money a company has invested in R&D, plant, property and equipment or how much the company believes its product to be "new and improved." Unless the customers' tastes are reflected in the product, the company will find it hard to make profits in a mature market.

Consequently, deep understanding of customers, or customer insight, should be the starting point of product planning. Customer strategies based on customer insight are vital to the development of profitable new products. In other words, "customer research" is as necessary as engineering research for a manufacturer hoping to develop profitable products.

(1) Customer insight

Customer insight is a deep understanding of customers that comes only from repeating customer research. A company's sustainable competitive advantage in terms of product differentiation meaningful to the customers, cost management, speed of development, and quality is affected by the quality and quantity of the customer insight the company has acquired. It is no exaggeration to say that a difference in customer insight is the difference in corporate competitiveness.

And because customer insight is not something easily imitated, it is fair to say that customer insight is the source and foundation of long-term competitive advantage. The ability to think up products that will sell is, so to speak, the ability to think up products that customers will choose. There is no doing that without customer insight. Developing products that will sell requires the kind of innovation and inspiration that can only be achieved through interactions with customers, as depicted in Fig. 1.

(2) Customer strategy

The speed of maturation varies widely from one market to the next. Companies need to be prepared for the time when their markets mature. Above I defined a mature market as one in which customers themselves best understand the products they want to buy, and in which companies cannot simply force their products on customers. In this type of market, if you have 100 different customers you will have as many different customer

Fig. 1 Customer preferences research

preferences. To deal effectively with this situation, our company's product planning department groups (segments) customers and works to make clear the customer groups, the top-priority customer groups (target segments), that will resolve the business concerns we face as a company. In mature markets, customers are selective, but at the same time, manufacturers must be selective as well.

Which customer group should we take care of by this product? If this group were to purchase the product, in what ways will the company benefit? What will be the competitors' reaction? Are our customers superior to the competitors' customers? These are the kinds of questions that need to be addressed. For instance, if stable cash flow stream is our goal, then it is important to increase the number of customers who show strong brand loyalty* and tendency of making cash purchases. The more the number of profitable loyal customers, the higher the economic stability in volatile times. That being the case, the products we develop need to elicit a strong response from that segment. A company's problems will be ultimately solved by its customers. This integrated way of thinking about target customers based on our business concerns is called a customer strategy.

* Brand loyalty: The tendency of customers to purchase specific brand products even when substitute products are available from competing companies, as well as their feelings of affection toward the brand.

(3) Segmentation studies and targeting

Our tool for identifying our most important customers (target customers) is segmentation. When done correctly, segmentation automatically reveals target segments. Brands and products will be developed for the target segments. Moreover, the ability to segment customers effectively determines the quality and effectiveness of our subsequent product development and the level of our product's profitability.

(4) Development plan as a Strategy Document

With so many people involved in product development, documentation is needed to align everyone's direction. The development plan should fully reflect customer insights based on our various forms of research and should be shared and thoroughly understood and agreed upon by all development personnel.

Naturally, as a strategy document, the development plan must be drafted with our strategic competitive advantage in mind. At the same time, the document must be crafted in a way that is as easy to understand as possible. The easier the plan is to understand, the greater the speed and accuracy of communication will be, and it means that the strategy will be executed effectively and efficiently and the expected results will be perfectly achieved.

(5) Voice of the Customers (V.o.C.) activities

In simplest terms, V.o.C. activities are those that bring the target customers into the product development process and elicit feedback and ideas from them. Such activities should begin from the time when the previous product model enters the market. At that stage customers can provide valuable development feedback that helps prevent the need to change directions or backpedal later on in the development process. "Customer-driven product development" based on V.o.C. places importance on post-sales.

Another anticipated benefit of V.o.C. is the inspiration that our engineers derive from direct contact with customer opinion, allowing them to generate highly competitive ideas as a result. Ideas to significantly lower costs also often emerge at this stage. That said, customers are not development professionals who can be expected to provide specific solutions, to identify alternative actions, or to offer concrete proposals for new products. Actionable ideas will solely come from the engineers themselves.

2 Important elements in product development

The mission of the R&D department is to meet targets in terms of schedule, cost, and product differentiation. These three elements are indicators of a company's competitive strength in product development. Each of these three elements is closely tied to customer insight.

(1) Schedule

As we define it, the development period begins the day the kickoff meeting for the product in development is held, and ends the day that normalized production begins. The business plan depends on the start date of normalized production for the new product. If that date is delayed, it can wreak havoc on revenues. Likewise, an extension of the development period not only can result in higher R&D expenses but also affects negatively the schedule of the next models. As obvious as it may seem, a delay in the schedule can never be regained. That is why, of the three elements, we place the greatest importance on adhering to the schedule. Adhering to the development schedule, much less shortening it, demands that any waste in the development process be eliminated. Development front-loading, which I will comment on below, is one method for achieving this.

(2) Cost

We execute comprehensive cost management on the understanding that a company's value depends on its ability to lower costs. By assigning cost coordinators to each product in development, we are able to see how much any given design change costs each time a design change is made.

New products are developed on the assumption that they will have a higher marginal profit ratio than existing products. Even so, there is no point to developing a product if carelessly lowering its cost in areas that are important to customers when making a purchase decision is going to result in developing a non-competitive product that sells fewer units. That is why we leverage customer insight to fully understand areas that customers do not value in order to aggressively reduce costs in those areas during the initial stages of development.

(3) Product Competitiveness; Purchase Motivation Drivers and Customer Satisfaction Drivers

When we talk about product strength, we need to know there are two kinds of product attributes, i.e., Purchase Motivation Drivers and Customer Satisfaction Drivers.

(i) Purchase Motivation Drivers (Product appeal)

Purchase Motivation Drivers are defined as "the ability to attract customers based on a product's attributes that customers recognize and understand *before* purchasing the product, and by outperforming other companies in the delivery of those attributes." To maintain sales levels in the long term after a product has launched, we need very strong Purchase Motivation Drivers over rival companies. We establish and continuously strengthen product appeal by obtaining customer feedback early on.

Customers, not companies, decide whether a product is appealing or not. This is why, to create new products with greater appeal than rival company's, it is important for R&D departments to actively use the language, metaphors, and stories that our customers use, to share with them a common "culture," and to make various R&D decisions from within that commonly fostered culture.

(ii) Customer Satisfaction Drivers (Brand Loyalty Drivers)

Customer Satisfaction Drivers, on the other hand, are defined as "the ability to satisfy and retain customers based on the differentiated product's attributes that the customers understand *after* purchasing the product, and by outperforming other companies in the delivery of those attributes." Strengthening Customer Satisfaction Drivers is vital if we want to retain customers who repeatedly choose our products and enable us to secure stable cash flow streams, and to do this by strengthening customer brand loyalty and our brands' "defenses" against the various forms of "attack" by rival companies, such as new products and price reduction.

(iii) What is a "Strong Product"?

A strong product is defined as "a product that continually attracts the target customers and contributes significantly to the corporate bottom line." In terms of customer satisfaction and marginal profit, the strongest product is one with the highest customer satisfaction score and the highest marginal profit.

By measuring annual changes in customer satisfaction and marginal profit by region, product, and brand, it becomes possible to identify our important areas.

3 How to develop "Strong Products"

The following is an overview of the elements of R&D management, i.e., Process and Structure, that are important for developing the "Strong Products."

(1) Process

(i) Front-loaded approach

Front-loading is primarily a means of keeping to the development schedule. Engineers must be pro-active, intuitive, and foresighted. The period between the kick-off and design freeze is referred to as the front-loading stage. In addition to maintaining the schedule, it is important during this front-loading stage to "produce a more complete prototype vehicle" by focusing on improvements in the development process. Because product appeal and cost are often determined at this stage, we make every effort during the image sketch stage, which occurs early in the front-loading stage, to invite discussion, encourage discoveries, identify negative aspects, and generate ideas. This sketch review, consisting of brain-storming sessions, is a means of making discoveries more rapidly. An effective way of doing this is to discuss previous ideas that were set aside for reasons of time during the development of earlier product models. These ideas can be put back on the table at the sketch review stage and discussed.

(ii) Closed loop development

The effectiveness of front-loading depends on feedback from customers regarding earlier product models. Rather than repeat the same mistakes over and over by repeatedly developing new products without customer feedback, engineers obtain feedback *directly* from customers to increasingly "strengthen" the product. Such closed loop development is also valuable because it cultivates intuition, which is important to supplement the limitations of knowledge in new product development.

Customer surveys are used as a means of obtaining actionable feedback, with an emphasis placed on the importance of post-sales. R&D activities do not end until feedback is obtained from the customers.

(iii) Regulatory measures and compliance

Regulatory measures and compliance in each country's market are also considered as a part of R&D, though I will not go into them in detail here. We make every effort not only to collect information about regulatory developments in our sales regions well in advance, but also to actively express the company's views on trends toward regulation. It is a part of R&D activities.

(2) Structure

(i) Organizational specialization

We currently develop a wide range of products, each with its own specific customers and rival companies. To achieve our development schedule and cost objective while generating product appeal, it is essential to make rapid, rational decisions about each product. For that reason, when development goals and target customers are highly specific to a given product, it is necessary to have development values that are specific to each development team. At Kawasaki, we have undertaken organizational specialization, still based on V.o.C.

① Profit-driven Team

The Profit-driven Team gives first priority to marginal profit. Throughout development, it keeps in mind that "a company's ability to lower costs is an important part of its value" and "cost management is accumulated knowledge about the target customers, and technologies are a source of competitiveness." They lead product development primarily for emerging countries.

② Tech-driven Team

There are some product areas where V.o.C. activities alone are not enough to increase product appeal. These include product areas driven by technologies that are superior to those of other companies, an area in which our company stood out in the past.

The engineers in this area need to create technological "spontaneous mutations" in our products that generate long-term excitement among passionate Kawasaki enthusiasts by delivering design specifications that are ten years ahead of their time. This team develops "technical barrier" technologies and products that could only be developed and produced at our mother factory, the Akashi Works. These are marketed primarily in advanced countries.

(ii) Organizational unit's value vector
(Performance measure and key driver)

Within these specialized organizational units, engineers share the same value vector in order to avoid schedule delays due to conflicting development decisions or cost increases as a result of excessive evaluation standards. As their value vector, a performance measure and key driver are identified in advance for each team when assigning them a product in development.

① Performance measure

This is the definition of product development success and the top priority among the many numerical objectives that development is expected to achieve. This number represents the degree of success and is used to draw comparisons with previous product models and ultimate objectives.

② Key driver

Among the many product development requirements (schedule, costs, product appeal, national regulations, testing and research costs, etc.), this is the driver that leads product development to success and is an important value vector for the development team.

For the Profit-driven Team, their performance measure and key driver are both marginal profit ratio; for the Tech-driven Team, the performance measure and key driver are the design specification and technical innovation, respectively.

Each development team requires specialized expertise to achieve competitive advantage over rival companies with which each development team directly competes. For that reason, even when teams face similar issues, their solutions to them may differ radically. This phenomenon is considered evidence that our organizational specialization is functioning properly.

(3) Development tools

(i) Research tools

In terms of achieving competitive advantage, the important question that management faces, beyond the development process and structure, is what development tools the management can provide engineers so they can meet their objectives in terms of schedule, cost, and product appeal. There are various tools—knowledge, insight, analytical software, management techniques, research tools, and networking with external professional organizations. Tools themselves are an important element of competitive advantage.

I have already said that customer research is vital to developing consumer products that are highly oriented to consumer tastes. The following is an overview of some of the tools currently used for customer research.

① Paperless marketing research

Engineers meet *directly* with the target customers to ask questions, seek confirmation, make discoveries, and take action. We do not take uncertain action based on reports written by intermediary people.

Fig. 2 Usage studies examine how customers use products

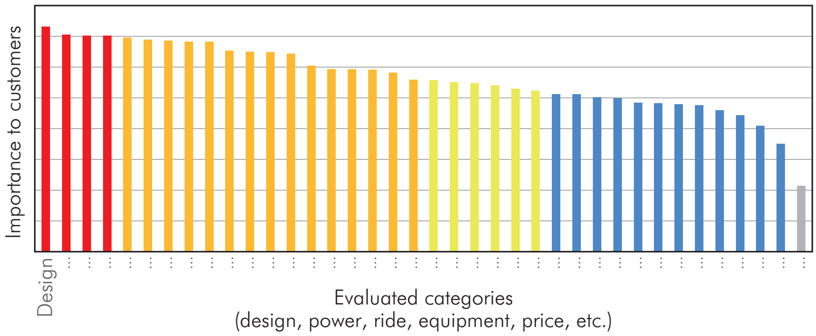


Fig. 3 Example of "visible" research results

② Usage studies (Fig. 2)

From the realization that some questions can only be answered by customers on-site, our engineers visit customers during the front-loading stage to study how they actually use our products. These studies have a major impact on schedule, cost, and product appeal during the subsequent product development process. Because usage differs from one customer to the next, usage studies are directed at the target customers identified in the development plan.

(ii) Visualizing the research results

In order to develop high quality products that satisfy requirements in terms of schedule, cost, and product appeal, everyone involved in development needs to share the results of research accurately. For that reason, the measured results of our research are always quantified (Fig. 3).

After making improvements to product appeal, we measure product strength by region and product model in order to understand what elements were more important to the customers when they made purchase decisions. We make these results "visible" so everyone understands at a glance where we should direct our spending to "strengthen" our products before our competitors do. The following are categories we measure for comparison with rival companies and our earlier products, our current position, and speed of improvement.

- Level of customer satisfaction (by region, by product model)
- Points of customer dissatisfaction, and their ranking
- Important attributes for customers, and their ranking (Sharing points of concern with customers)
- Level of customer satisfaction for important attributes

Closing

Our V.o.C. activities after the launch of a product allow us to hear directly from customers around the world. Customers' voices permeate our R&D office. In their own words they tell us enthusiastically how Kawasaki's products have benefited them. The emotional relationship between our engineers and customers will create a bright future by allowing Kawasaki to keep introducing "Strong Products."

Ninja ZX-14R – A new flagship that delivers both power and controllability

The Ninja ZX-14R (ZZR1400 in Europe) was developed with the goal of creating Kawasaki's ultimate flagship model. Its engineers gave their all to take motorcycle performance to a whole new level. This monster of a machine delivers stunning acceleration with its overwhelming power while ensuring a stable ride even at 300 km/h — it is also surprisingly easy to handle even in everyday riding situations. This paper gives a behind-the-scenes look at how the ZX-14R was developed.

** Model names for the Japanese market are used for this article.*

Preface

Carrying on the lineage of the ZZR1100 (ZX-11 in North America) released in 1990 that was passed down through successive flagships, the ZZR1400 (ZX-14 in North America) released in 2006 has received high evaluations in the market with a compact riding position realized by a creative frame structure, light handling, and a smooth engine with little vibration. However, due to the weak throttle response in the everyday range and other factors, it did not manage to outstrip its rival models by a decisive margin. For this reason, the Ninja ZX-14R (ZZR1400 in Europe) was developed with the aim of creating Kawasaki's ultimate flagship model that offers greater performance improvements.

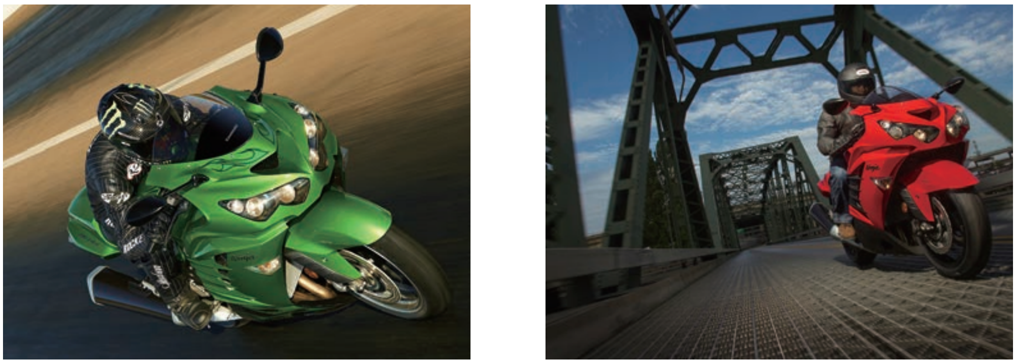
1 Concept and features

(1) Concept

In order to leverage the market evaluation of the predecessor model in the development of the ZX-14R, the opinions of the owners of the predecessor model were surveyed and analyzed, and the design policy was determined as follows.

- Aim for the best-performing motorcycle.
- Take the popular creative external design a step further (Fig. 1).
- Build on the strengths of the predecessor model and thoroughly improve the weaknesses.
- Aim for a presence befitting a flagship model by focusing on quality that exudes a sense of luxury.

Fig. 1 Conceptual sketch



(a) Sport riding

(b) City riding

Fig. 2 Various riding situations

In the course of our survey, we heard many of the owners use the expression "a large motorcycle with an imposing presence." We decided this was another important keyword that we needed to focus on.

(2) Features

With its powerful styling and outstanding performance, this is without a doubt a true monster machine. Nevertheless, once the motorcycle is straddled, one finds it surprisingly easy to handle with its compact riding posture, not only for sport riding and long-distance touring but for daily use as well (Fig. 2). This diversity is what makes the ZX-14R truly appealing.

(i) New engine that demonstrates overwhelming power (Fig. 3)

The engine with increased torque over the entire range easily delivers 147.2 kW for the various specifications around the world. Straight from the manufacturing lines with no enhancements made, this monster machine zips through a quarter mile in just 9.77 seconds from a standing start.

(ii) Creatively designed body with excellent maneuverability

The superb handling of the predecessor model, which was described as being almost like riding a supersport model, was taken up a notch thanks to improved frame rigidity and reduced wheel weight. The characteristic quadruple headlights and sharply edged cowling not only added to the imposing appearance and presence, but also improved the windscreen performance and heat dissipation. The more substantial tail volume makes for a dignified presence suitable for a flagship.

(iii) Advanced control which improves controllability

The KTRC (Kawasaki TRaction Control) traction control system optimized for riding on public roads assists the driver with throttle control in various riding situations, from large-output sport riding to negotiating unpaved gravel roads. Using the KTRC with power mode selection will enable the rider to unleash the full power of the engine with confidence.

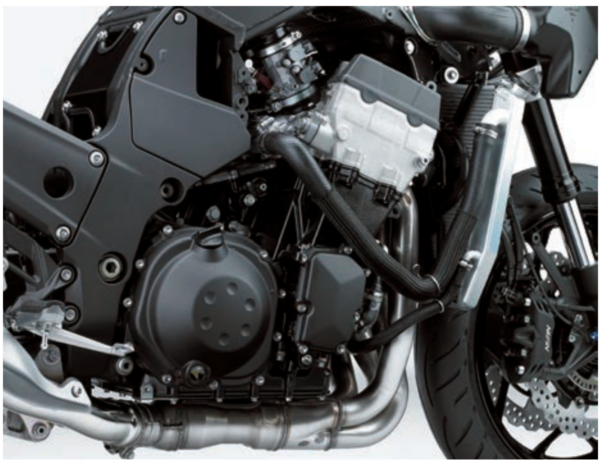


Fig. 3 Newly developed 1,441 cm^3 engine with 147.2 kW

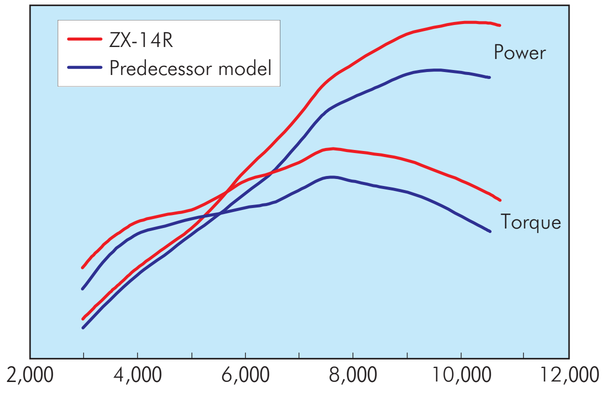


Fig. 4 Engine performance

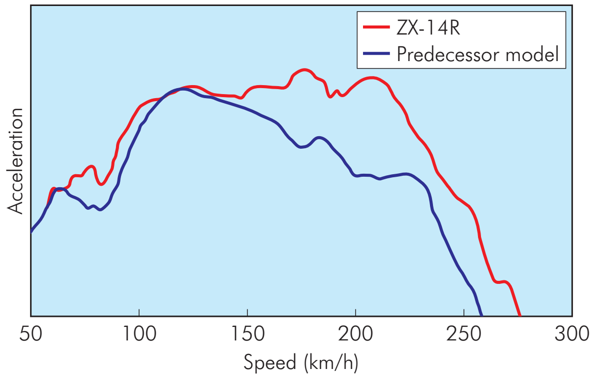


Fig. 5 Acceleration performance

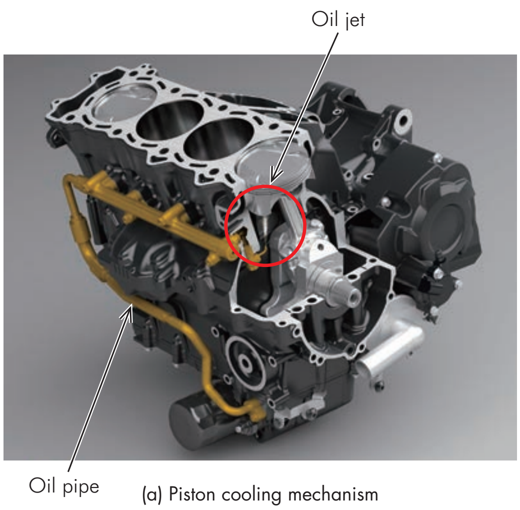
2 Engine related technology

In order to increase the "low-range torque" to overcome the weakness of the predecessor model, and further boost acceleration in the mid- to high-range to add to its strength, the displacement was increased to 1,441 cm^3. However, when the engine becomes larger, the wheel base of the motorcycle also expands, detracting from its maneuverability. Therefore, the piston stroke was increased as much as possible within a range where the center distance between the crankshaft and the transmission does not expand. As a result, the power and torque were substantially improved without changing the size of the engine in the front and rear directions of the body, and the development goal of realizing an "overwhelming engine performance" was achieved (Fig. 4 & Fig. 5). The main changes and improvements we made to achieve the development goal are discussed below.

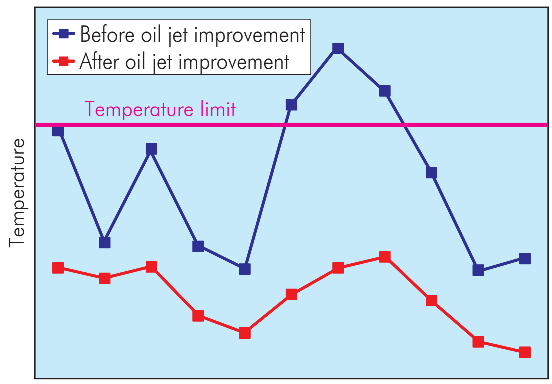
(1) Engine

(i) Compression ratio, intake and exhaust ports

By changing the combustion chamber configuration that consists of the cylinder head and pistons, we were able to increase the compression ratio from 12.0 to 12.3, thereby improving combustion efficiency. In addition, the volume of intake air was also increased by adding a polished finish to the inner surface of the intake ports of the cylinder head, expansion of the exhaust ports, and raising the position of the intake and exhaust valves.



(a) Piston cooling mechanism



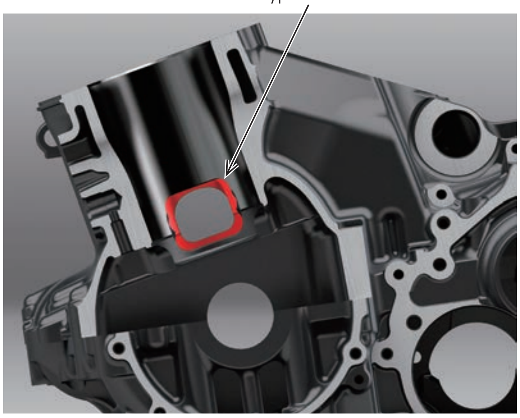
(b) Temperature of each part of piston by oil jet

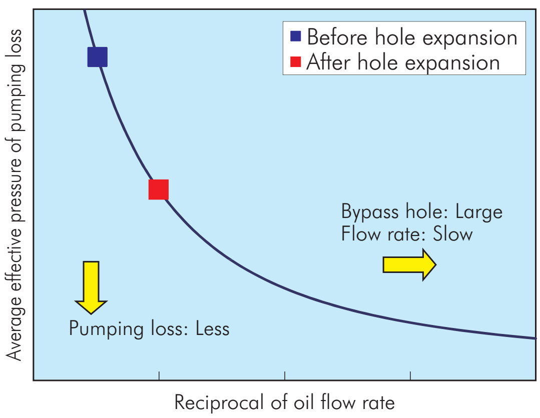
Fig. 6 Oil-jet piston cooling system

(ii) Engine valve system
The stress applied to the valve springs increases with the raising of the position of the intake and exhaust valves. Therefore, in order to ensure the springs have sufficient durability, the specification of the spring was optimized through stress analysis.
(iii) Piston cooling mechanism
When the engine power increases, so does the calorific value. As a result, the temperature of the piston increases, reducing the strength. For this reason, in order to control the increase in temperature, an oil jet (Fig. 6 (a)) was provided to directly inject oil to the back side of the pistons. With this oil jet, oil can always be injected to the appropriate portions on the back side of the pistons, even when they are moving up and down.

The diameters of the oil pipe and the oil jet nozzle were also optimized through hydraulic pressure analysis, so that the hydraulic pressure and oil amount in each part of the engine are made suitable.

As a result, even though the calorific value of the engine was increased compared with the predecessor model, the piston temperature of the ZX-14R was reduced by dozens of degrees, which satisfied the temperature limit to ensure durability (Fig. 6 (b)). Durability was also tested by stress analysis.
(iv) Reduction of pumping loss
When the pistons move up and down, the pressure on the lower part of the pistons varies, which generates a pumping loss (intake and exhaust loss). The pressure can be released through the bypass hole (Fig. 7 (a)) at the bottom of the cylinder. While the pumping loss can be curbed by expanding this hole, the durability of the cylinder decreases. Therefore, the relationship between the size of the bypass hole, oil flow rate, and the average effective pressure of the pumping loss was studied through analysis (Fig. 7 (b)). Moreover, stress analysis around the bypass hole was performed to determine the shape of the bypass hole that enables controlling the pumping loss with minimal increase in stress. Consequently, we succeeded in reducing the pumping loss compared with the predecessor model.
(v) Hydraulic pressure chain tensioner
When the position of the intake and exhaust valves is raised, the amplitude (variation) of the cam chain becomes larger, the load applied to the cam chain increases, and the engagement sound also increases. In the ZX-14R, the method of the hydraulic pressure chain tensioner was changed, to optimize the leak gap of the tensioner and the relief valve opening pressure. As a result, the load applied to the cam chain, and the amplitude of the cam chain could be suppressed. The amplitude of the cam chain became even smaller by adjusting the axial clearance (backlash of the plunger), and particularly the noise which occurs when the engine is started was dramatically reduced.
(vi) Optimization of balancer weight
In a 4-cylinder engine, the primary vibromotive force and moment of the engine speed which are generated by the vertical motion of the pistons and the rotary motion of the crankshaft are negated. On the other hand, the secondary vibromotive force and moment of the engine speed which

Bypass hole

(a) Bypass hole at the bottom of the cylinder



(b) Relationship between oil flow rate and pumping loss by bypass hole

Fig. 7 Minimizing pumping loss

are generated by the vertical motion of the pistons and combustion pressure remain. In order to suppress these vibromotive forces and moment, dual-shaft secondary balancers (Fig. 8 (a)) were adopted in the predecessor model. However, since the piston stroke was changed in the ZX-14R, the vibration characteristics also changed naturally. Accordingly, in order to minimize these vibromotive forces and moment, the balancer weight was optimized by analysis (Fig. 8 (b)). As a result, even though the displacement increased, the vibration was successfully controlled and maintained at a low level, allowing us to keep a feature that was popular in the predecessor model.

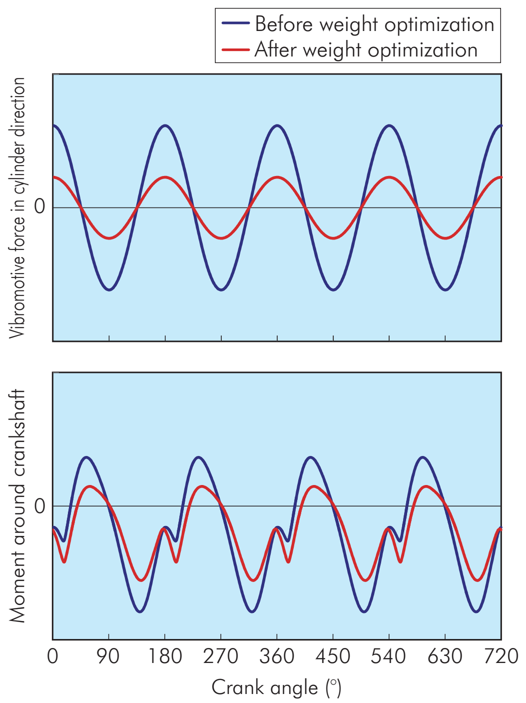
(2) Intake system

In order to minimize the drag of engine intake air passage as much as possible, the retention structure of the air cleaner element was reviewed and revised. While expanding the area of the intake air passage and reducing the number of parts, we made it serve as a structural member at the same time, which also contributed to the improvement of the frame rigidity. The expansion of the effective filtration area by improving the filter installation method reduced the air flow drag of the element by 60%.

(3) Exhaust system (muffler)

Since we knew that users of this model consider a "large motorcycle with an imposing presence" as an important status from our market research, a large capacity muffler was adopted as a part of the styling of a "rear shape design with an impact," as shown in Fig. 9 (a). This allowed some flexibility to make modifications such as extending the pipe inside the muffler (Fig. 9 (b)), ensuring a balance between increased power and noise control. In addition, the low- to mid-range torque was increased by changing the shape of the exhaust pipe assembly, adding bulkheads, etc.

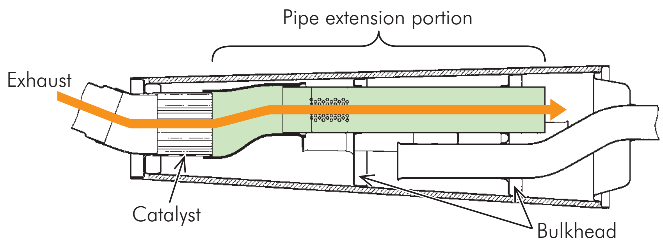
(a) Dual-shaft secondary balancers



(b) Effectiveness of balancer weight optimization

Fig. 8 Vibration damping through dual-shaft secondary balancers

(a) Rear shape design



(b) Internal structure of muffler

Fig. 9 Large-capacity muffler

Fig. 10 Modified components of the aluminum monocoque frame

3 Chassis related technology

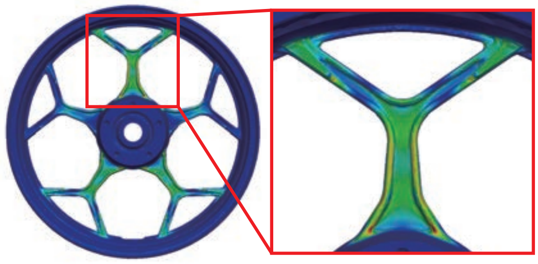
(1) Improvement in frame rigidity

While inheriting the basic frame configuration of the predecessor model, it was necessary to address the increase of engine power, and ensure a sportier handling. Therefore, we changed a large number of components to improve the longitudinal and torsional bending rigidity of the main frame. The modified components of the aluminum monocoque frame are shown in Fig. 10.

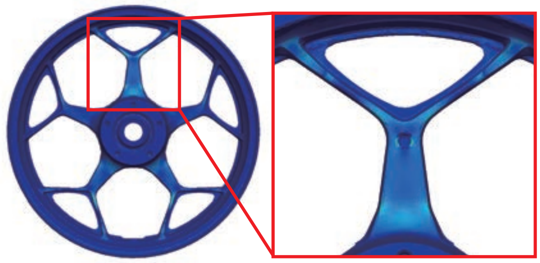
① Rigidity was ensured by changing the bottom plate thickness of the head pipe, and revising the internal configuration to accommodate the altered mounting structure of the air cleaner.

② The cover of the rear opening portion of the battery box was changed from a resin cover to a reinforced aluminum plate, to make it function as a cross member.

③ The body rigidity was optimized by altering the shape while reducing the cost. This was achieved by internally producing the high vacuum die cast parts of the swing arm brackets.



(a) Initial stages of analysis



(b) After modification

Fig. 11 Wheel strength analysis

(2) Wheel weight reduction

Reducing the weight of wheels, which leads to a reduction of the inertial weight and gyro effect during acceleration and deceleration, greatly contributes to the improvement in the maneuverability of the motorcycle body. Since the unsprung weight is reduced, it also leads to improvement in the suspension performance, which makes it an important consideration in designing a motorcycle.

In order to reduce the weight of the wheels, a strength analysis was conducted in parallel with styling design in the early stages of development. We repeated the method of correcting the design and re-analyzing the corrected design, until we arrived at a shape with no concentrated stress while maintaining the necessary rigidity (Fig. 11). As a result of pursuing strength and weight reduction to the limit, we achieved a reduction of 360 g in the front wheel, and 1,030 g in the rear wheel while ensuring a strength equivalent to the predecessor model.

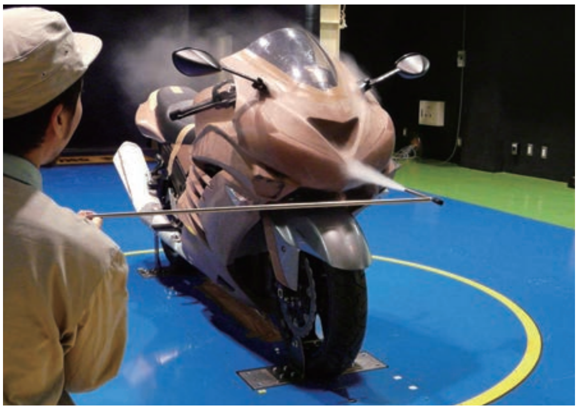


Fig. 12 Wind tunnel test

(3) Balancing aerodynamics with design

The ZX-14R has the potential to easily handle a ride at 300 km/h. Earlier models were also praised for their windscreen performance as well as aerodynamics. In order to achieve high aerodynamics and windscreen performance as well as a powerful design suitable for a flagship, we carried out wind tunnel tests from the early stages of the styling design (Fig. 12).

(4) Measures against damage from engine heat

Since this motorcycle adopts a large-displacement engine, it is important to take measures against the effects on the rider caused by the heat discharged from the engine, regardless of whether the motorcycle is moving or stopped. For this reason, we performed an analysis to confirm the effect from the engine exhaust heat before a mockup was produced (Fig. 13).

After the mockup shape was determined, we performed a thorough investigation of the flow of the engine waste heat using test vehicles. In order to prevent rider discomfort by contact with the engine waste heat in various conditions, such as when riding or idling, we have modified the opening configuration of the sides of the side cowl and the internal bulkhead of the cowl for improved ride comfort (Fig. 14).

(5) Multifunction switch

Motorcycles these days have been increasingly adopting electronic control features. Accordingly, instead of mounting multiple switches for each function, we have developed an integrated multifunction switch that enables selection of functions and adjustment of settings without lifting hands from the handlebars. Moreover, this switch has been provided with an ability to switch between various meter displays, including current and average fuel consumption and remaining range, for added convenience.

4 Control related technology

(1) Traction Control (KTRC)

Traction control is a system which controls the ignition and air volume to optimize the wheel slip ratio according to the riding conditions based on various information, such as the front and rear wheel speeds, throttle opening angle, etc.

Kawasaki announced its KTRC traction control system, which controls wheel slip on slippery road surfaces, with the 1400GTR (Concours 14 in North America) released in 2010. Then in 2011, Kawasaki announced the S-KTRC (Sport-KTRC), optimized for sport riding on circuits, with the Ninja ZX-10R.

The ZX-14R, which is designed for public roads, is equipped with two integrated traction controls with different concepts. This system has been made to respond to various conditions with a simple switching operation between various modes, including a mode to draw out the maximum sports performance on dry road surfaces, a mode suitable for riding on paved road surfaces in a rainy

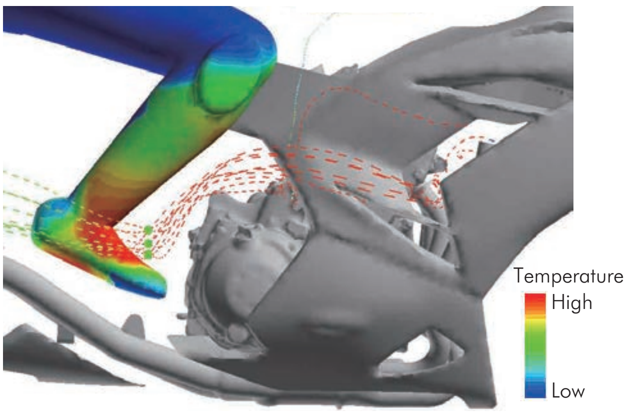
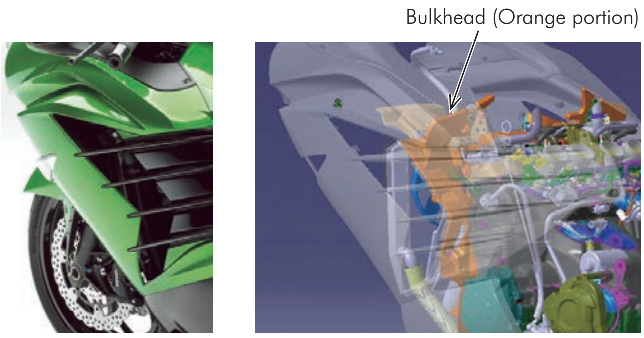


Fig. 13 Analysis of engine waste heat flow



(a) Appearance of side cowl   (b) Internal structure of side cowl

Fig. 14 Side cowl and internal bulkhead structure

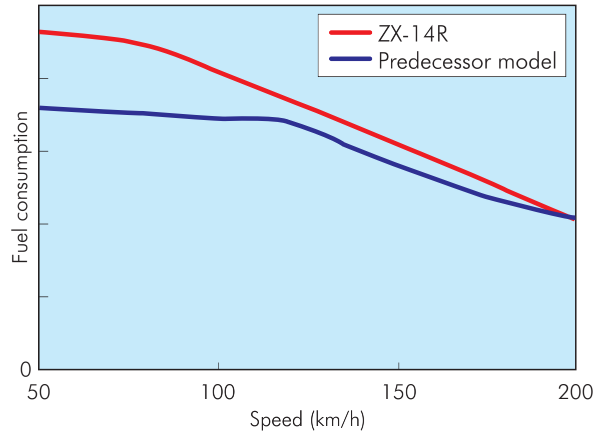


Fig. 15 Fuel consumption at cruising speed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weather, and a mode for riding on slippery unpaved road surfaces which are encountered occasionally on public roads.

(2) Braking system (ABS: Anti-lock Brake System)

In the predecessor model, focus was placed on stability on slippery road surfaces. Subsequently, we gathered more information on the actual usage conditions of users, and it became clear that there was a clear need to improve the braking performance on road surfaces that included rough sections. In response to this need, we improved the performance on rough road surfaces, while maintaining the ABS performance of the predecessor model on slippery road surfaces. The deceleration rate on rough road surfaces was improved by 12% with front braking operation only, and 16% with both front and rear braking operation compared to the conventional rate.

(3) Environmental performance

(i) Emission performance

In order to maintain a constant idling speed to eliminate adjustments to the outside temperature or elevation, a new idle speed control valve (ISCV) was adopted. Utilizing this mechanism, oxygen is supplied to the combustion chamber during deceleration with the throttle fully closed, to accelerate the combustion of unburnt gas. As a result, while minimizing the increase of the catalyst volume which causes the engine power to decline, we were able to satisfy the emissions control.

(ii) Fuel consumption

As a result of advancing the ignition timing towards the MBT (Minimum advance for Best Torque) side from the conventional position to optimize the fuel injection amount, we were able to dramatically improve the fuel consumption when riding on a level surface at a constant speed of 120 km/h or less, even though the reduction ratio was shifted toward the acceleration side (Fig. 15).

Concluding remarks

We gave an overview of the development of the “Ninja ZX-14R” in this report.

In addition to the above, in order to design an external appearance suitable for a flagship, we also paid considerable attention to detail and produced a motorcycle with a sense of quality and luxury that meets the expectations of Kawasaki fans around the world. Whether in terms of the performance specification, maneuverability, dignified external appearance, or outstanding presence, it is safe to say that this machine is the “ultimate flagship model.”

Reference

1) H. Arisawa, M. Nishimura, H. Watanabe, A. Ueshima, K. Arima, A. Yamasaki: “Study on Similarity of Pumping Flow in Engine Crankcase,” SAE, No. 2009-32-0051 (2009)

Ninja 250/300 — A strategic global model beyond its class

Motorcycles with an engine displacement of 250 cm³ represent a class that is increasingly popular as entry models in developed nations, and as high-end models in emerging countries. The first Ninja 250R model went on to achieve an outstanding sales record around the world after being introduced in this class in 2008. This paper will examine the distinct characteristics of the second generation model Ninja 250/300, and the engine and chassis technologies that underpin its exceptional product appeal.

Preface

Launched in 2008, the first generation Ninja 250R (Fig. 1) recorded favorable sales by being positioned as a high-end model in emerging countries such as Indonesia and Brazil, and as an entry model in developed nations including the U.S. and Japan. As such, it has established a position as Kawasaki's strategic global model. Not in the least content with the success of the predecessor model, we sought further improvements in the successor model Ninja 250/300 with the ambitious goal of developing a peerless model that transcends its class.

Fig. 1 First generation model Ninja 250R

1 Product concept and design policy

(1) Product concept

The predecessor model achieved its success based on the product concepts of "supersport looks" and "ease of riding." In developing this model, we sought to create a definitive "Ninja Entry" that embodies the quintessential product appeal and marketability of the Ninja brand.

(2) Design policy

(i) Engine

To meet the needs of each market, we developed two types of engines with displacement of 249 cm³ and

Table 1 Main Specifications

		Ninja 250	Ninja 300
Engine	Displacement (cm^3)	249	296
	Bore ×Stroke (mm)	62.0 × 41.2	62.0 × 49.0
	Maximum output (kW/rpm)	23.0/11,000	29.0/11,000
	Maximum torque (N･m/rpm)	21.0/8,500	27.0/10,000
	Compression ratio	11.3	10.6
Chassis	Length × Width × Height (mm)	2,020 × 715 × 1,110	2,015 × 715 × 1,110
	Wheelbase (mm)	1,410	1,405
	Frame type	Diamond	
	Seat height (mm)	785	
	Curb weight (kg)	172	
	Front tire	110/70-17M/C 54S	
	Rear tire	140/70-17M/C 66S	

296 cm^3. The Ninja 250, equipped with a 249 cm^3 engine, featured an improved intake and exhaust system to meet the engine performance requirements of each country. For the 296 cm^3 model Ninja 300, numerical targets including the following were established as compared with the predecessor model.

① Improve the maximum speed by 10 km/h.

② Reduce the acceleration time from 0-400 m by 0.7 seconds.

③ Ensure at least an equivalent driving force in the next higher gear.

(ii) Chassis

In order to further improve the ride comfort and a sense of high quality valued by the target customers, we achieved reduced vibration, improved shock absorption, and reduced hot air from the radiator felt by the rider, and adopted a digital speedometer. This also became the first Kawasaki motorcycle in its class to offer an ABS model.

(iii) Design

To make its Ninja heritage unmistakably clear, we adopted a styling based on the same design philosophy as the higher-end models of the Ninja series.

(3) Main specifications

The main specifications of the Ninja 250 and the Ninja 300 are shown in Table 1.

2 Engine related technology

(1) Assist & Slipper Clutch (Fig. 2)
— Featured on the Ninja 300

A clutch is a mechanical device to engage/disengage the power transmitted from the engine to the transmission. The transmission of power is achieved by pressing down the friction material with a spring.

Although the power to be transmitted increases with

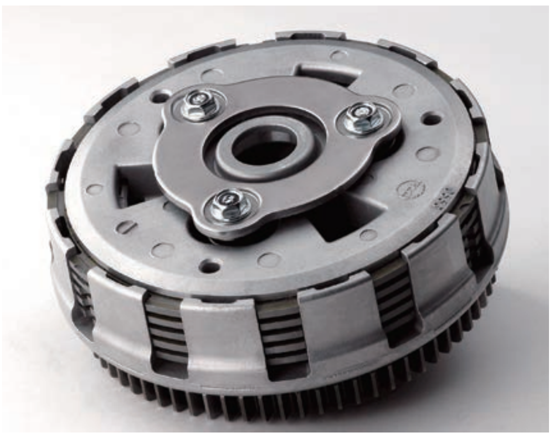


Fig. 2 Assist & Slipper Clutch

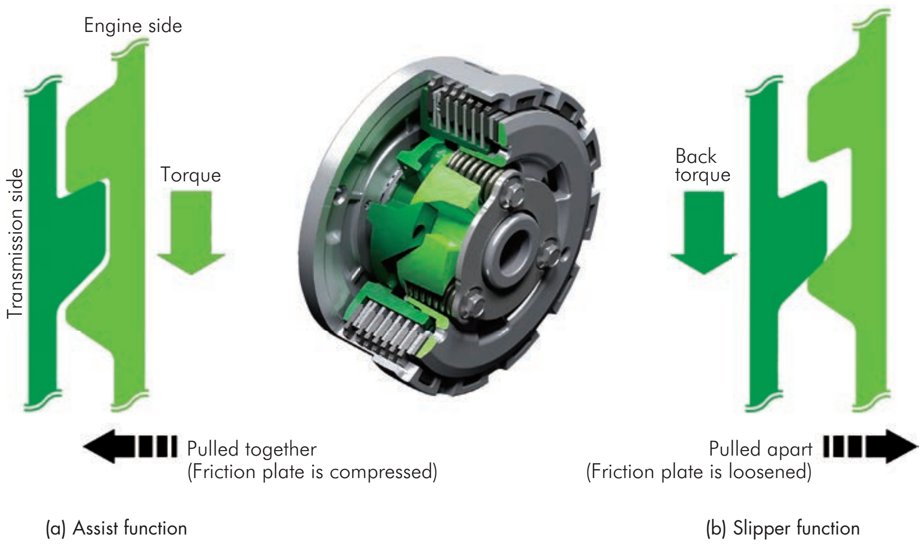


Fig. 3 Cam mechanism of the Assist & Slipper Clutch

the displacement, when the spring load is increased in response to this, the load of the clutch lever increases and makes it difficult for the rider to operate the clutch. To address this issue, an F.C.C. clutch equipped with an assist function for the clutch lever grip was adopted.

Under reduced clutch spring load, the friction material begins to slip when excessive power is transmitted. This problem was resolved by incorporating a cam mechanism. As soon as the parts begin to slip and move away from their relative positions, they are pulled together to produce an effect similar to being pressed by a spring, thereby controlling the slippage (Fig. 3 (a)). This resulted in a 20% increase in displacement, and a 25% reduction in the clutch lever load.

This cam mechanism is also equipped with a slipper function that operates in the direction that reduces the spring load, when a large back-torque is applied when braking (Fig. 3 (b)). This causes the clutch to slip, which helps prevent the hopping of the rear tire during deceleration and maintain stability when braking.

(2) Heat management

"Increased comfort against hot engine air" was highly demanded by riders in Southeast Asia. To ensure this strategic global model meets this need, we aimed to reduce the hot air from the radiator to a barely noticeable level. We particularly focused on finding a way to direct the hot air from the radiator fan away from the rider while idling. To this end, we developed a radiator fan cover as shown in Fig. 4.

This cover enables the hot air to be discharged away from the rider, as shown in Fig. 5. The temperature

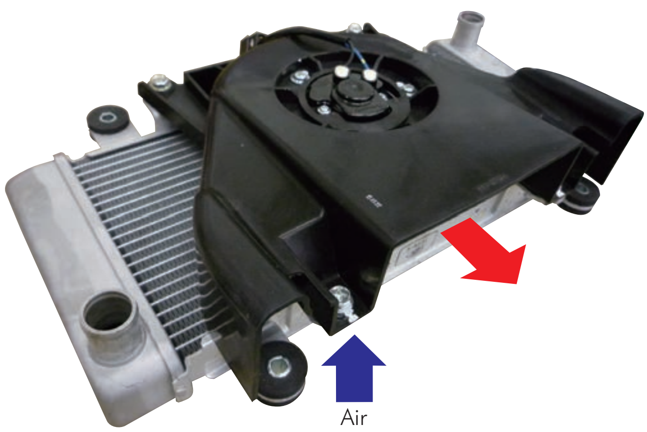


Fig. 4 Radiator fan cover

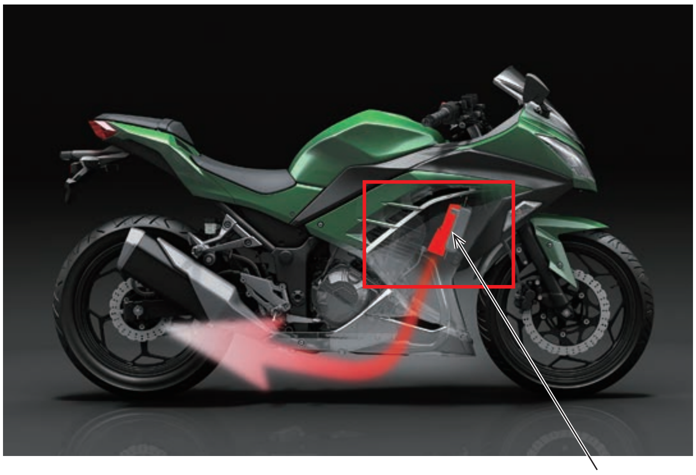
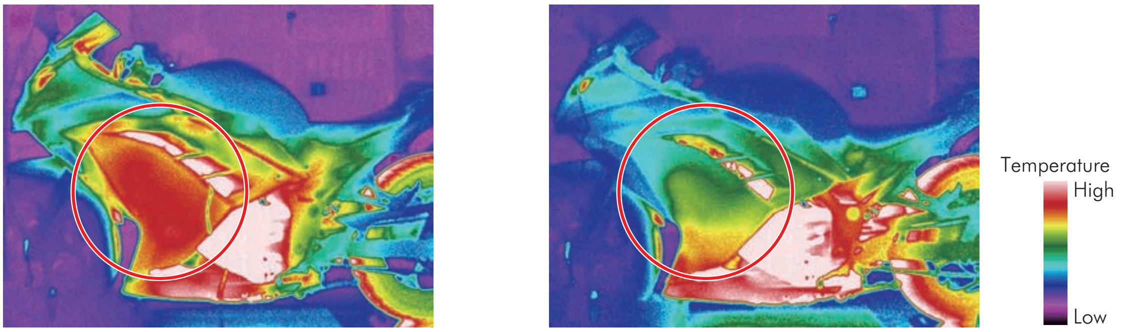


Fig. 5 Flow of hot air with radiator fan cover attached



(a) Without fan cover

(b) With fan cover

Fig. 6 Effect of the radiator fan cover on temperature distribution

distribution with and without the fan cover attached is shown in Fig. 6. It is clear that the cowl surface temperature remains low with the cover attached, and the heat is dissipated instead of being accumulated inside the cowl.

This cover was also effective in reducing the temperature of the electrical components located above the engine.

(3) Complex cross-section short muffler

In order to conform to noise regulations, generally it is necessary to increase the muffler volume as the displacement is increased. However, in order to design a sportier motorcycle, the muffler needs to appear as small as possible. Therefore, in the predecessor model, the catalyst arranged inside the muffler was housed inside an upstream joint pipe, to increase the effective capacity of the muffler and maintain an equivalent volume. Furthermore, the cross-section was changed to a complex trapezoidal shape from a round shape (Fig. 7), which

Fig. 7 Short muffler with complex cross-section

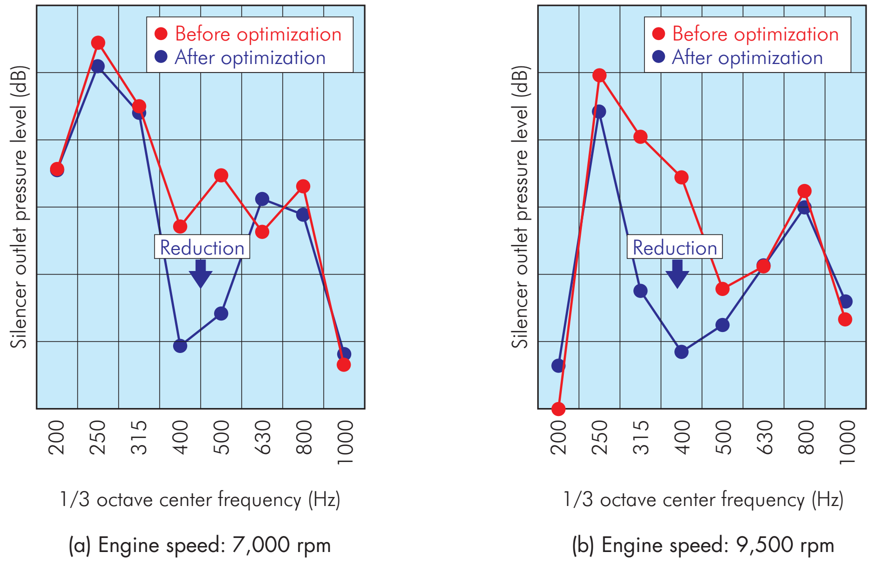


Fig. 8 CFD analysis of noise reduction effect

increased the cross-sectional area and allowed the overall length to be shortened.

Also, the volume ratio of the three expansion chambers was optimized by a CFD analysis, which enabled the noise value to be reduced while maintaining the engine performance (Fig. 8).

3 Chassis related technology

In order to achieve a high-quality ride feel, we worked on reducing engine vibration.

Among the three positions (upper front, upper rear, and lower rear) where the engine is mounted onto the frame, we changed the upper front mount from a rigid mount to a rubber mount. The configuration before and after the change is shown in Fig. 9.

As a result of a preliminary validation of the vibration reduction effect by analysis, it was confirmed that the portions in red representing high vibration areas seen in Fig. 10 (a) were eliminated in (b). The effect of this change was also measured using a test vehicle, which showed sufficient vibration reduction across the entire range of the engine speed (Fig. 11).

Since this change prevented the engine from being used to support the rigidity of the frame, we also improved the rigidity and strength of the frame itself.

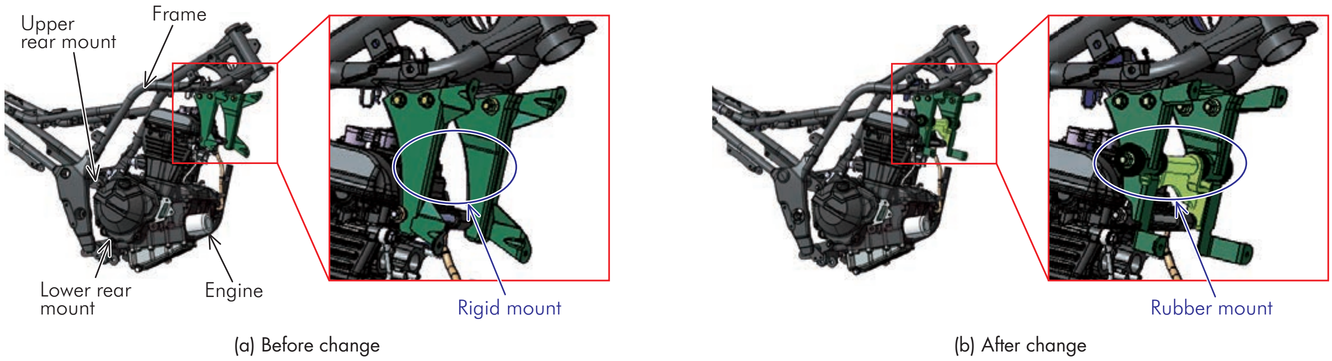


Fig. 9 Rubber engine mounts

Concluding remarks

In Indonesia, orders started flooding in right after launch, and people had to wait several months to receive their motorcycles. After one and a half years, supply is finally catching up with the demand. The Ninja 250/300 have won great popularity in every country including Japan, where orders from dealers reached the annual production schedule in just three days. We will not content ourselves with this success, and will continue to make ceaseless efforts to improve the product appeal and marketability of this model, so that the people who purchased this motorcycle will become a true fan who believes the Ninja is the best brand.

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(a) Before change (b) After change

Fig. 10 Results of vibration analysis

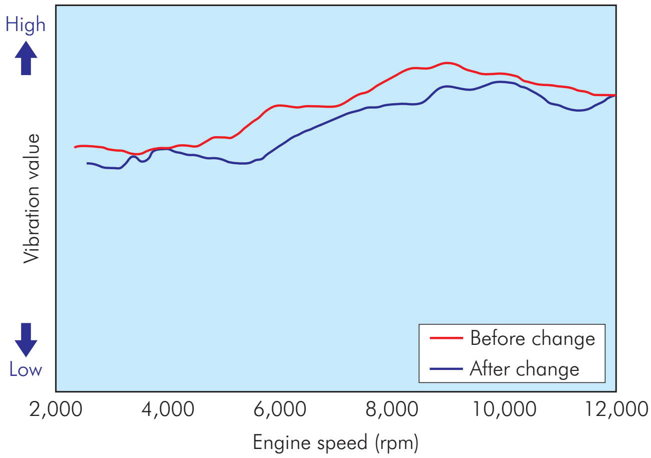


Fig.11 Vibration reduction effects of rubber engine mounts

Z1000 – The Supernaked that delivers the ultimate excitement

The Z-Series is one of the most popular brands of Kawasaki motorcycles, and the Supernaked Z1000 sits at the pinnacle of Z machines. This paper will discuss various technologies incorporated into Z1000, from technologies that realize its aggressive styling concept, to those that enable the nimble and sure handling as well as the powerful acceleration feel adding to the exciting riding character of this model.

Preface

As represented by the ZEPHYR, the conventional naked bikes were a genre where the classic style was considered to be ideal. When the Z1000 was released in 2003, it established a new genre called the Supernaked with its radical design and exceptional agility and riding performance. Although motorcycles with similar concepts were subsequently released by competitors, we carried over the status and advantages from the previous model as the pioneer of this genre, and developed the 2014 model Z1000.

1 Concept

We examined what is required in the 2014 model Z1000 as a Supernaked from various angles, and decided to focus on enhancing the following elements.

① Styling/design
② Exciting riding character

An "exciting riding character" refers to the sum of all elements the rider feels when riding a motorcycle, such as the feeling of power, handling, and acceleration sound.

2 Styling/design — Pursuit of *sugomi*

The design concept of the new Z1000 was summarized into one word: *sugomi*. Meaning "awe-inspiring energy and intensity" in Japanese, this word set the tone for the styling image, which can be expressed as a "predator in a crouching posture, gathering its energy in preparation to strike" (Fig. 1). In order to realize this image, it was particularly necessary to make the headlamp thinner and smaller. To this end, we developed an LED headlamp which meets the requirements in collaboration with Stanley Electric Co., Ltd.

Fig. 1 Front styling

In order to develop a smaller headlamp, we worked on the following issues.

(i) Maintaining radiation performance while reducing headlamp size

The high luminosity LED used for the headlamp generates heat on the side opposite from the light emitting direction. Therefore, it was necessary to attach a radiator to maintain the LED performance. While the built-in type where the

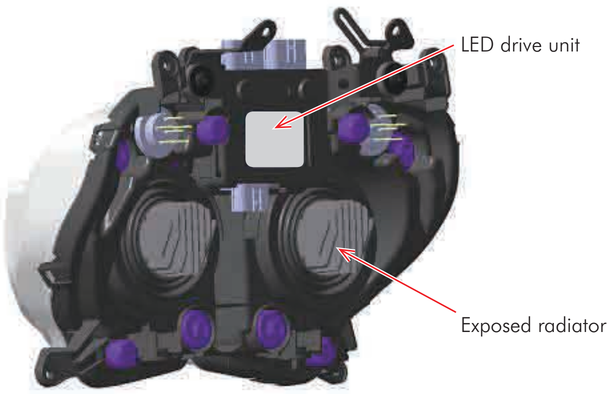


Fig. 2 Headlamp structure (rear side)

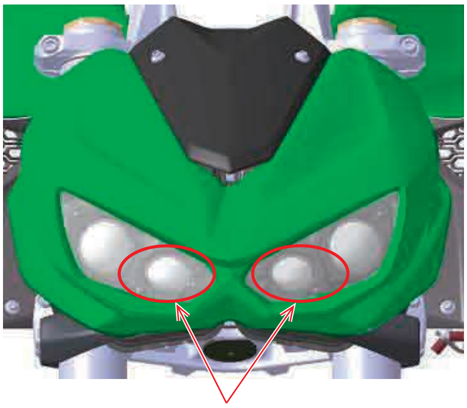


Fig. 3 Inner oval lenses

radiator is embedded in the housing is mainly used in four-wheel vehicles, this would make the overall headlamp too large. To address this issue, we designed a portion of the radiator to be exposed on the back side so that the headlamp can be made smaller without compromising radiation performance.

The drive unit of the constant current which lights the LED at a constant brightness was installed in the space on the back side of the headlamp to develop a smaller headlamp. Accordingly, the distance between the headlamp and drive unit became closer, which enabled the harness to be shortened and simplified.

The structure of the headlamp is shown in Fig. 2.

(ii) Optimizing irradiation range while reducing headlamp size

It is necessary to provide a reflector or an inner lens to condense the light from the LED element to irradiate the road surface. Since priority was given to achieving a smaller size, an inner lens was adopted for this model. Furthermore, in order to make the lens opening look narrower when viewed from the front, an inner oval lens was adopted on the low beam side (Fig. 3). This allowed us to narrow the irradiation range in the vertical direction so that the lights will not blind oncoming vehicles, while widening the irradiation range in the horizontal direction.

Improvements were also made to the routing of the cables and the optical axis adjustment mechanism, making the structure far more compact than the previous model, and allowing us to express the design concept of *sugomi* (Fig. 4 and Fig. 5).

Reducing the size of the headlamp, which greatly affects maneuverability, and bringing it closer to the steering axis decreased the moment around the steering axis, and also contributed to improvement in the handling.

(a) Previous model

(b) 2014 model

Fig. 4 Styling comparison (front)

Fig. 5 Styling comparison (side)

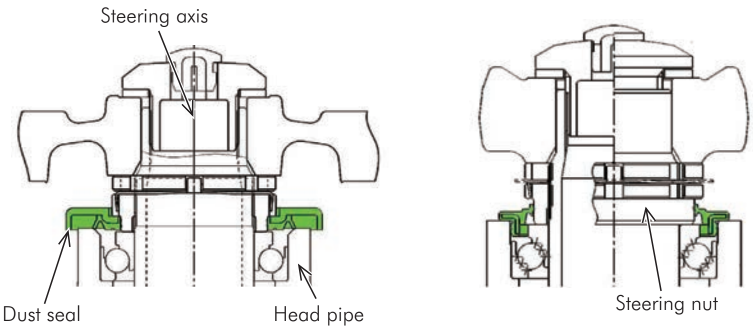


Fig. 6 Configuration of steering dust seals

3 Exciting riding character — Pursuit of riding impact

Improving the engine output or the throttle response also increases the impact that the rider feels while riding. However, the rider also feels the acceleration from the riding position, handling, and even the various sounds while riding.

(1) Nimble and secure handling

(i) Aggressive riding position

The riding position is an important factor which greatly influences the character of a motorcycle. In order to improve the exciting riding character, the handle position was moved forward even further than that of the previous model. This design change made it easier to handle the front wheel, which led to improvement in maneuverability.

(ii) Weight reduction

The total weight of the front and rear wheels, which has the greatest impact as an unsprung weight, was reduced by 1.5 kg from the 12 kg of the previous model, while ensuring the same level of strength was maintained through analysis. As a result, the gyro effect decreased, making it easier to change the direction of the vehicle body.

(iii) Reduction of friction loss of steering

As shown in Fig. 6 (a), the dust seals of the steering axis used to slide along the top of the head pipes in the previous model.

As shown in Fig. 6 (b), the shape of the dust seals was changed so that they slide along the side of the steering nut, which reduced the sliding radius and the rotation resistance. This change dramatically improved the handling, particularly while riding at low speeds.

(iv) Optimization of suspension settings

Since the previous model had established a reputation for excellent balance, the 2014 model was designed so that the rider would be in almost the same position as the previous model. However, the set height of the suspension was lowered in an unloaded state, and the springs of the shock absorbers and the damping force were substantially enhanced (the damping force in the elongation direction was nearly doubled compared to the previous model). As a result, we were able to minimize the change in the posture in the front and rear directions during acceleration and deceleration. With this improvement, we were able to achieve secure handling while delivering quick convergence and a nimble ride, even on the rough and winding roads of Europe.

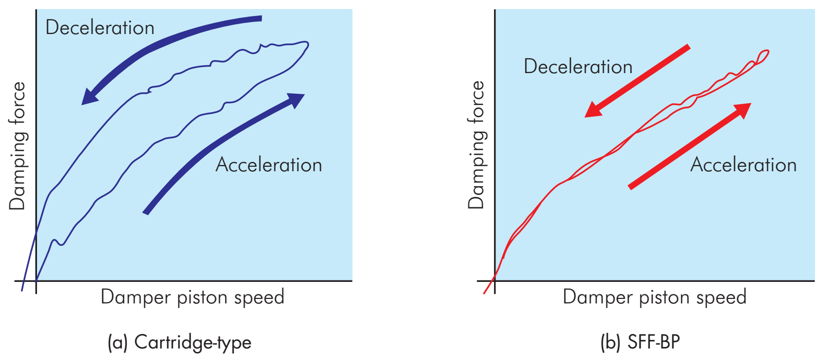


Fig. 7 Comparison of responsiveness of the front fork

(v) Improved response by adoption of Separate Function Fork-Big Piston (SFF-BP)

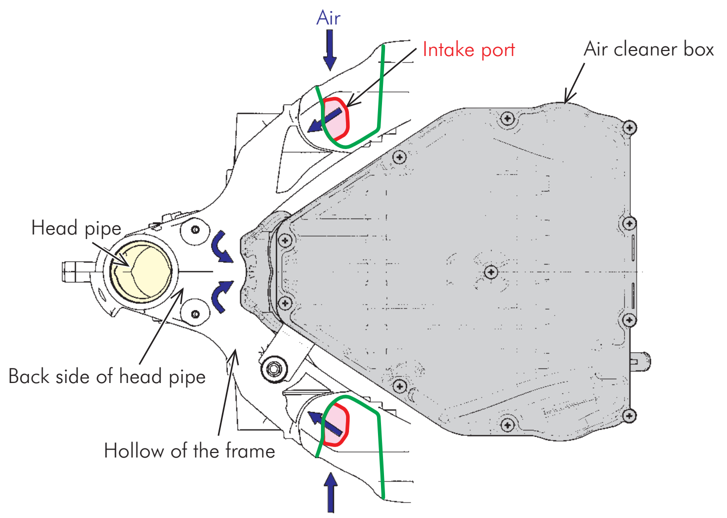
As shown in Fig. 7 (a), in the cartridge type damper that was used for the front fork in the previous model, the damping force is applied late during acceleration and convergence also begins late during deceleration. However, the Showa SFF-BP adopted for the 2014 model has minimal delay in the damping force. As shown in Fig. 7 (b), the damping force kicks in smoothly during acceleration, and quickly converges following the same trajectory during deceleration.

Moreover, while the previous model was equipped with springs and dampers on both sides of the wheel, the new Z1000 has a damper only on one side to achieve a weight reduction of about 300 g.

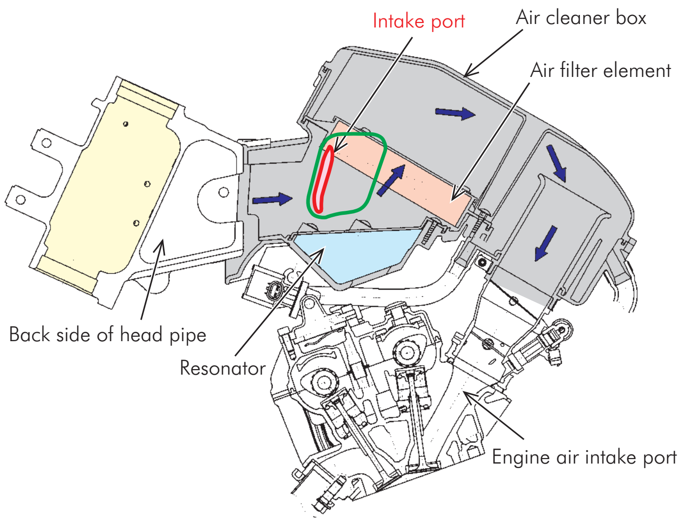
(2) Intake howl which produces the powerful acceleration feeling

Among the sounds which occur during acceleration, we focused on the intake howl experienced by the rider, and attempted to improve the acceleration feeling by correlating the engine characteristics with the intake howl characteristics.

The channel of the intake air is shown in Fig. 8. Air is taken in from the intake port of the frame, and is guided to the air cleaner box from the back side of the head pipes via the hollow part of the frame. Furthermore, foreign matter, etc. in the intake air are removed by the air filter element before the air is supplied to the engine.

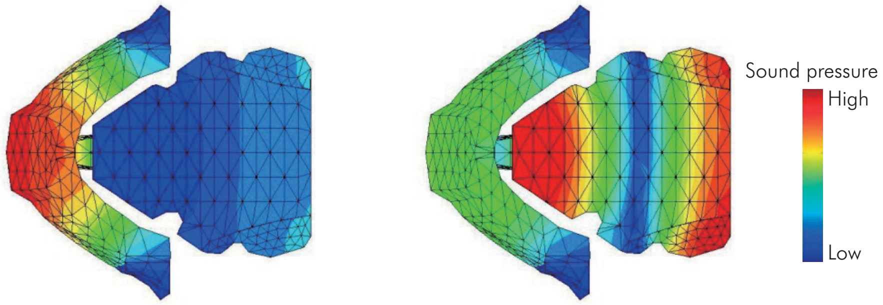


(a) Top view (Cross section)



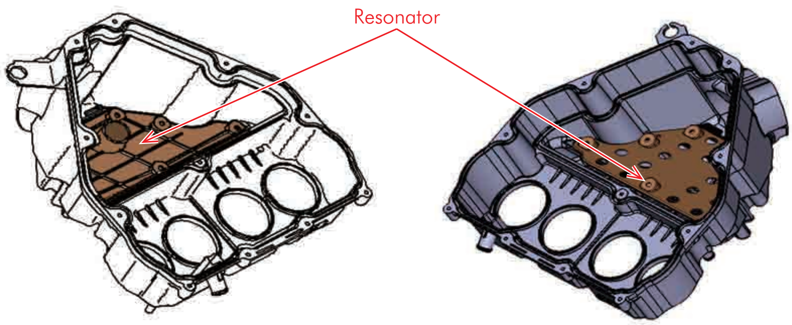
(b) Side view (Cross section)

Fig. 8 Air cleaner box structure and intake air channel



(a) Resonance in hollow of the frame (b) Resonance in front/rear direction of air cleaner box

Fig. 9 Analysis results of sound pressure distribution



(a) Previous model (b) 2014 model

Fig. 10 Changes in the resonator structure

(i) Sound pressure distribution

In order to understand the intake howl which occurs when air passes through the intake path in more detail, we analyzed the sound pressure distribution in the frame and air cleaner box. As a result, two types of resonance were identified in the hollow part of the frame and the front and rear directions of the air cleaner box (Fig. 9).

(ii) Enhancement of intake howl

We designed a structure that enhances the auditory note of the intake by utilizing the resonance which occurs in the front and rear directions of the air cleaner box as the sound is radiated outside.

The resonator in the air cleaner box resonates the air in the enclosed space provided in the middle of the intake path with the intake howl, and reduces the noise of the intake howl. As shown in Fig. 10, this structure was changed from a single pipe configuration to a multi-hole configuration in the 2014 model, to reduce the noise with a specific frequency. Furthermore, the internal structure of the air cleaner box was modified to raise the frequency of the intake howl to promote its radiation.

(iii) Measurement results of sound experienced by the rider

In order to clarify the acoustic effects of the structural change, a test motorcycle was used to measure the sound experienced by the rider. The results of the frequency analysis are shown in Fig. 11.

From the measurement results and sound analysis, we believe that the gray framed portion ① of the previous model shows the resonance in the hollow part of the frame, and the pink framed portion ② reflects the resonance in the front and rear directions of the air cleaner box. In the 2014 model, the resonance (pink framed portion ②) in the front and rear directions of the air cleaner box shifted toward a higher frequency. The red portions increase along with the engine speed, indicating that the sound experienced by the rider is increasing.

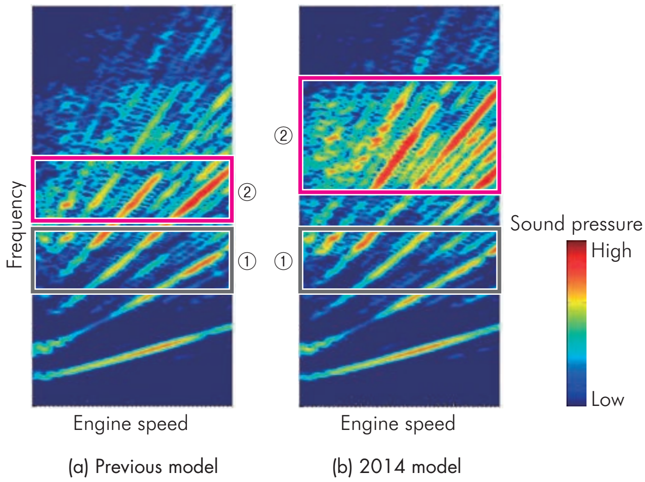


Fig. 11 Measurement of sound experienced by the rider (during acceleration in 3rd gear)

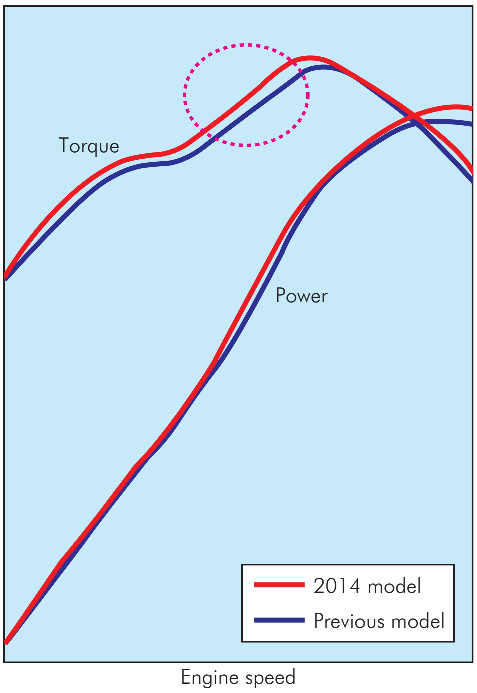


Fig. 12 Enhanced acceleration feel through intake howl

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As a result, the sound experienced by the rider (intake howl) increases at the juncture where the torque increases along with the engine speed (Fig. 12), and the intake howl is synchronized with the increase in the torque. We were thus able to improve the acceleration feeling actually felt by the rider.

Concluding remarks

The Z1000 is the highest-end model of the Kawasaki Z brand. This report introduced the technologies with which we achieved its design concept and exciting riding character.

The Ninja 1000 (Z1000SX), which was developed at the same time, made huge advances in functionality by adopting the Kawasaki TRaction Control (KTRC) and the Pannier system, jointly developed with GIVI of Italy. We will continue to expand these two brands in the future, and develop products which respond to the expectations of our customers.

Supersport of watercraft Jet Ski ULTRA 300 Series

What riders seek in a personal watercraft are powerful acceleration, greater maximum speed and excellent maneuverability on rough water. To meet these demands, Kawasaki developed the Jet Ski ULTRA 300 Series powered by a high-power engine featuring an ultra-efficient supercharger. Kawasaki then added further improvements in the ULTRA 310 Series, developed as the 2014 model.

This paper discusses the structures and distinct features of the high-powered engine and hull of the Jet Ski ULTRA 300 Series — a supersport of watercraft.

Preface

In recent years, the market for personal watercraft including Jet Ski (Fig. 1) has become increasingly polarized into high price range models (high power and high functionality) and low price range models (relatively low power with basic functions only) as shown in Fig. 2. The low price range models are mainly used for rentals at resorts, while personal riders are increasingly drawn toward the high price range models featuring high power and high functionality.

In order to respond to the demands of these riders, such as "powerful acceleration," "greater maximum speed" and "excellent maneuverability on rough water," recent personal watercraft have been equipped with a supercharged engine. Kawasaki has offered the Jet Ski ULTRA 250X equipped with a supercharged engine since 2007.

However, engines have rapidly become increasingly more powerful in recent years, and in order to respond to the demands of the riders, it became necessary to develop an engine with an even higher power. Under such circumstances, Kawasaki adopted a highly efficient supercharger to develop the higher power Jet Ski ULTRA 300 Series, without increasing the size of the engine or the hull.

Fig. 1 Jet Ski ULTRA 300X

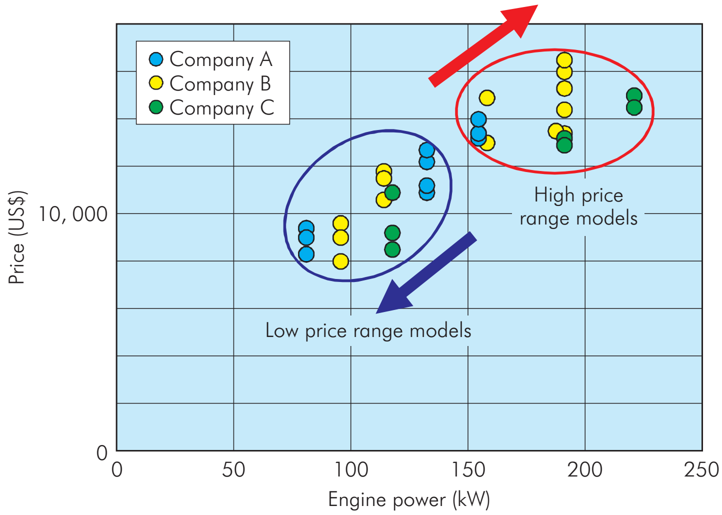


Fig. 2 Engine power and price distribution

1 Development of high-power engine — Pursuit of superior supercharged pressure

(1) Selection of supercharger

The pressure ratio of the ULTRA 250X engine is 1.8. This ratio is the same as conventional supercharged engines including automobiles, etc., equipped with a centrifugal type or roots type supercharger or turbocharger.

First, we selected an ideal supercharger aiming for a pressure ratio of 2.2 or more. In order to acquire powerful acceleration, it is necessary to have a large engine torque which can efficiently rotate the jet pump from a low rpm range. For this reason, a supercharger which can discharge a sufficient flow rate from a low rpm range was required, and thus we adopted a roots type supercharger.

Unlike other types of supercharger, the roots type can generate high supercharged pressure constantly over the entire rpm range from very low speeds to the maximum speed range, and achieve a flat and heavy torque curve. However, a common roots type supercharger could only achieve a pressure ratio of up to 1.8 due to structural limitations. Therefore, we adopted the TVS (Twin Vortices Series) supercharger (Fig. 3) newly developed by Eaton of the U.S. This TVS is the latest type of supercharger which can achieve high pressure-charging at a pressure ratio of 2.4. However, since this product was originally developed for automobiles and was never before used in a marine product, various modifications had to be performed.

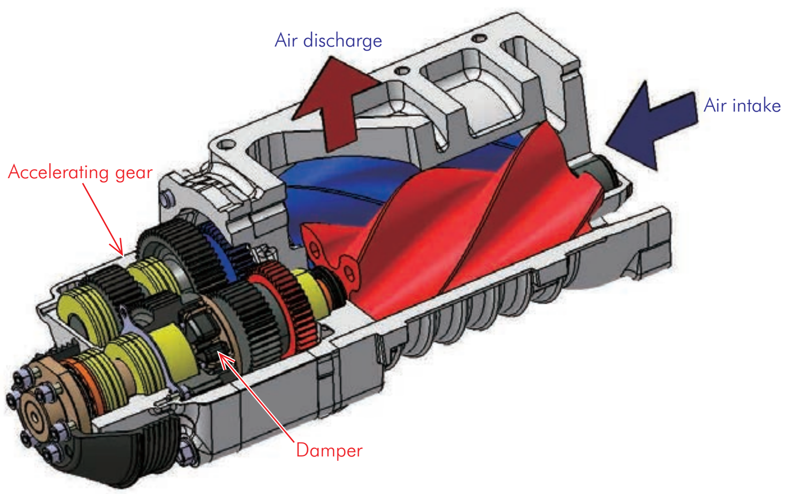


Fig. 3 Internal structure of the TVS supercharger

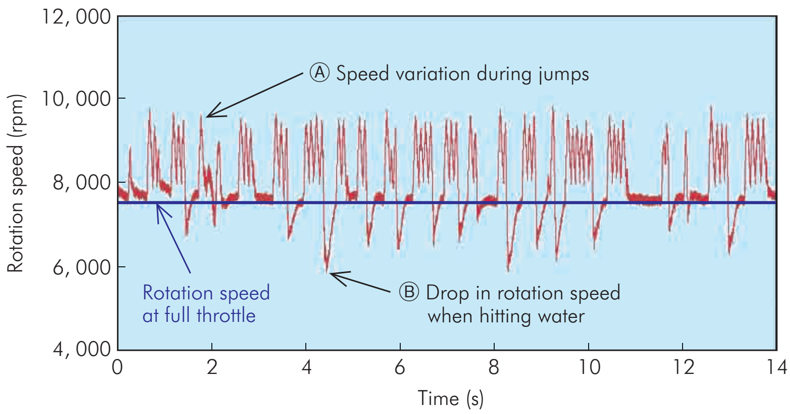


Fig. 4 Engine speed variation data

(2) Application of TVS supercharger in a marine product

Personal watercraft jump over waves as they are propelled forward. While jumping, the load is released since water is not supplied to the jet pump, and the engine runs in an overspeed range beyond the rated rpm (Fig. 4 Ⓐ). This is like making an automobile jump repeatedly. In this overspeed range, the engine speed rises and falls repeatedly in a short cycle. When a watercraft hits the water, a load is suddenly applied as the water enters the pump, which causes the engine rpm to drop suddenly (Fig. 4 Ⓑ), and the load on the engine becomes extremely high. Similarly, a large load is also applied to the supercharger, as it is linked with the engine to rotate the internal rotors. In order to reduce the load, various investigations were performed on the drive of the supercharger.

First, as shown in Fig. 5, a belt drive was adopted. It was arranged so that the belt slips during overspeed to release the load, while maintaining an appropriate belt load with an auto belt tensioner. However, since this is not enough to absorb the large load when the watercraft hits the water, a special damper was additionally provided inside the TVS as shown in Fig. 3. As shown in Fig. 6, these two mechanisms reduced the load transmitted to the TVS, and it became possible to mount it on a personal watercraft.

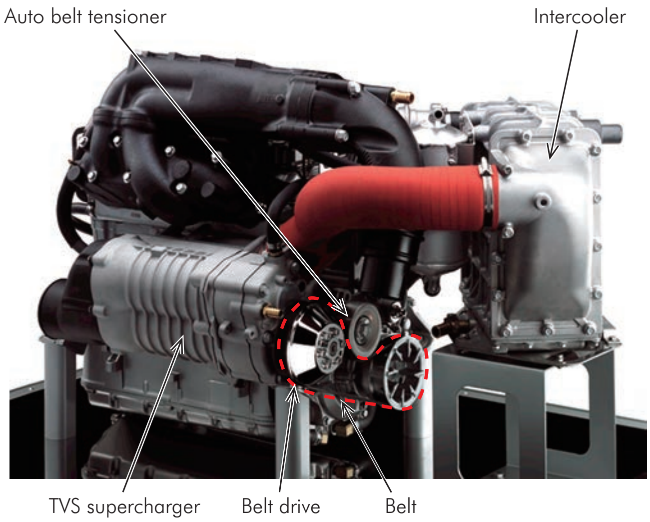


Fig. 5 Engine layout

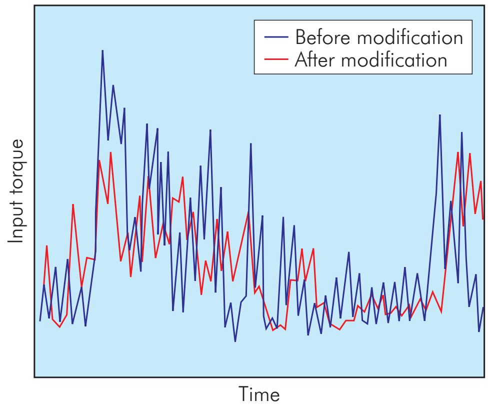


Fig. 6 Torque input to the supercharger

(3) Increasing the efficiency of supercharging

To obtain high power by an efficient supercharge, the following improvements were added. First, a large size water-cooled intercooler was provided to increase the charging efficiency by cooling the supercharged intake air. The temperature of the intake air which increased during the supercharging was substantially reduced by utilizing the abundant surrounding water. In order to prevent the sufficiently cooled intake air from being warmed up by the engine heat no matter how slightly, a resin intake manifold was adopted for the first time in a supercharged engine. In order to efficiently burn the highly supercharged intake air, the appropriate valve timing, fuel injection volume and ignition timing were selected, while checking the actual combustion condition based on an analysis of the combustion and power.

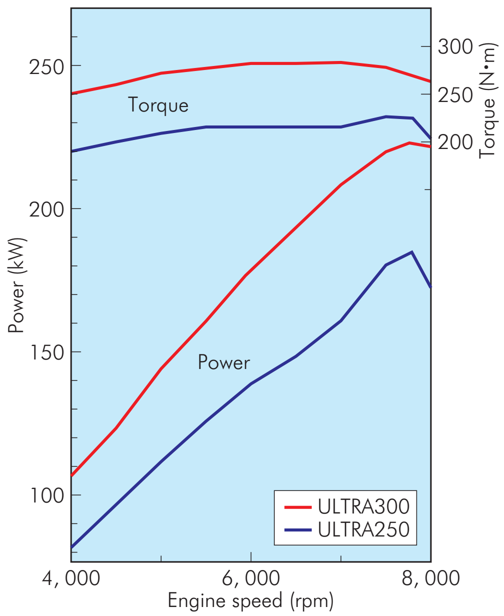


Fig. 7 Engine power properties

These improvements realized the highest power in the personal watercraft industry, with a pressure ratio of 2.2 and a maximum power of 221 kW, even with an engine displacement of 1.5 L. The engine power properties are shown in Fig. 7. In addition to the high power, this new engine also realized a huge reduction in discharged gas. It is an environmentally friendly engine that cleared the U.S. EPA (Environmental Protection Agency), CARB (California Air Resources Board), which is the most severe standard in the world, and EU standards.

2 Optimum hull for the high power engine — Pursuit of acceleration

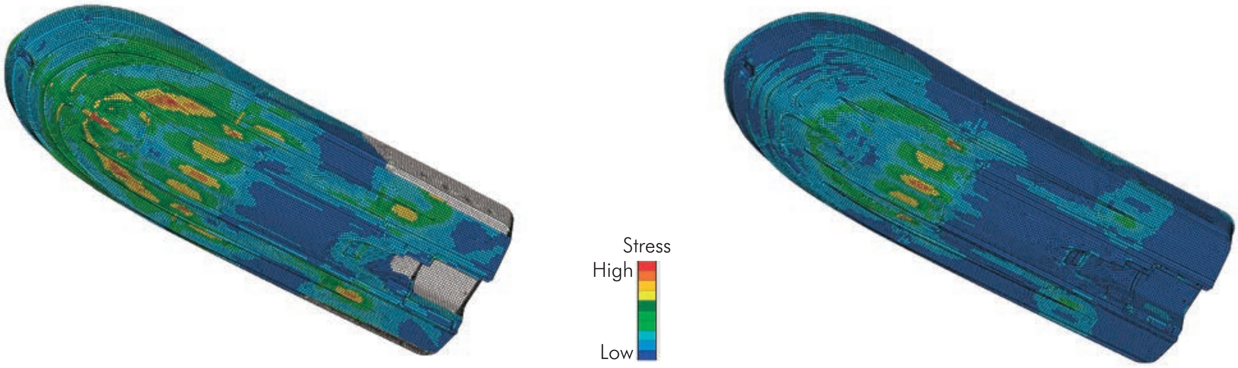
Personal watercraft do not always cruise over a smooth water surface; they are also driven over rough water. Moreover, "fast" not only means "maximum speed" but also often refers to "acceleration," as in various other vehicles. Therefore, in the ULTRA 300 Series, the development target was to realize "high acceleration performance" on "any water surface."

(1) Hull (bottom) form

The hull form was designed as a deep V type warped hull with a 22.5 degree dead rise (Fig. 8). As well as improving wave cutting performance, this form eased wave shocks and improved riding stability on rough water.

Normally, if the V form of the hull is sharpened to improve wave cutting performance and ease wave shocks, the drag of the hull will increase, and as a result, the maximum speed and acceleration performance will deteriorate. However, since this can be compensated by the high power engine, we focused on riding stability on rough water and adopted this form.

Fig. 8 Hull form



(a) Conventional structure

(b) New structure

Fig. 9 Stress analysis results of the hull

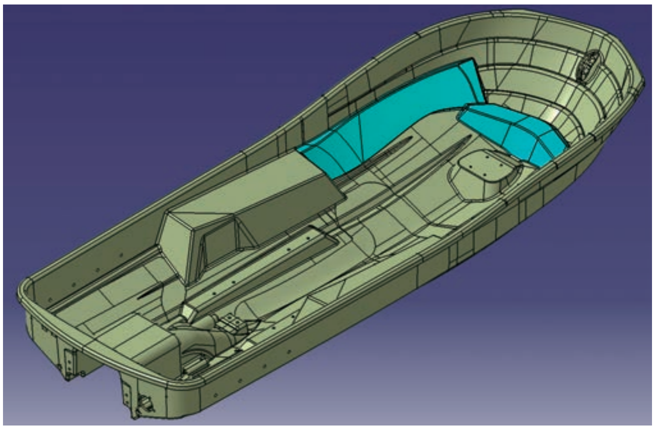


Fig. 10 Structure of the new lightweight hull

(2) Hull weight reduction

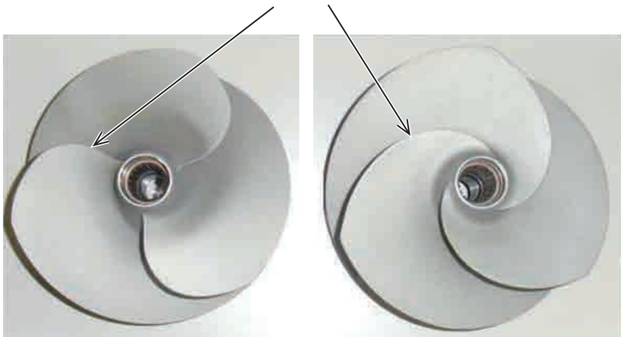
The weight of the hull greatly affects acceleration performance and riding stability on rough water. For this reason, we have reduced the weight of the hull, which makes up the largest portion of the weight.

The analysis results of the stress which is generated on the bottom of the hull during a ride is shown in Fig. 9, and the new hull structure where the thickness and reinforcement structure were changed based on the analysis results is shown in Fig. 10. By adding reinforcement (light blue portion in Fig. 10) to the portion where high stress is generated in the conventional structure (red portion in Fig. 9) and reducing the overall thickness, the new structure achieved high rigidity and reduced the weight of the hull to 85 kg, approximately 17 kg lighter than the conventional model ULTRA 250X.

3 Optimum jet pump for the high power engine

We designed a new jet pump along with improvements in the engine power, and the inner diameter was set at 160 mm, which is larger than the conventional model. We also made substantial changes in the shape of the impeller on the leading edge side, and by increasing the surface area of the impeller blades by about 13%, we were able to efficiently convert the torque of the high power engine into propulsive force without generating cavitation*. The conventional shape and new shape of the impeller are shown in Fig. 11, and a comparison of the standing start acceleration performance is shown in Fig. 12.

* Phenomenon where foam is generated in a short period of time by the pressure difference in the flow of a liquid.



(a) Conventional shape (b) New shape

Fig. 11 Shape of the impeller

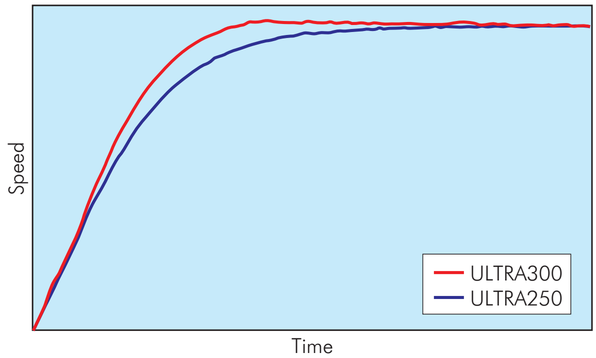


Fig. 12 Starting acceleration performance

Fig. 13 Jet Ski ULTRA 310LX

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Concluding remarks

Kawasaki developed the ULTRA 300 Series based on the concept of "powerful acceleration," "greater maximum speed" and "excellent maneuverability on rough water," which riders seek in a personal watercraft. This ULTRA 300 Series is equipped with excellent functionality, including a high supercharging, high power engine, and a hull which maximizes the engine performance. This series was the center of all attention at the Japan International Boat Show 2013. Moreover, for the 2014 model, we developed the ULTRA 310 Series with further improvements added (Fig. 13). As well as clearing the U.S. and EU standards, we also achieved great reductions in emission gas, and great improvements in fuel consumption. We wish to change the image of personal watercraft in society by paying full consideration to the environment, and contribute to the revitalization of the global market.

Overwhelming performance motocrosser KX250F

The Kawasaki motocrosser KX250F comes loaded with numerous technologies directly derived from factory machines, including the Launch Control Mode, which gives riders an advantage in getting a good start in motocross races, and the Dual Injection System, which optimizes fuel delivery in both high and low rpm ranges. This paper presents an overview of the features of the KX250F and the technologies supporting them.

Preface

Motocross is a major motorsport in the US, its largest market. The pinnacle of stadium motocross racing, the AMA Supercross Championship (Fig. 1), is a grand event attracting over 50,000 spectators per race. Our KX450F motocrosser has won the title for three consecutive years in the main class, 450 cm^3. This has done great things for the Kawasaki brand image.

Meanwhile, our KX250F, competing in the 250 cm^3 class, has recorded great success in races all over the world since its release in 2003 (Table 1). In the last few years, it has consistently been ranked highly in "shootouts" with rival vehicles in motocross publications, establishing it as a major contender.

Table 1 Number of titles won by KX250F (2003–2012)

	Titles won	Total in 10 years
AMA Supercross	11	20※
AMA Motocross	7	10
All Japan Motocross	6	10

※2 titles/year, West Class and East Class

Fig. 1 American Motorcyclist Association Supercross (stadium race)

Fig. 2 Moment of start

1 Development concept

As this product is a commercial race machine, we set its development concept as "a machine that can win a race as-is, without modification." To achieve this, we aimed for two certain performance features: an engine that emphasizes not only power, but also ease of handling; and a body that obeys the rider's will.

After continued development of the machine according to this development concept, in recent years, the market has accorded it just the reputation we hoped for, as the most race-ready machine.

2 Engine technology

Aiming for an engine that can win a race, we set a development course towards the following two targets.

① Holeshot* win
② Fastest lap time** win

To reach these goals, the KX250F's engine has the following features.

*Holeshot: Being first in the first turn after the start
**Lap time: Time to go around a course once

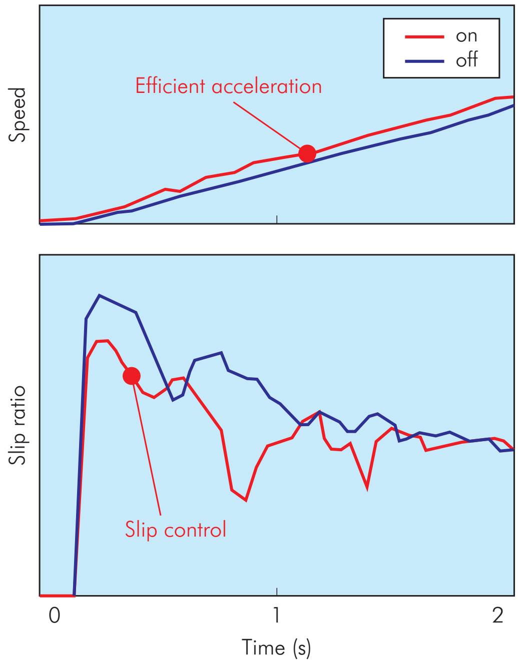


Fig. 3 Launch Control Mode operation

(1) Launch Control Mode operation — Holeshot win

In a motocross race, the starting dash (Fig. 2) is a key point. Success in the holeshot depends on the slightest of differences. It is easy to slip in the sudden start, so winning the holeshot requires fine control of the throttle and clutch.

What makes the engine control help with this highly technically demanding start is Launch Control Mode operation. This control mode originates from Kawasaki factory machines competing in the AMA Supercross and Motocross Championships, and now it has been brought to the mass-produced motocrossers KX450F and KX250F. It is a system which switches the engine characteristics to optimize them for the start.

All the rider has to do is press the button on the handlebar, and the engine map switches to Launch Control Mode, with optimal ignition timing for the start. This controls sharp torque fluctuation when starting, reduces wheelspin, lowers slip ratio, and speeds up acceleration (Fig. 3). Launch Control Mode is only active right off the

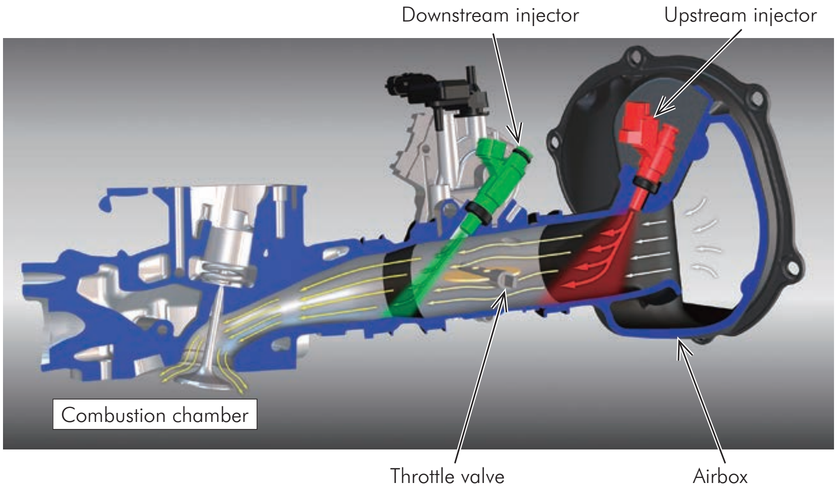


Fig. 4 Dual Injection System

start, disengaging and returning to the standard engine map automatically once certain conditions are fulfilled in driving.

Wise use of this system for the course conditions will make it an extremely effective tool for winning the holeshot.

(2) Dual Injection System
— Fastest lap time win

(i) System configuration

The KX250F is the world's first mass-produced motocrosser to feature a dual injection system. In our Dual Injection System, as shown in Fig. 4, there are two injectors around a butterfly-style throttle valve: one on the side of the combustion chamber and one on the side of the airbox. By using each of these injectors as appropriate, the vehicle can achieve both agile response in the low rpm range and high peak power in the high rpm range.

The downstream injector is the main force in the low rpm range, used in the starting dash, which requires rapid acceleration, and in cornering, which requires accurate and precise engine speed control. The injector is positioned close to the combustion chamber, so that the fuel injected will be delivered to the combustion chamber immediately,

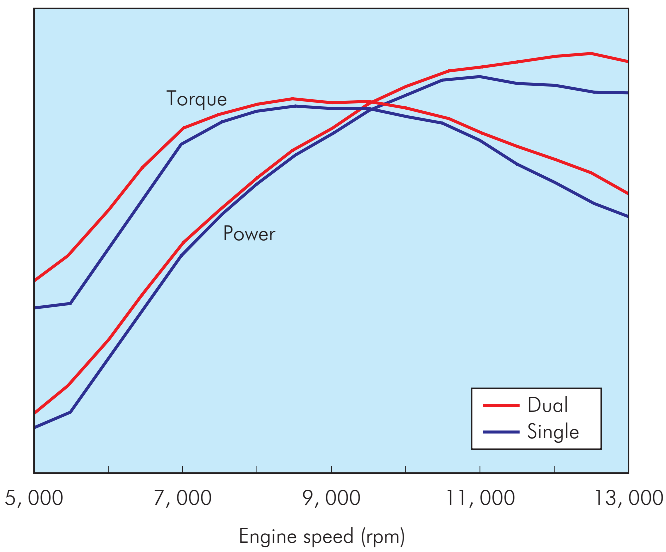


Fig. 5 Performance enhancement with the Dual Injection System

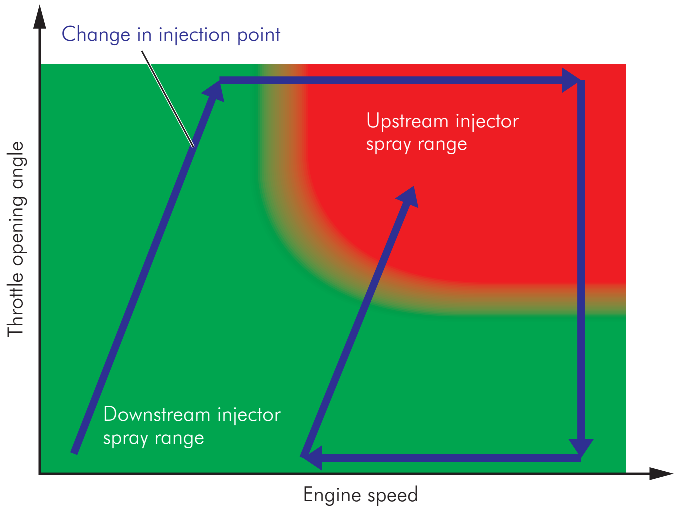


Fig. 6 Map of fuel injection

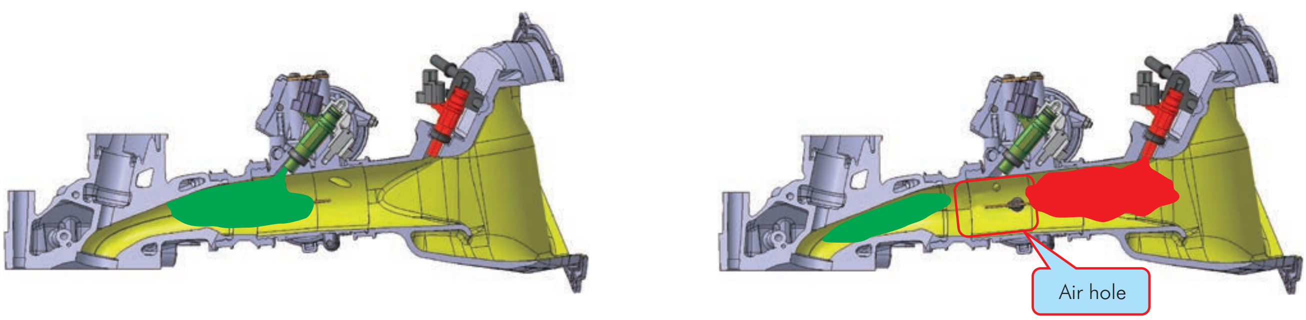
for quick response.

The upstream injector is the main force in the high rpm range, which are about power. This injector is positioned at a distance from the combustion chamber, so that the fuel injected has time before it enters the combustion chamber. This makes it easier for the fuel and air to mix (turning the fuel into a gas) and cool, which makes the air-fuel mixture fill the combustion chamber more efficiently and raises power (Fig. 5).

(ii) Rate limit control

A motocrosser changes engine speeds and throttle opening angle extremely violently. Therefore, the injection point goes back and forth frequently between the downstream and upstream injector spray ranges, as shown on the map of fuel injection (Fig. 6).

Figure 7 shows what happens in the switch from the downstream to the upstream injector. When injection is switched from the downstream to the upstream injector,



(a) With downstream only

(b) Switch from downstream to upstream

Fig. 7 Injector spray diagram

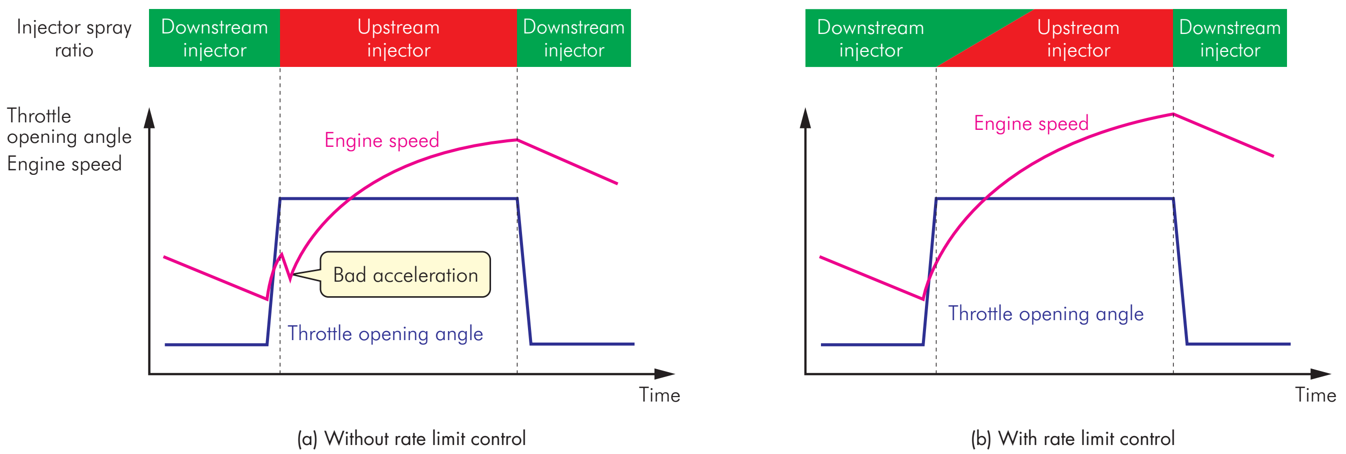


Fig. 8 Effect of rate limit control on engine speed

an air hole forms in the air-fuel mixture, which slows the fuel response and harms acceleration, as shown in Fig. 8 (a).

Our solution to this problem is rate limit control. By having the map of fuel injection draw a continuous transition in injection ratio instead of switching instantly from the downstream injector spray range to the upstream injector spray range, delay in fuel response can be eliminated.

On the other hand, when the engine speed is lowered, if rate limit control is still used, it creates the problem of fuel accumulating at the upstream side of the throttle valve. Therefore, we chose to have injection switch instantly from the upstream injector to the downstream injector in this case (Fig. 8 (b)).

This kind of rate limit control gives the Dual Injection System a clear edge over single injectors and contributes to winning the fastest lap time.

3 Chassis technology

Aiming for a body that obeys the rider's will, we set a development course towards the following two targets.

① Straight-line stability on rough roads
② Cornering performance that feels light and stable

(1) Main frame — Straight-line stability

For secure acceleration on rough roads, higher body rigidity is not always better. If the body is too rigid, it will not be able to absorb the bumps in the road and will behave without stability. To a certain degree, the body itself has to be able to bend and absorb shock, so the balance of rigidity is extremely important. Thus, we analyzed strength and rigidity and set balanced rigidity by assembling the main frame appropriately out of forged, extruded, and cast materials (Fig. 9). This secured high straight-line stability even when riding on rough roads at high speeds.

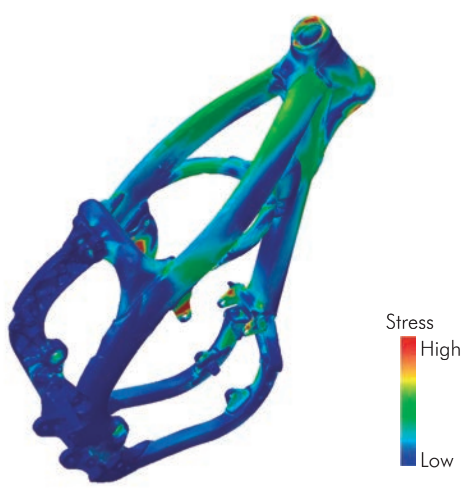


Fig. 9 Example of main-frame stress analysis

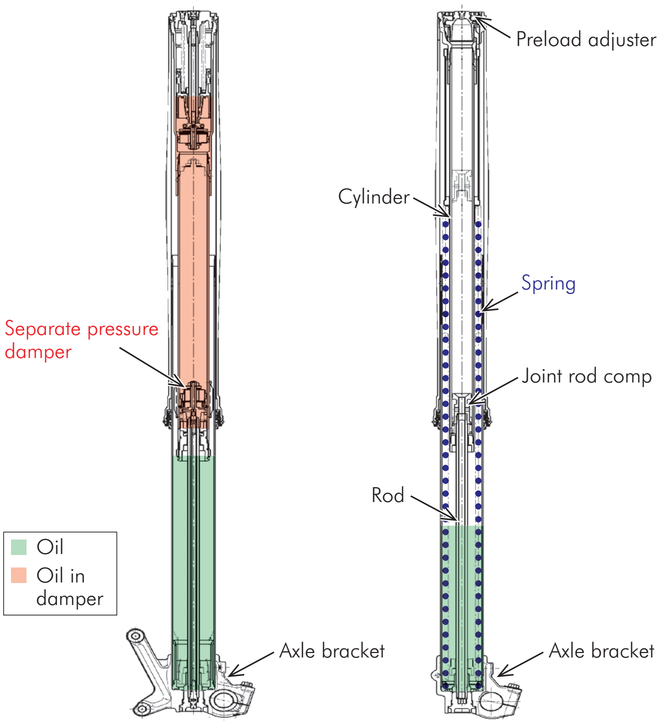


Fig. 10 Structual diagram of SFF (2014 model)

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(2) SFF (Separate Function front Fork)
— Cornering performance

Previous front forks had both body retention (spring) function and damping function in each leg, left and right. In the SFF, developed jointly with Showa Corporation, as shown in Fig. 10, the functions are divided into a separate pressure damper on the left leg for the damping function and a spring on the right leg for the retention function.

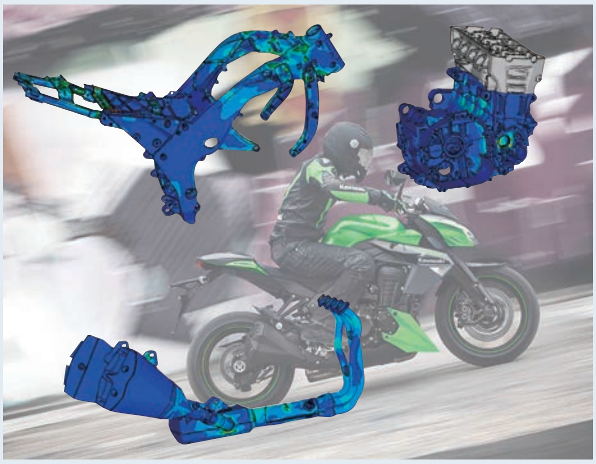
This achieves the effects of lightening mass by reducing the number of parts and reducing sliding friction by using only one spring. Thus, we were able to make the front fork lighter and improve its absorption power. Also, to change the preload (the spring's initial load setting), it used to be necessary to take apart the front fork, but now we have installed a preload adjuster on the right leg, expanding the setting possibilities by enabling adjustment of preload with a complete vehicle.

The SFF inverts the right (spring) leg's internal components (joint rod comp: a part connecting a rod with cylinders), which improves external cylinder damping force, dependent on stroke. Also, on the left (damping) leg, we have expanded the damper size to an outer diameter of 30 mm for gains in both shock absorption power and sense of control. At the same time, we have expanded the inner tube to an outer diameter of 48 mm, adjusted the rigidity of the axle bracket region, and more to optimize rigidity over the front fork as a whole. This achieves cornering performance that feels both light and stable.

Concluding remarks

We have developed many technologies and applied them to the KX250F. Remembering how they have made the KX250F what it is today, we intend to keep on aggressively developing daring new technologies to improve its competitiveness yet further.

Advanced simulation technology that enables front-loading of development



In order to develop attractive motorcycles with greater efficiency, it is extremely important to achieve high quality and performance upstream in the development process when there is greater freedom for design study. To enable such frontloading of the development process, Kawasaki has been developing advanced numerical simulation technology and validation technology.

This paper will focus on aspects that concern durability, and examine how such technologies are actually applied in virtual simulation, body weight reduction and road simulator testing.

Preface

In order to develop attractive motorcycles, it is important to secure quality and to achieve high performance and marketability. This is accomplished most efficiently by, as shown in Fig. 1, polishing quality and performance upstream in the development process, when there is greater freedom for design, and then, in later development, focusing on such factors as feel which require a prototype vehicle to confirm. Through such front-loading of development, we hope to shorten development time and reduce cost.

In the upstream development process, when there is not yet an actual vehicle, accurate evaluation of various factors, as shown in Fig. 2, requires numerical simulation technology and evaluation technology to be more accurate than ever. Building these technologies requires advanced experiment and measurement technology to elucidate the theory behind phenomena.

This paper will focus on aspects that concern durability, in regard to the critical engine crankcase, muffler, and frame of a motorcycle, and road simulators for durability tests.

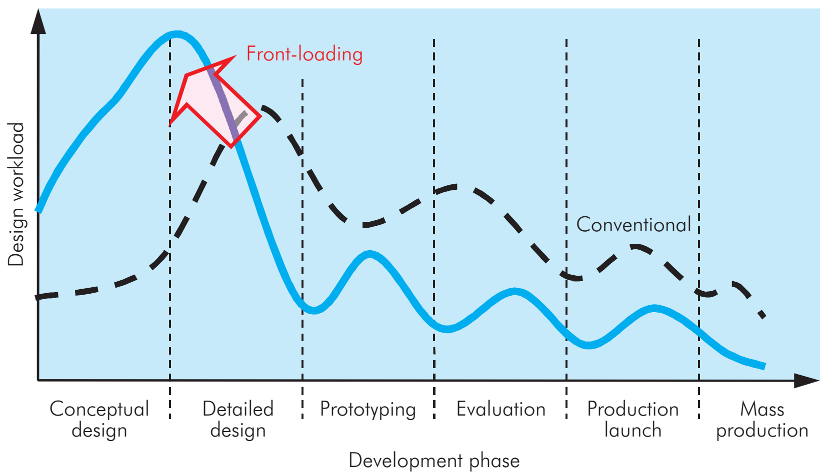


Fig. 1 Front-loading of development for design workload reduction

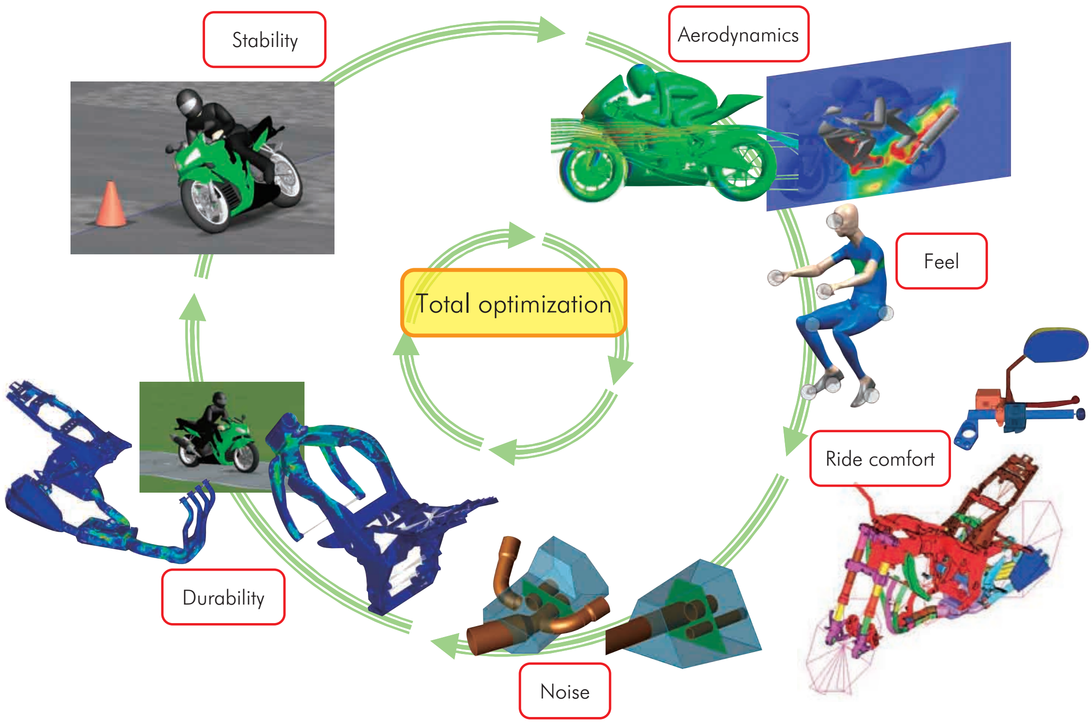


Fig. 2 Total optimization through mutual cooperation

1 Virtual durability simulation

(1) Engine (crankcase)

It is particularly important for a motorcycle engine to have a high engine speed and power and at the same time to be light. To achieve these at the same time, it is necessary to evaluate precisely the durability of the engine in the early stages of design. To do this, Kawasaki has developed highly accurate virtual durability simulation technology[1).

In the actual operation of an engine, as the piston-crank mechanism moves back and forth and rotationally, the force and inertia from the engine combustion act repeatedly on the crankcase. The magnitude and direction of the forces change with time, and therefore the stress conditions of the crankcase are complex and change every moment.

For such reasons, dynamic simulation would be best for numerical simulation of the crankcase. However, from a design efficiency standpoint, it is not practical to apply dynamic simulation, due to the calculation load and result volume. Instead, from the results of dynamic simulation using the model shown in Fig. 3, we decided to select multiple load conditions that would be hard on the engine

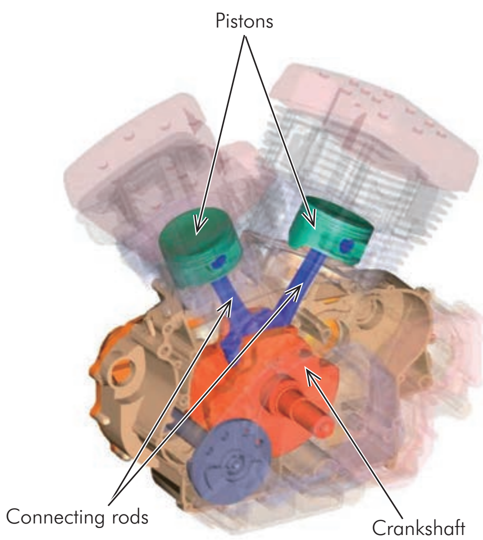


Fig. 3 Dynamic simulation model for engine

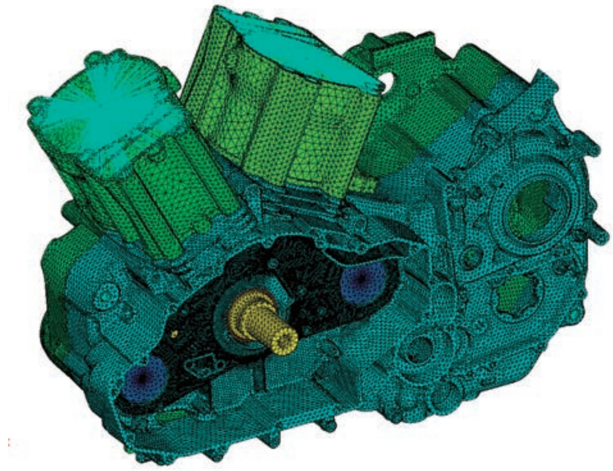


Fig. 4 Static analysis model for engine

in terms of strength, to evaluate durability based on their results. We applied these load conditions to the model shown in Fig. 4 and used the individual simulation results to calculate fatigue damage (durability evaluation). Example evaluation results are shown in Fig. 5.

Using this technology, it is now possible to conduct a virtual engine durability test and to consider many factors useful for polishing design.

(2) Muffler

In order to evaluate the stress applied to the muffler, the engine vibration needs to be analyzed accurately, and the muffler needs to be modeled appropriately. In addition, an evaluation method for the fatigue damage of welded joints is needed to predict the fatigue life of the muffler.

① We calculate engine vibration using mechanism analysis. Since the engine vibrations in a motorcycle range widely, they are evaluated by frequency domain.

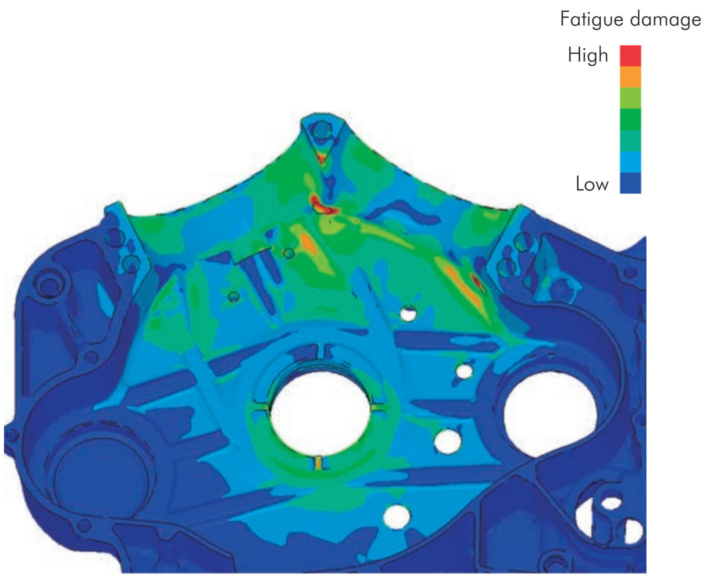


Fig. 5 Distribution of fatigue damage inside the right crankcase

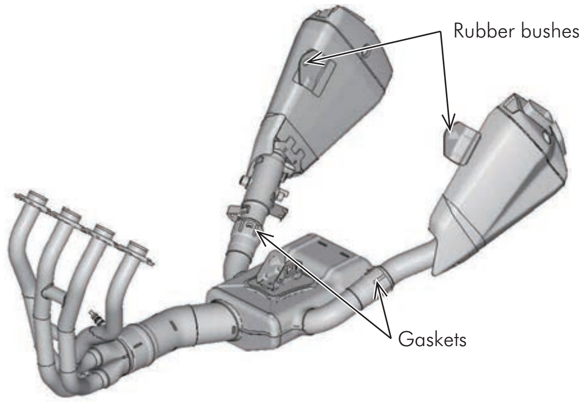


Fig. 6 Vibration analysis model for exhaust system

Fig. 7 Vibration test for exhaust system

② To evaluate muffler vibration characteristics, we improve the accuracy of the simulation by using a vibration analysis model as shown in Fig. 6 which includes gaskets for the joints with the engine and rubber bushes for the joints with the frame. We also validate the accuracy of the vibration simulation using a vibration test for the exhaust system as shown in Fig. 7.

③ In weld durability evaluation, we apply an evaluation method based on hot spot stress, allowing consistent evaluation that does not depend on the joint form of the weld. Hot spot stress is defined as a structural concentration of stress, not including local concentration of stress from weld beads. This method was originally developed mainly for application to thick plate components such as those used in ships and rolling stock, but we developed a technology by which the method can also be applied to thin plate components such as mufflers. We also take into consideration effects from heat from the engine.

The results of applying durability evaluation technology using these methods to actual mufflers (fatigue damage to the weld) are shown in Fig. 8.

Thus, we are now able to implement actual durability tests virtually, to consider design efficiently.

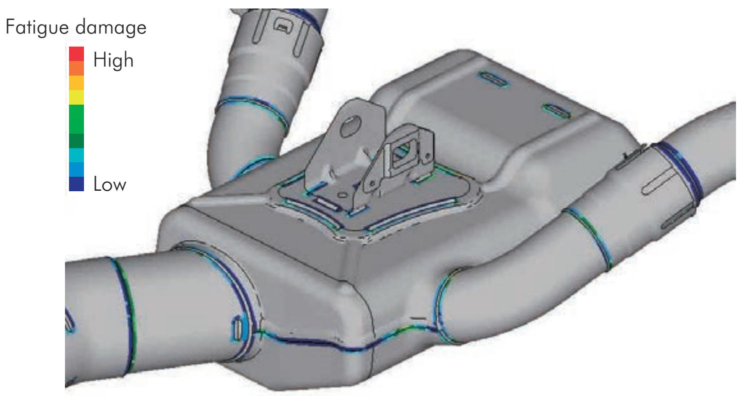


Fig. 8 Distribution of fatigue damage in exhaust system welds

2 Body weight reduction

Lighter frames are demanded, but they must maintain appropriate rigidity and strength. Therefore, we developed optimization technology for considering efficient form and component placement that fulfill the requirements for frame rigidity and strength.

Our frame optimization analysis model is shown in Fig. 9. We used the range in which the components of the main frame can be placed as the design space, while also modeling the engine, rear frame, swingarm, etc. The form obtained from our optimization analysis and the subsequent frame optimization process are shown in Fig. 10. We used the form obtained from our optimization analysis as a reference in determining the placement of ribs on the frame, etc. This makes possible efficient design that fulfills the conditions of rigidity, strength, and light weight demanded of a frame.

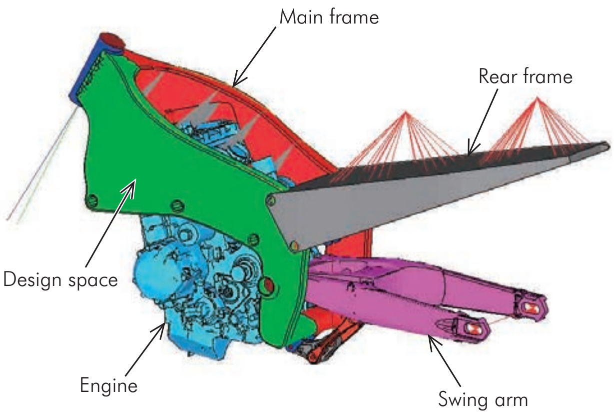


Fig. 9 Optimization analysis model for frame

3 Development of a road simulator for durability testing

In the use of virtual durability simulations, numerical simulation technology is becoming dominant. However, it is still essential to conduct validation tests under actual use conditions using a prototype vehicle.

Therefore, to verify rationally and efficiently that a product fulfills its target durability, we are advancing the use of a bench vibration system (road simulator) that can reproduce the conditions of riding on a course for an actual durability test (body load).

We are conducting durability validation tests with prototype vehicles in each development stage for motorcycles. However, these tests not only take a long time, but also are affected by the weather, cannot necessarily be continued day and night, and place a heavy

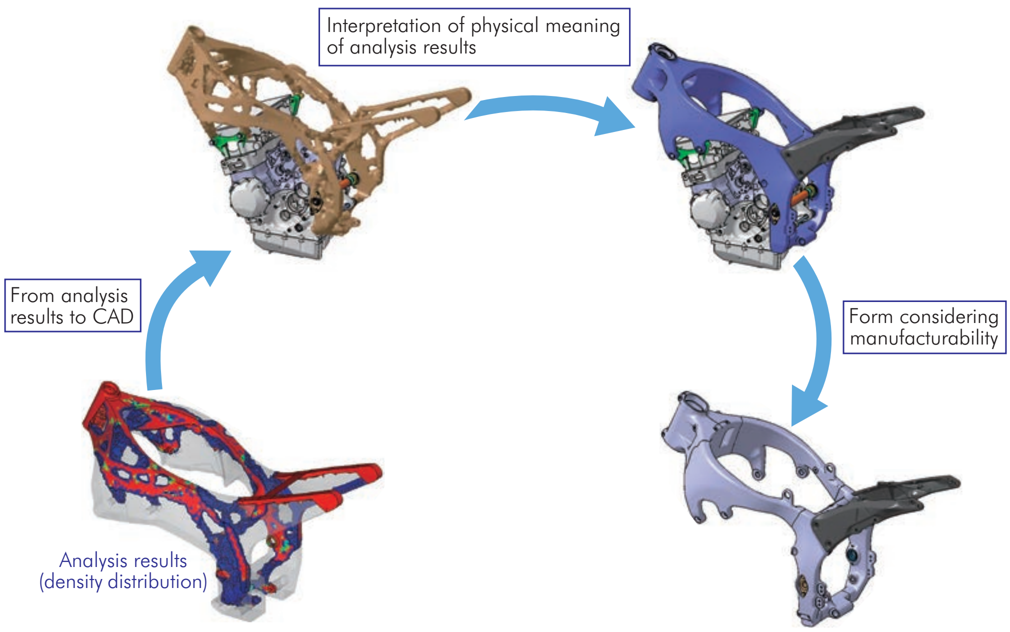


Fig. 10 Frame optimization process

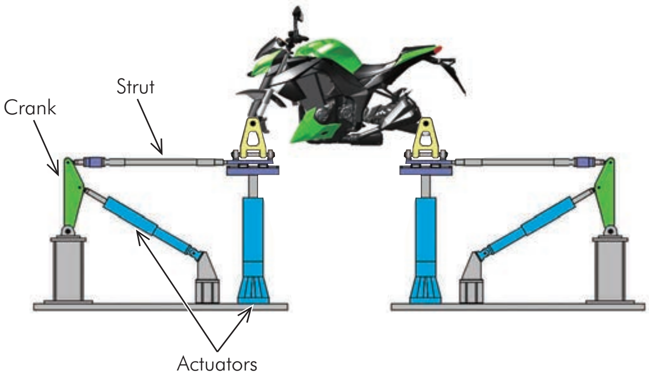


Fig. 11 Equipment composition of road simulator

Fig. 12 Durability test using road simulator

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load on the riders. Moreover, since they form the final process in development, if there is some problem with them, it makes it difficult to stick to the target development period.

Therefore, it is crucial to establish a simpler and quicker test method to supplement actual riding durability tests, in order to make durability validation more efficient. Thus, we developed a road simulator for motorcycles, as shown in Fig. 11 and Fig. 12, as a bench testing method that can reproduce the conditions of an actual riding durability test with high accuracy.

The road simulator controls multiple actuators to faithfully reproduce the damage inflicted on the body when riding on an actual durability test course.

Concluding remarks

We have demonstrated our front-loading technology for motorcycle development and how it can be applied to durability evaluation.

We intend to continue to make our front-loading technology more precise, in order to make our development more efficient, and to develop technology that will help to polish product value.

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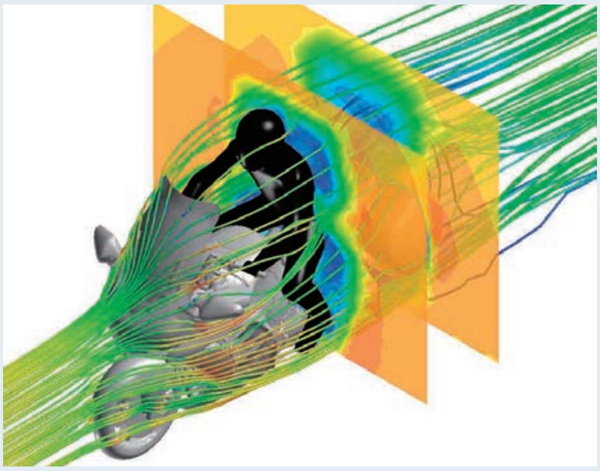
Engineering riding comfort and aerodynamic and cooling performance in the sketching stage



In the development of a motorcycle, design is as important an element as performance. Therefore, a technology for achieving the optimal balance between design and performance during the sketching stage is vital. This paper will examine development evaluation methods for the chassis during the sketching stage aimed at improving aerodynamic and cooling performance as well as riding comfort.

Preface

In the development of a motorcycle chassis, to improve marketability, design is as important an element for development as performance improvements such as in riding performance and comfort. Many sketches are drawn in the earliest stages of development, and, from these, a design that realizes the product concept is set. To improve acceleration performance and fuel efficiency, it is particularly important to reduce aerodynamic drag (CD value) at high speeds[1]. However, this is greatly affected by the shape of the design of the cowling that shields the chassis.

For touring products used for long-distance rides, improved wind protection and improved comfort through reduction in sensory temperature in the summer can both contribute to the enjoyment of riding. The shape of the wind shield is important to improve the rider's wind

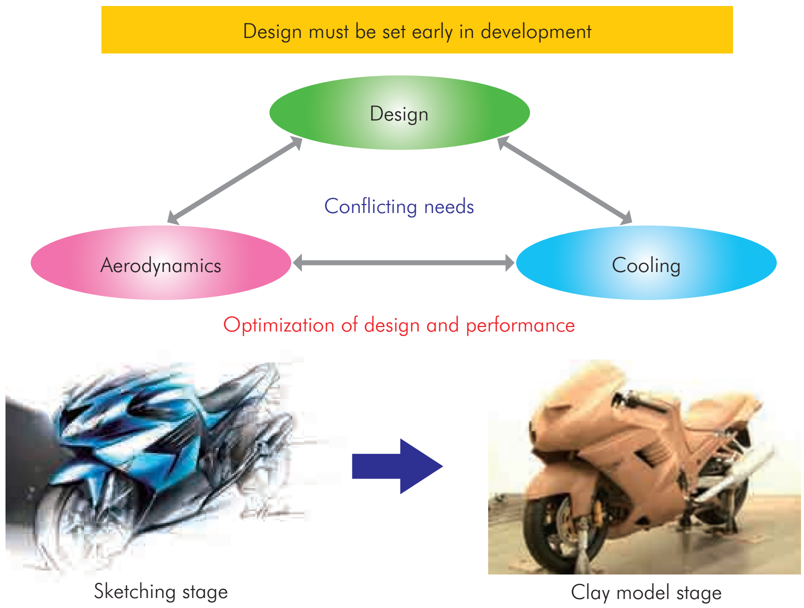


Fig. 1 Optimal balance in the sketching stage

protection, and the shape of the side is important to reduce the sensory (subjective evaluation of) temperature. Also, to improve engine performance, it is necessary to cool the engine cleverly by leading wind efficiently across the radiator. For this purpose, the shape of the cowling covering the engine must be optimized. Thus, the form of a motorcycle chassis is closely related to its function in aerodynamics, wind protection, sensory temperature, and engine cooling.

However, the design of the chassis shape is set at the very start of the development process, at the stage of sketches and clay models (clay mockups) reflecting the sketches. Changes after that are severely limited in scope due to the demands of form and function. Therefore, development in performance, including aerodynamics and cooling, must enter at the sketching stage, considering many specifications through simulation, so that the design can be optimized accordingly (Fig. 1).

This paper will examine efforts in motorcycle chassis development during the sketching stage aimed at improving aerodynamic and cooling performance as well as riding comfort. It will also examine the use of more efficient and quick models.

1 Application to development of touring models

Our 1400GTR tourer offers pleasant riding through its improved performance in wind protection, important for long-distance touring, and comfort, reducing sensory temperature in the summer. Since it places an engine with a car-level displacement of 1,400 cm^3 in a narrow engine compartment, the challenge is how to cool the engine efficiently. Wind protection, thermal comfort, and engine cooling are all closely related to design-based shape decisions, such as for the cowling. Therefore, in the earliest stages of development, the sketching and clay mockup stages, we apply total-vehicle computational fluid dynamics (CFD) analysis (reproducing entire components) and wind tunnel tests.

In particular, since wind tunnel tests are a vital stage for optimizing design while improving aerodynamic performance, in 2009, we installed an actual vehicle wind tunnel facility dedicated to motorcycles, one of the very few in the world, to improve design and aerodynamic performance[2].

The 2008 model of the 1400GTR is compared to the improved 2010 model in Fig. 2. One will notice that the cowl side shape has been changed to make the design more functional.

(1) Improvement in engine cooling

For our first development target, we aimed to improve engine cooling, which plays a major role in improving the performance of the motorcycle. To cool the engine, wind must be guided efficiently across the radiator. An obvious step might be to widen the opening of the front of the radiator, but, in fact, to increase the air passing the radiator, the space at the back is more critical than the area where the air enters at the front. The space at the back is closely related to the shape of the side cowl. To come up with a shape that would uphold the design in the sketching stage while improving cooling performance, we predicted cooling performance using total-vehicle CFD analysis, modeling the chassis including all parts in the engine compartment.

The old method was to first make a prototype in the design stage and then experiment to check its cooling performance. However, in the development of the

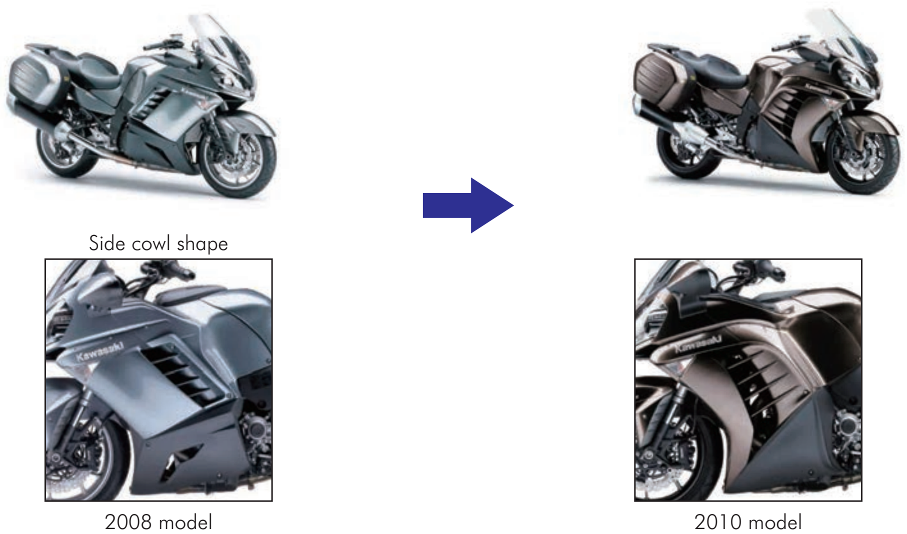


Fig. 2 Design change of 1400GTR

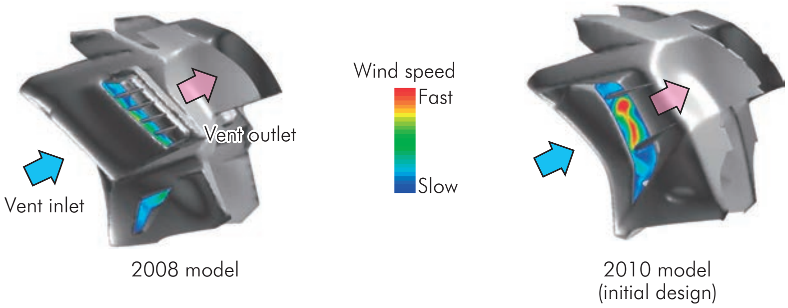


Fig. 3 Engine cooling prediction during the sketching stage

1400GTR, we analyzed the sketch shape based on a 3D CAD-generated design model.

The flow of cooling wind from the side cowl during idling, as implemented at the start of development, is shown in Fig. 3. One will see that, in the 2008 model, the blue area indicating slow wind speed is prominent, but in the 2010 model, there is a larger red area indicating fast wind speed. This demonstrates that the cooling wind is passing the radiator more efficiently. Comparing the initial design for the 2010 model (Fig. 3) with what went into production (Fig. 2), the number of ribs increased from two to four, but the shape of the side cowl is the same as in the initial design. We succeeded in starting development with a cowl shape that fulfills both design and cooling performance.

(2) Reduction of temperature on the rider's legs

Through the efforts described in section (1) above, we achieved our aim of improving engine cooling performance, but as the heat flow improved, there came the new issue of the possibility of the hot air from the side cowl hitting the rider's legs. Therefore, we used total-vehicle CFD analysis to look at how to reduce the temperature at the rider's legs. The flow of hot air onto the rider and the analysis results for the rider's temperature are shown in Fig. 4. With the 2008 model, there was somewhat of a tendency for hot air to hit the rider's legs, but we tweaked the cowl shape to deflect the hot air outward and reduce the temperature of the rider's legs.

(3) Reduction of pressure on the rider

Improving wind protection requires windshield work, but what is demanded is a design that does not make the windshield larger and yet offers excellent wind protection. A comparison of flow lines on the helmet is shown in Fig. 5 (b). With the 2010 model, the flow lines flow smoothly over the helmet, reducing the high-pressure zone of the 2008 model. It can be seen that there is less pressure on the shoulders as well, enhancing the rider's comfort (Fig. 5 (c)).

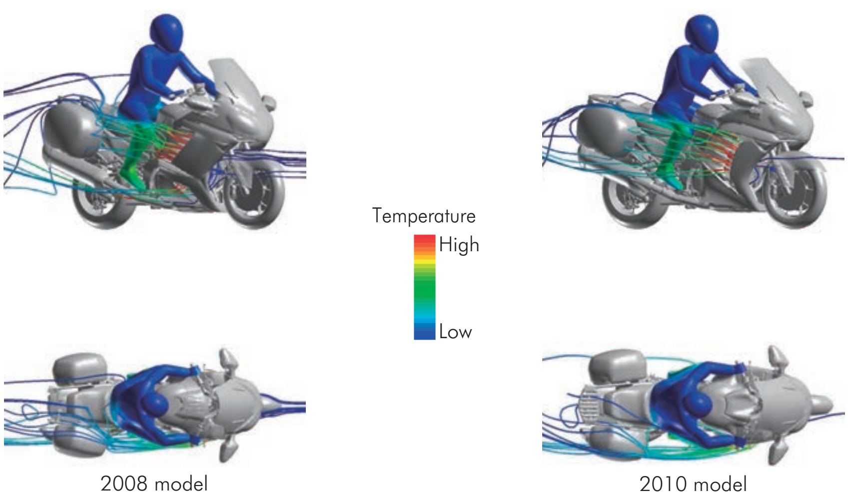


Fig. 4 Evaluation of the riders' thermal comfort

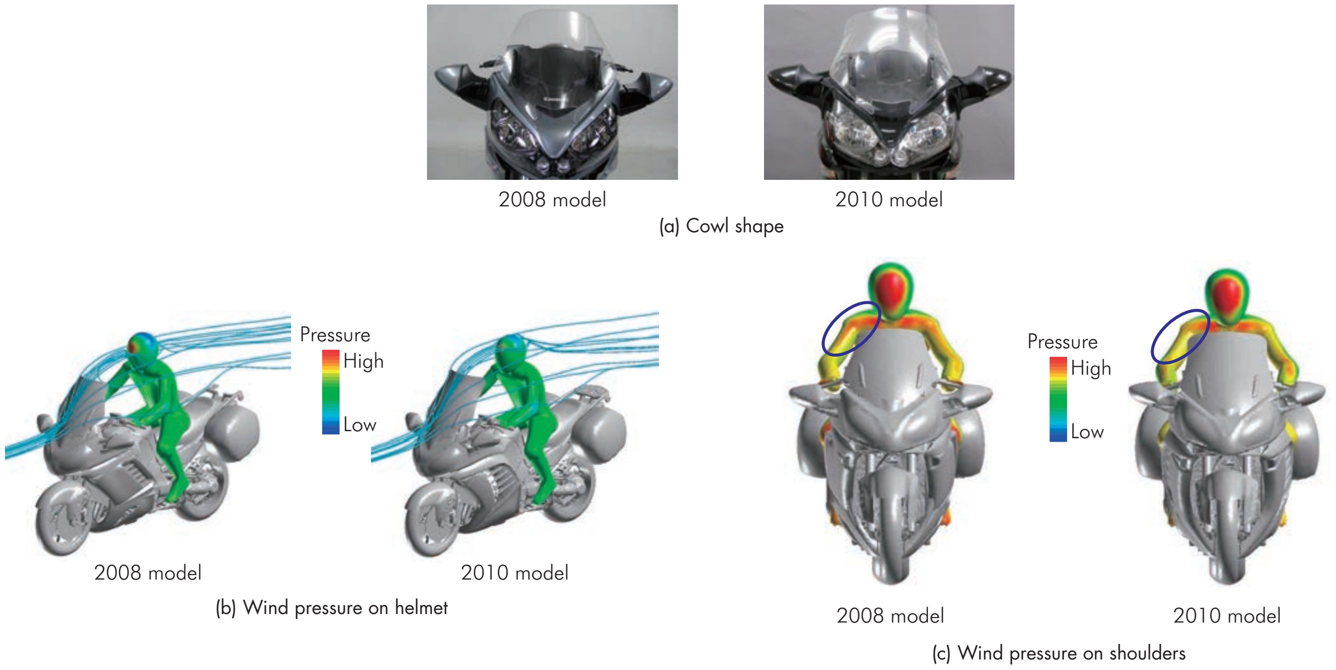


Fig. 5 Wind protection evaluation of 1400GTR

2 Advancement of wind tunnel aerodynamics and cooling prediction methods

For total-vehicle CFD analysis, we obtained validation data in our wind tunnel, and we have improved our analysis model. Smoke tests in the wind tunnel facility are compared with flow line maps from total-vehicle CFD analysis in Fig. 6. The test vehicles are the 2005 and 2009 models of the 600 cm^3 supersport ZX-6R. In the 2005 model, the upper region of the cowl is relatively large, with the intent of deflecting wind with the grip. The 2009 model has a more compact design. Wind tunnel tests made the flow visible using multiple streams of smoke from comb-shaped nozzles. It can be seen that the wind deflection pattern around the grip differs between the two models, and this is represented likewise in CFD analysis.

To evaluate engine cooling performance, it is not possible to directly measure water temperature using clay models (mockups), but considering optimization with design, it would be best if it could be predicted and validated in wind tunnel testing. Therefore, we are developing technology for aerodynamic optimization by placing many small anemometers to measure the amount of wind passing the radiator, which affects the liquid temperature, while measuring the six aerodynamic components using a balance.

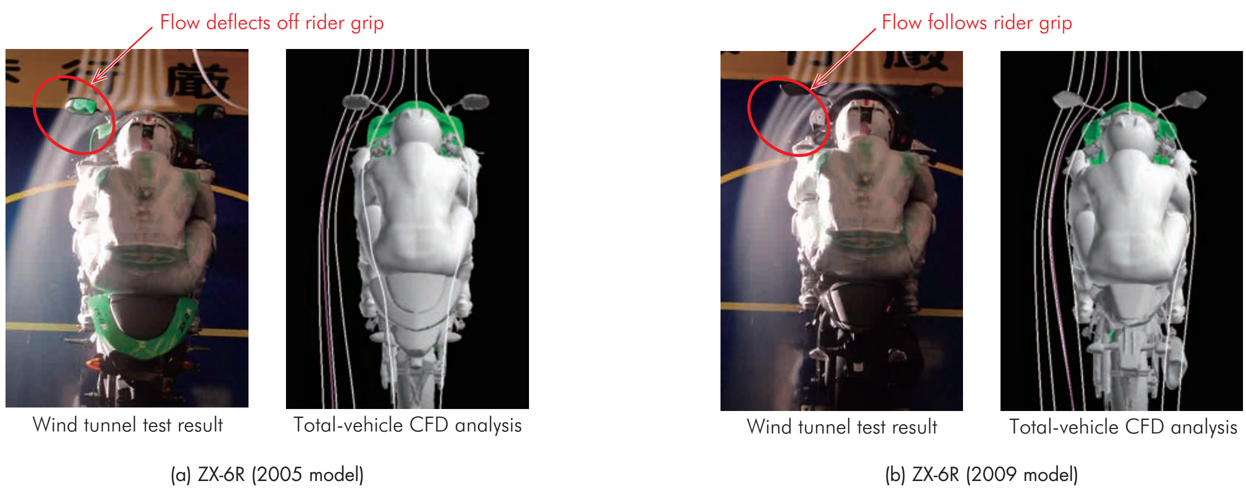


Fig. 6 Aerodynamic test in a wind tunnel facility

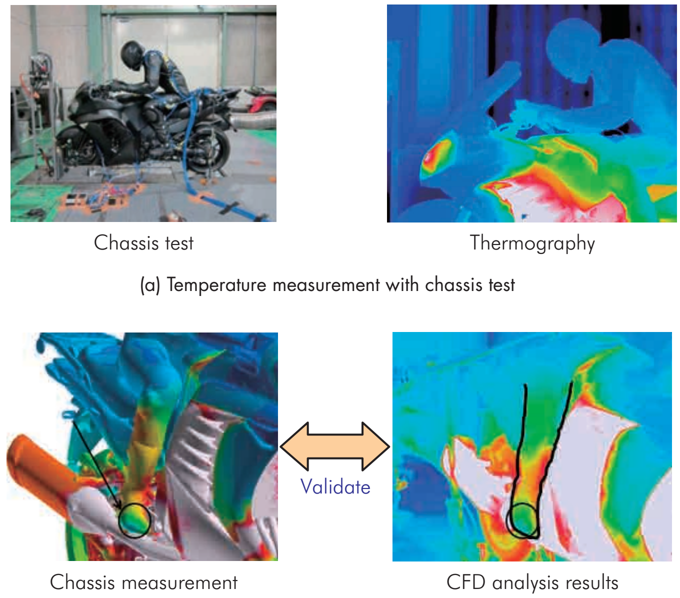


Fig. 7 Hot air test and advanced analysis model

3 Improvement of hot air evaluation prediction methods

To reduce sensory temperature in the summer, we use chassis tests in the prototype stage, in which an actual engine can be run, and we measure the temperature of the rider simulating actual riding. However, since hot air cannot be seen, it is difficult to measure its paths, and we end up relying on trial and error in tests for development. To deal with hot air, it is necessary to evaluate thermal comfort with total-vehicle CFD analysis early in development. It is important to predict precisely not only the wind flow, but also the temperature distribution. To measure temperature all over the rider's body in a chassis test, we made a hot air evaluation dummy with its surface painted black for a radiation factor of 1, and we measured temperatures using thermocouples and thermography (Fig. 7 (a)). A comparison of thermographic measurement of the rider's leg in chassis tests with analysis results is shown in Fig. 7 (b). The temperature distribution around

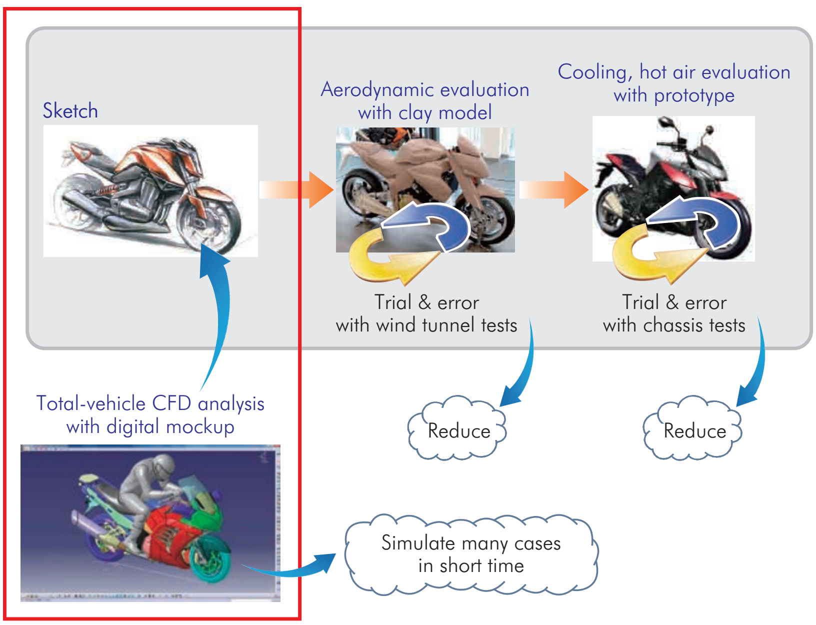


Fig. 8 Application of total-vehicle CFD analysis in the sketching stage

the rider's leg is successfully reproduced. We were able to make this analysis relatively precise in regard to temperature prediction by modeling not only heat transfer from convection, but also the impact of radiation from hot parts such as the exhaust pipe.

4 Automation of total-vehicle CFD analysis in the sketching stage

By improving total-vehicle CFD analysis as described above, we were able to predict in advance the aerodynamics, cooling, and hot air in the design process of an actual vehicle. Now, to make design even more efficient, we are working on automating total-vehicle CFD analysis in the sketching stage (Fig. 8). A key point for automation is to make it possible to use data for CFD analysis without manipulating the original 3D model. The original 3D model includes information unnecessary to CFD analysis, such as on gaps and overlaps between parts and the internal structure of parts. Such information only gets in the way of creating grid data for CFD analysis. Previously, such editing was done by hand, but now we can make full use of wrapping technology to eliminate editing work and automate grid generation. Using such automation technology for total-vehicle CFD analysis, we can now generate models for CFD analysis to make analysis much more efficient, compare and consider many cases in a short time, and optimize design, aerodynamics, and cooling performance in the sketching stage.

Concluding remarks

We have developed technology to optimize the balance of design, aerodynamics, and cooling performance in the sketching stage. We used validation to improve and to systematize this technology for application to design in the sketching stage. It is expected to become only more important in the future, improving motorcycles' performance in aspects such as engine cooling, as well as their comfort and marketability. We look forward to applying this technology to the development of more new models, advancing development towards a higher-level balance of design and marketability, and continuing to improve the technology itself.

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Developing "Fun to Ride" factors that attract motorcycle riders on an emotional level

The chassis as well as engine performance needs to be improved in order to enhance "Fun to Ride" factors that appeal to the rider. In particular, a pleasing engine sound, excellent riding comfort and greater handling stability are "Fun to Ride" factors that determine the value of a motorcycle as a product. As such, they are essential in maximizing the brand appeal of a model targeting customers in advanced countries. In this paper, we report the technologies involved in creating these "Fun to Ride" factors.

Preface

We aim to develop attractive motorcycles that are "Fun to Ride" for riders to the maximum degree possible. Some factors that make a motorcycle "Fun to Ride" are a pleasing engine sound, excellent riding comfort, and greater handling stability. These are described below.

① Pleasing engine sound:
Technology to scientifically evaluate and control the impression of the engine sound to make it pleasing

② Excellent riding comfort:
Technology for whole-body vibration analysis to control and present the vibration from the engine, which significantly influences riding comfort

③ Greater handling stability:
Technology for measurement of dynamic deformation of motorcycle bodies and for creating functional design to efficiently enhance the rider's feeling of control

1 Pleasing engine sound

While observing each country's noise regulations, we are developing technology to create pleasing engine sounds. The powerful sound of a sport bike creates a feeling of acceleration, and the comfortable sound and pulsating harmonic vibrations of a cruiser give it appeal (Fig. 1). To create sounds that appeal to riders on an emotional level, we have been developing technology for sensory evaluation to grasp rider psychology objectively, and technology to control sound to meet the targets obtained from sensory evaluation. These technologies have been applied to the development of the Z1000[1] to achieve an excellent feeling of acceleration through intake howl.

(a) Sport bike

(b) Cruiser

Fig. 1 Category of motorcycles

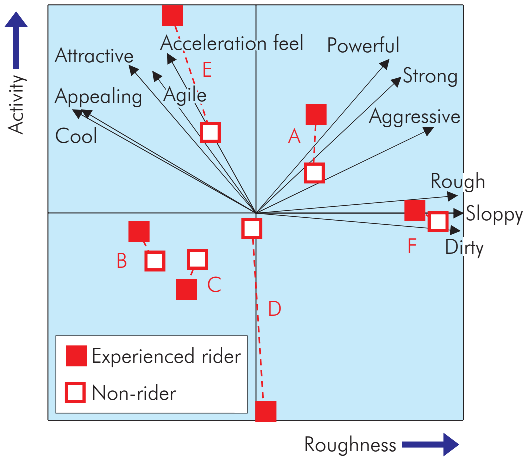

Fig. 2 Impression of engine sounds of six different models (A-F)

(1) Sensory evaluation technology

To improve marketability, customers' psychology must be interpreted and reflected in design, but challenges arise from the difficulty of quantifying people's feelings about things. However, we developed a motorcycle sound evaluation method based on the SD (semantic differential) method to scientifically capture emotional impressions[2].

Figure 2 represents an example of evaluating engine sound impressions for six sport bike models (A through F). The sound impressions are plotted on a 2D plane so that one can see their relations. One notices that there are some differences in the way people interpret the sounds, such as depending on whether they have experience riding motorcycles. By examining the relationships between these impressions and the corresponding acoustic characteristics, we are clarifying the directions in which sound should be taken in development of future models.

(2) Sound control technology[3]

To create the sounds targeted, we are utilizing acoustic analysis of intake and exhaust systems from the early stages of development, as well as factor tests with existing models, etc. We pick out methods that will help us achieve our target acoustic characteristics, such as using resonance from the air cleaner box or adjusting the muffling characteristics of the exhaust muffler. Also, we predict the pressure pulsation in the engine using non-stationary one-dimensional computational fluid dynamics (CFD) analysis to balance intake and exhaust sounds and power characteristics. An example of calculation of exhaust pressure pulsation is shown in Fig. 3.

While such a process is used to construct a prototype model, in the end, it is still necessary to refine it using people's ears. We do all of this so that customers can enjoy a polished sound finely tuned by the hands of the engineers.

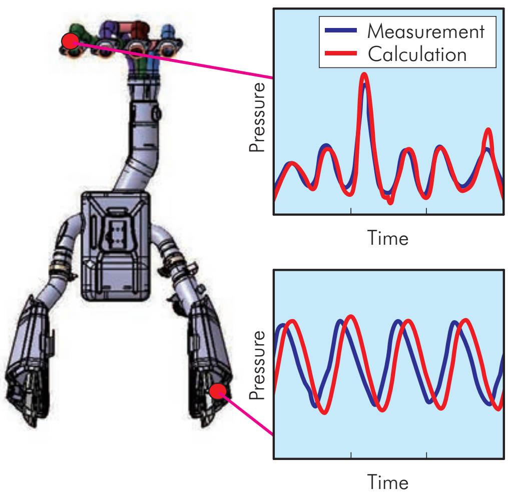

Fig. 3 Calculated pressure pulsation in exhaust system

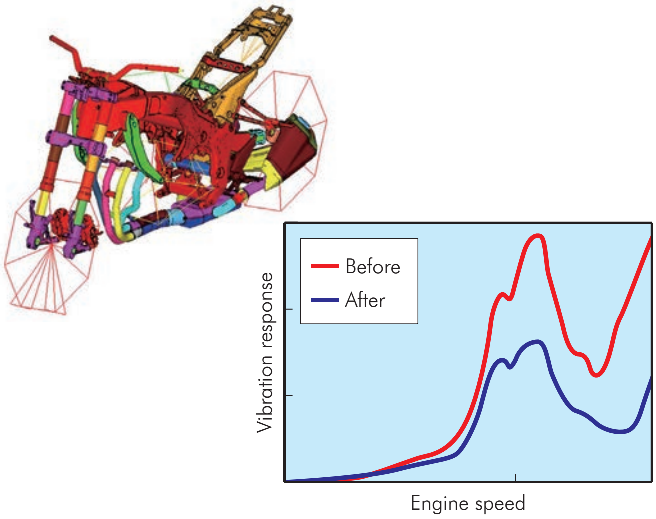

Fig. 4 Example of application of the whole-body motorcycle vibration analysis system (sport type)

2 Excellent riding comfort

(1) Motorcycle body vibration

Vibration is an important factor affecting the riding comfort of a motorcycle, but is not as simple as limiting vibration as much as possible. Sometimes bringing vibration to the forefront is just what is needed to improve riding comfort.

For example, on a sport bike, the rider's whole body is used, feeling the motorcycle body and the road conditions, to enjoy a sporty ride. The rider will feel uncomfortable if the body vibration is too strong. Vibration must be limited on such models. On the other hand, on a cruiser, a unique kind of vibration is favored which allows the rider to feel the pulsation of the engine and the strength of the machine. In such a case, vibration makes the ride more fun.

Thus, motorcycle vibration, from a riding comfort standpoint, must be separated into vibration that should be limited and vibration that is desired, according to the product category.

(2) Technology for improving riding comfort

Our motorcycles have started to apply a whole-body motorcycle vibration analysis system to predict the vibration of the whole body from the early stages of development. With this analysis system, we model the whole motorcycle body using the finite element method (FEM), consider the vibratory force from the engine, and evaluate vibration values at various points on the body.

An example of application to a sport bike is shown in Fig. 4. In this category, it is desired to limit unpleasant vibration, so we make design changes to the main frame and rear frame structures, reduce vibration at our points of concern, and improve riding comfort.

We apply the same kind of analysis to cruisers. In this category, it is required to play up vibration, so, unlike with the sport bike, we work on the structure at various points of the body in order to achieve certain vibration values.

These technologies have been applied to the development of the sport-type Ninja 250/300[4], helping to improve riding comfort by reducing vibration.

3 Handling and stability

(1) Technology for measuring dynamic deformation of motorcycle bodies[5]

To create the rider's feeling of control, it is important to use riding tests, a base of development, to quantitatively grasp body behavior, which is closely connected to the rider's feeling of control. "Body behavior" refers to the way the motorcycle body responds to rider handling, the way vibration and acceleration communicate the riding conditions to the rider, etc. A major factor in body behavior is elastic deformation of the body, always changing from moment to moment. One method to measure deformation is to use a relatively large measurement apparatus to directly measure the relative displacement between two points. However, since a motorcycle has a light body weight, such measuring equipment will have a relatively large impact, changing the motorcycle's motion performance. Therefore, instead of measuring displacement directly, we have developed technology to

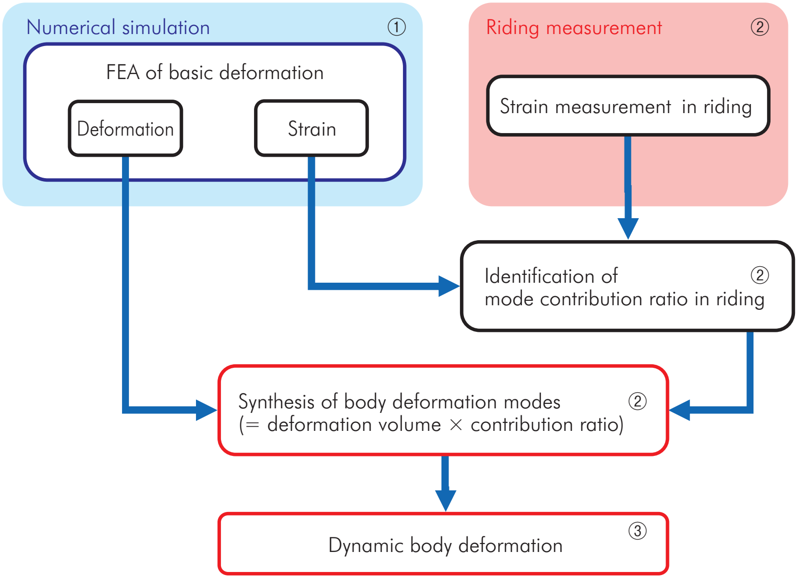

Fig.5 System flow for measuring dynamic deformation of motorcycle bodies

appropriately combine the numerical simulation and the measurement of strains without measuring the displacement directly.

The system flow developed is shown in Fig. 5, and an outline is shown in Fig. 6. Our idea was that the constantly changing dynamic deformation of a motorcycle body could be expressed by superimposing the individual deformations (basic deformation modes) for the dominant individual forces acting on the body. First, ① a detailed numerical simulation is used to calculate deformation volumes for each basic deformation mode of the body and the strain corresponding to each. Next, ② the strain in actual riding is measured, and the strains in the basic deformation modes are compared in order to superimpose the deformation in each mode and its contribution ratio. Finally, ③ the dynamic body deformation at a given time during riding is calculated.

As shown in Fig. 7, the dominant forces deforming the body are the load input from the tires (suspension) and the chain tension which transmits the engine's drive to the tires.

To precisely calculate the dynamic deformation of a motorcycle body, it is necessary to calculate the contribution ratios* of the basic dynamic deformation modes (hereafter "mode contribution ratios") from actual measured data. So we calculated the mode contribution ratios from strain, which can be measured with high precision using little space. Since measurement location has great effect on the precision of the body deformation measurement system. Therefore, the positions of strain gauges are selected from the following viewpoints.

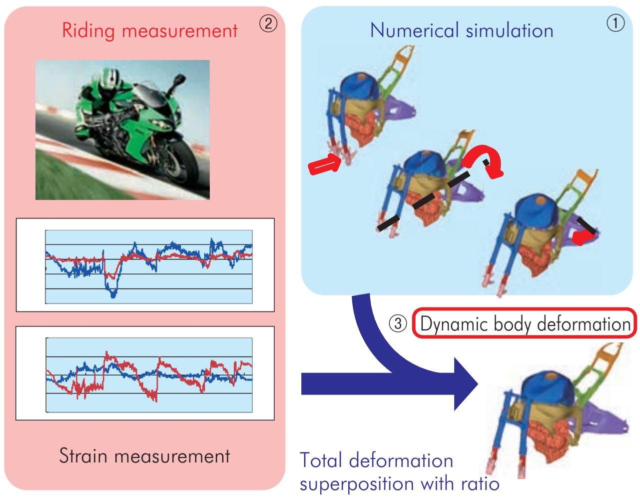

Fig. 6 Outline for measuring dynamic deformation of motorcycle bodies

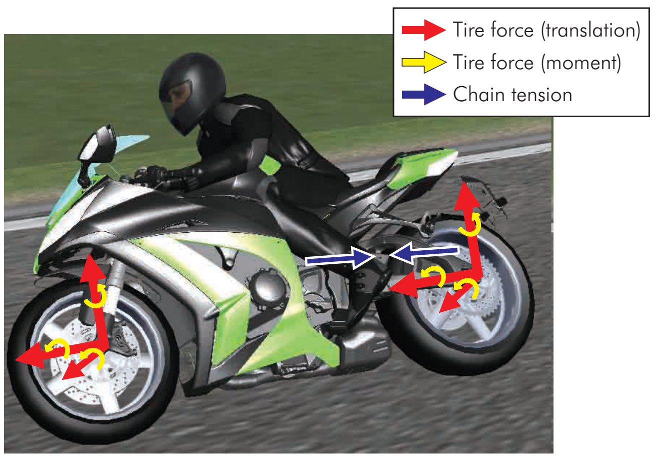

Fig. 7 Load acting on a motorcycle

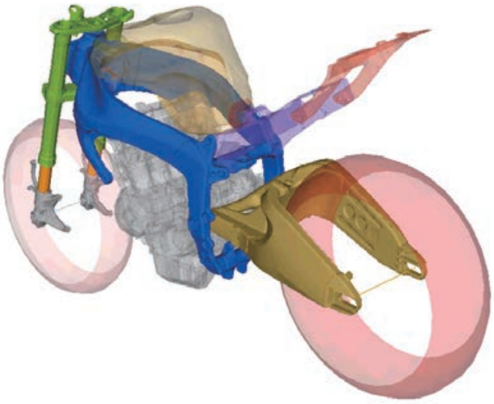

Fig. 8 Dynamic deformation of a motorcycle body

① Positions where strain due to individual forces is easily identified
② Positions where temperature does not influence strain
③ Positions where the change of strain is small (not sudden)

Calculation results for dynamic deformation of a motorcycle body are shown in Fig. 8. Thus, we are now able to visualize dynamic deformation of a motorcycle body based on measurement data in actual riding and to evaluate it quantitatively.

*Mode contribution ratio: The ratio expressing the magnitude of basic deformation.

(2) Technology for creating functional design

In the design of motorcycle parts, there are many factors that must be evaluated, such as weight, stiffness, strength (stress), vibration, and design. Previously, we have refined parts using repeat tests by experiment based on past experience. However, in recent years, there is a demand for better analytic technology to allow for better industrial design in the concept stage.

Therefore, using motorcycle wheels as an example, we developed technology for structural optimization analysis to calculate the lightest shape which would fulfill characteristics including stiffness, strength (stress), and vibration. An overview is shown in Fig. 9.

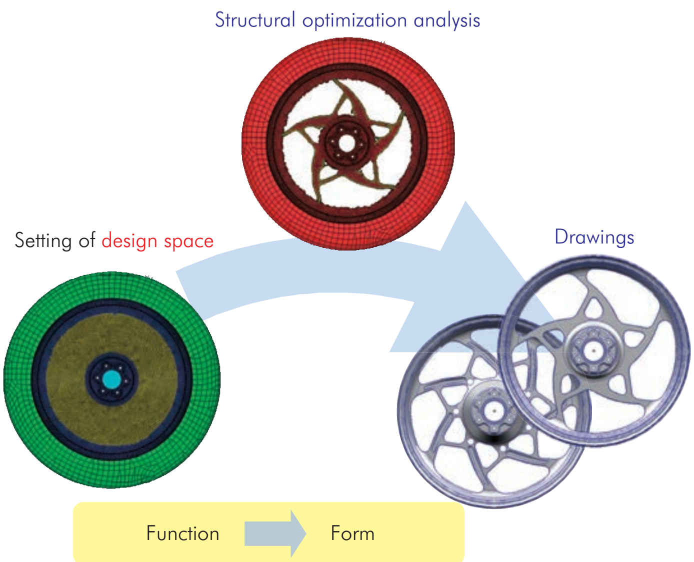

Fig. 9 Overview of technology for creating functional design

Setting the design space in which parts can be placed, and then specifying required performance values, such as stiffness, strength (stress), and vibration, we find the lightest placement of parts. The results of this structural optimization analysis are used as a base for drawings by a designer. This makes it possible for us to achieve functional design (design grounded in function) that is polished from an engineering standpoint without having to go back.

The wheels produced using this technology have been received well among riders in riding tests. Becoming able to grasp quantitatively the performance demanded in wheels has helped us greatly to make our products "Fun to Ride" for riders.

Concluding remarks

This paper has introduced our efforts to address major factors in motorcycle development that make a motorcycle "Fun to Ride," namely a pleasing engine sound, excellent riding comfort, and improvement of handling and stability. We intend to continue improving the technology involved and to develop motorcycles with greater product value.

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Balancing outstanding power feel with low environmental load

This paper discusses technologies for improving fuel efficiency and reducing harmful substances contained in exhaust gas without taking away from the outstanding power feel that is the hallmark of a Kawasaki motorcycle. This is achieved through technologies that improve engine combustion and control fuel injection volume as well as catalyst technologies.

Preface

The motorcycle is a vehicle that tends to be used for recreation, so the pleasure of riding and fun of handling are important factors in determining the marketability of the product. However, social demands for lower environmental load get stricter every year, as seen in emission standards. Moreover, better fuel efficiency is required to control global warming, a problem that affects society all over the world.

In such a climate, we are working to develop technology for improving fuel efficiency and reducing harmful substances contained in exhaust gas without taking away from the outstanding power feel (output performance) that is the hallmark of a Kawasaki motorcycle.

This paper introduces technologies which will be fundamental to achieving this, including technology for improving combustion in cylinders, as well as technology for fuel injection volume control and catalysts which will help to satisfy emission standards that become stricter each year.

1 Improving fuel efficiency while upholding power feel

To improve fuel efficiency, it is effective to address the range of ordinary riding, which comprises most of the time a motorcycle is operated.

We are working to improve engine combustion in the ordinary riding range, while increasing the volume of air intake to achieve strong power feel. We are also working to optimize ignition timing and to reduce friction loss.

(1) Improving combustion

To improve fuel efficiency in the ordinary riding range, it is important to reduce residual exhaust gas in cylinders, to stabilize combustion.

To achieve this, it is important to optimize for the model concept the valve overlap time (the time the intake valve and exhaust valve are open simultaneously), which is an important factor affecting the exhaust gas residual ratio.

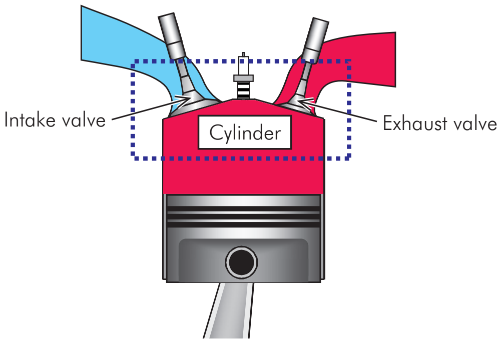
Figure 1 and Fig. 2 show examples of analysis of cylinder flow speed and exhaust gas residual ratio in cases with long valve overlap time and with short valve overlap time.

In the ordinary riding range, the opening angle of the throttle valve stays in a relatively small range, so the pressure in the intake port becomes more negative. This negative pressure causes exhaust gas to flow back into the cylinder and intake port during valve overlap. As seen in Fig. 1, setting a short valve overlap time helps to control exhaust gas backflow, which reduces the exhaust gas residual ratio in the cylinder and allows an increased ratio of fresh air (Fig. 2).

(2) Increasing volume of air intake

To achieve strong power feel from a low-speed range, we need to increase the volume of air intake into the cylinder. To achieve this, we are optimizing the timing to close the intake valve, an important factor affecting the volume of air intake.

The pressure pulsation of the intake port, caused by dynamic effects of the intake, is shown in Fig. 3. By optimizing the timing at which the intake valve closes, we

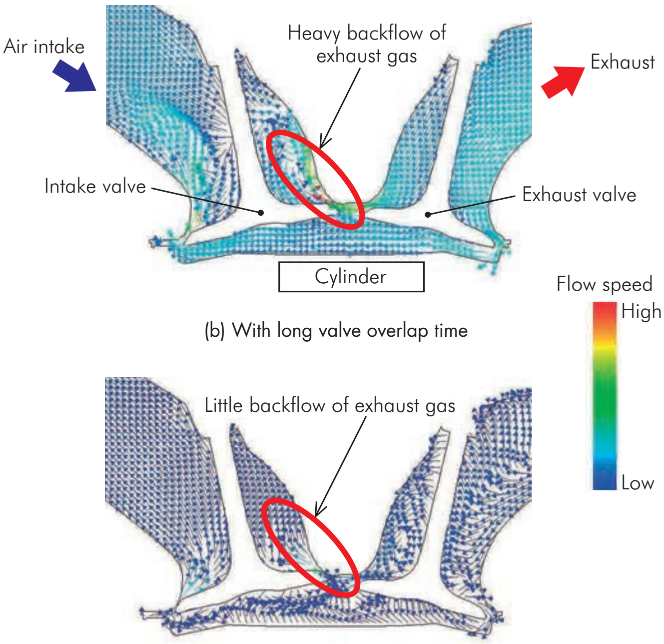


(a) Evaluation location

utilize the interval in which the intake pressure is positive after the bottom dead center, increasing the volume of air intake.

(3) Optimizing ignition timing

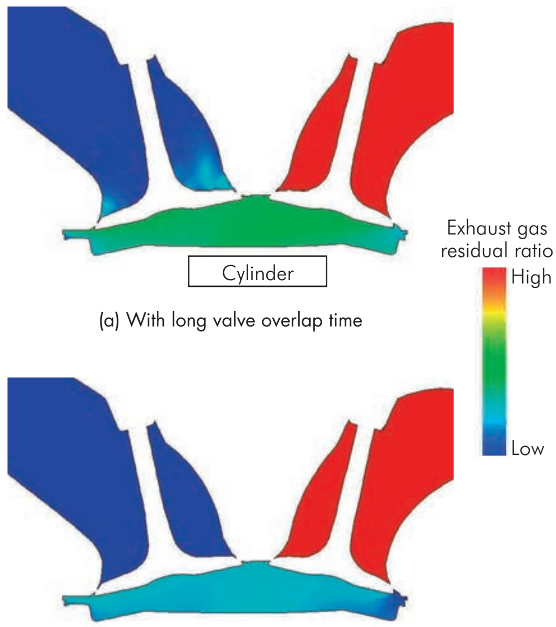
There is an ignition timing that is best for output and fuel consumption (MBT: Minimum advance for the Best Torque), but under riding conditions with heavy engine load, it may not be possible to bring the ignition timing to the MBT, because of the necessity to control knocking. To address this, we find the ignition timing at which knocking occurs (knocking limit) and set a margin to the ignition timing relative to the knocking limit so that knocking can be avoided even under poor conditions, such as when the engine coolant temperature or oil temperature is high.



(b) With long valve overlap time

(c) With short valve overlap time

Fig. 1 Predicted flow fields



(a) With long valve overlap time

(b) With short valve overlap time

Fig. 2 Predicted residual ratio of exhaust gas

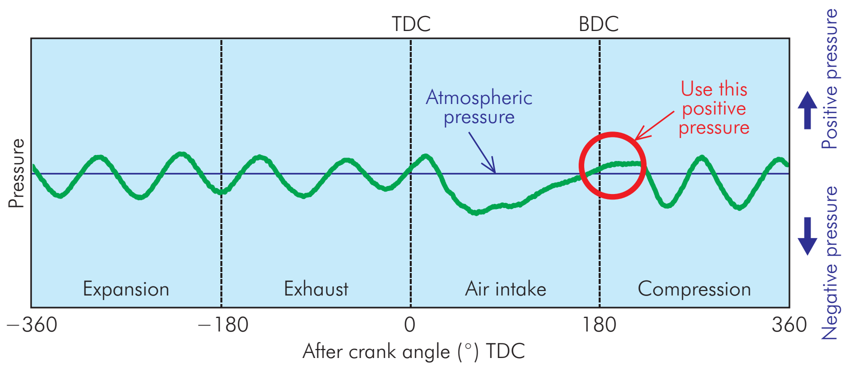


Fig. 3 Intake pressure pulsation of intake port

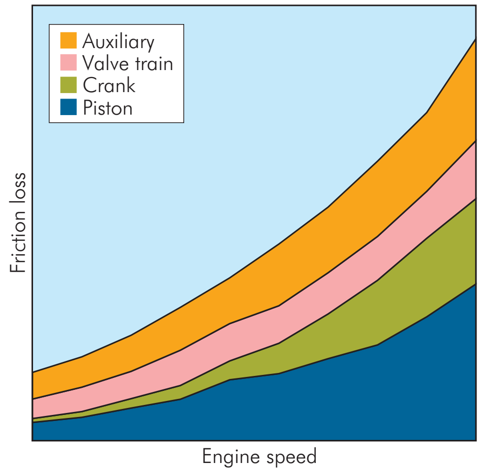


Fig. 4 Friction loss of each engine part

(4) Reducing friction loss

Reducing engine friction loss is an effective method to improve fuel efficiency and achieve high output.

By quantitatively determining the proportion of friction loss from each part of the engine (Fig. 4), we can determine which parts are most important for reducing friction loss according to the engine speed. This speeds up development.

2 Reducing harmful substances in exhaust gas

In recent years, concern regarding global environmental problems has been strengthening, and so have demands to reduce harmful substances in motorcycle exhaust gas. Many countries have been introducing new emission standards. For example, Europe, a major market for large motorcycles, is planning to apply the Euro IV emission standards from 2016, and the Euro V standards from 2020.

These new standards require vehicles not only to meet certain values when they are new, but also to keep amounts of harmful substances in exhaust gas below certain values after traveling a certain distance.

(1) Maintaining cleaning performance by controlling fuel injection volume[1)]

We use three-way catalysts for our exhaust systems, to clean the three harmful substances of CO, HC, and NOx with oxidation and reduction reactions. Also, to clean these three substances efficiently at the same time, we use O_2 feedback control. O_2 feedback control is an electronic control system in which an ECU (Electronic Control Unit) adjusts the fuel injection volume based on the signal from an O_2 sensor installed at the upstream side of the catalyst and keeps the air-fuel ratio stoichiometric* (approximately 14.5). The relation between air-fuel ratio and catalytic conversion efficiency is shown in Fig. 5.

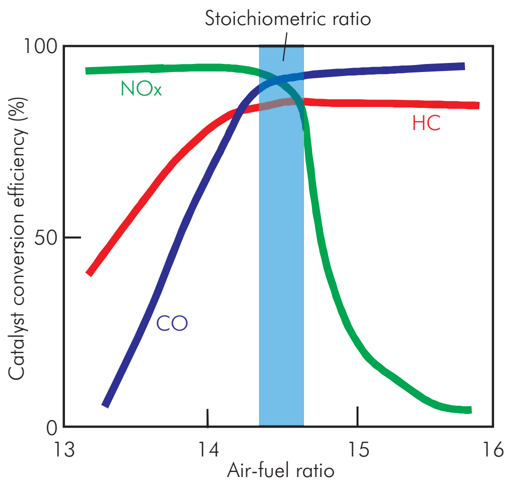


Fig. 5 Conversion of catalyst

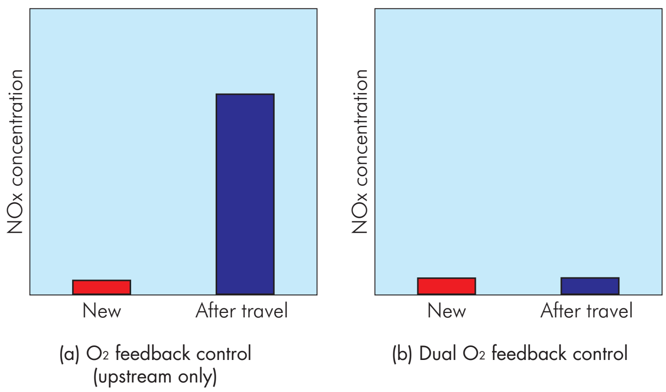


Fig. 6 NOx concentration in emission gas

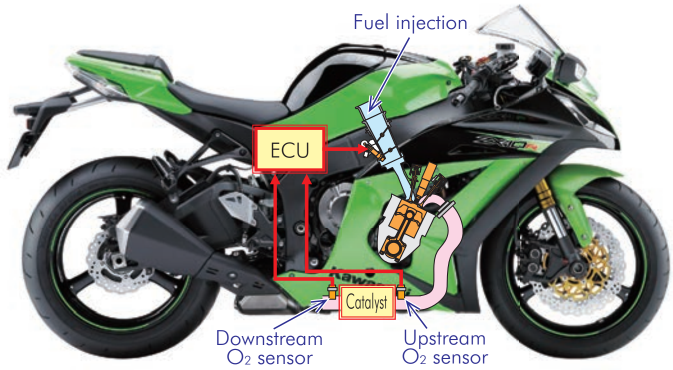


Fig. 7 Dual O_2 feedback system

However, O_2 feedback control has the problem that the O_2 sensor installed at the upstream side of the catalyst tends to degrade as distance traveled adds up. This can prevent the system from operating near the stoichiometric ratio and cause an increase in harmful substances in exhaust gas (Fig. 6 (a)).

To address this, we install another O_2 sensor at the downstream side of the catalyst to check the condition of the exhaust gas after catalytic conversion. This sensor's signal is used to correct the degradation of the O_2 sensor installed at the upstream side of the catalyst. With this, we have developed dual O_2 feedback control, enabling operation at the stoichiometric ratio even after long travel distance (Fig. 7). Such control makes it possible to control the increase in harmful substances in exhaust gas after long travel distance (Fig. 6 (b)).

* Stoichiometric ratio: The air-fuel ratio at which the air and the fuel can react with each other with no shortage or surplus of either

(2) Predicting catalyst life

The development of technology to meet emission standards requires more than reducing harmful substances using engine control before catalytic treatment: it is also essential to improve the cleaning performance of the catalyst itself. As catalytic conversion efficiency degrades with distance traveled, there is a need to develop durable catalysts that can withstand long travel distance (Fig. 8).

However, if catalyst development were to involve evaluating durability performance by actually driving a vehicle tens of thousands of kilometers, it would require an extremely long development period. Therefore, a technology important to catalyst development is performance evaluation predicting in a short time exhaust gas emission after tens of thousands of kilometers traveled.

Fig. 8 Three-way catalyst for motorcycle (Honeycomb form)

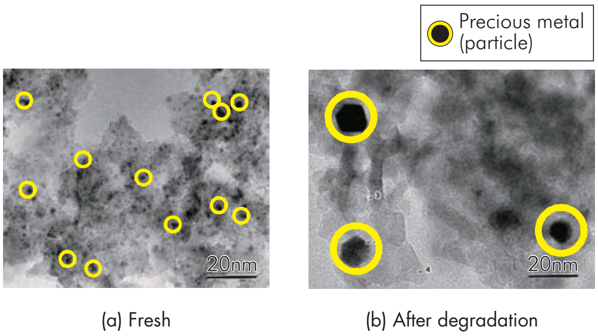


Fig. 9 TEM images of precious metals in catalyst
(Fresh and after degradation)
*TEM:Transmission electron microscopy

Degradation in catalytic conversion efficiency is thought to be caused by the particles of the precious metals which are the active sites sintering with each other, under the influence of heat and the air-fuel ratio, reducing the active surface area that can contribute to the reaction (Fig. 9). If this is true, then appropriate control of temperature and air-fuel ratio fluctuation, the factors degrading catalytic conversion efficiency, should enable prediction in a short time of the conversion efficiency after it drops after travel.

Thus, we started by taking a vehicle which already met the standard values and examining the details of its catalyst use conditions (temperature and air-fuel ratio). Next, based on this data, we used an electric oven, capable of adjusting the gas atmosphere, to accelerate the degradation in efficiency by subjecting the catalyst to a higher temperature than it would experience in operation in an actual vehicle as a simulation. The results confirmed that we were able to reproduce in only tens of hours the conversion efficiency after tens of thousands of kilometers traveled. (Fig. 10). This technology can be applied to narrow down appropriate catalyst candidates in a short

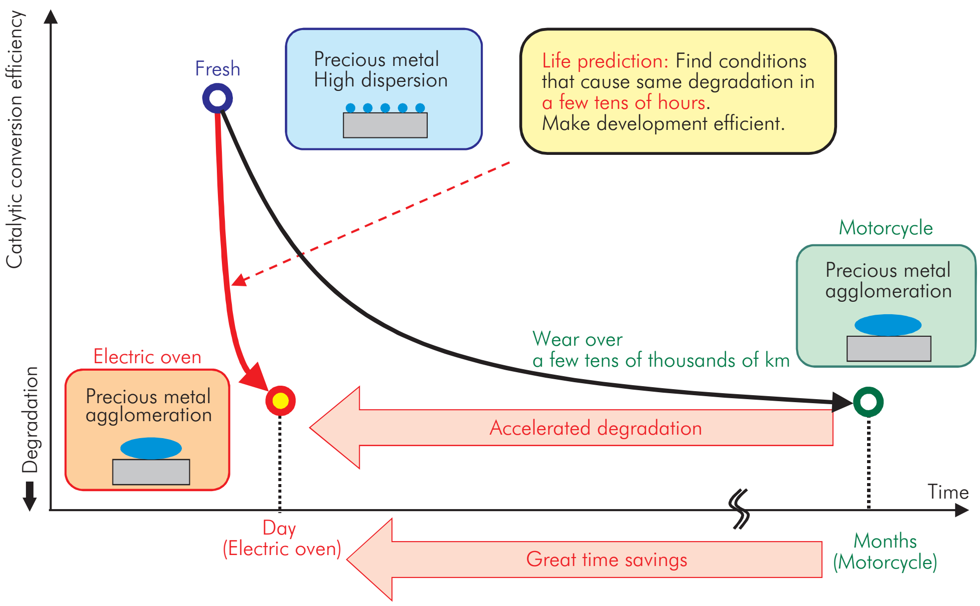


Fig. 10 The images of catalyst life predicting method

time, making it possible to develop vehicles that meet emission standards in a short period.

We are also conducting research to improve the durability of the catalyst itself. At the large-scale radiation experiment facility SPring-8, capable of tracking the internal structure of catalysts at the atomic level, progress is being made in understanding the phenomena by which precious metals such as platinum and palladium sinter.

Improving the conversion efficiency of catalysts not only can help the environment, but even can help to control engine power reduction, since it allows reduction in the amount of catalysts used, which resist exhaust.

Concluding remarks

This paper has introduced technology to realize motorcycles that answer societal demands for reduced environmental load without taking away from the outstanding power feel that is the hallmark of a Kawasaki motorcycle. We intend to continue improving environmental performance and fulfilling our social commitments, while providing customers with motorcycles that enrich their lives and grant them dreams.

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Accelerating global production through upgraded manufacturing capabilities

Kawasaki is taking active steps in emerging markets to implement a global strategy that covers from production to sales, while seeking to upgrade its manufacturing capabilities by handling production back home in Japan.

This paper discusses the development of a cylinder that contributed to the production of a lighter engine with higher output while improving production capacity. It also introduces readers to cases in which robots were employed to automate welding and finishing processes in order to achieve superior quality.

Preface

In emerging countries, demand for motorcycles is growing year after year, accompanying remarkable economic development. In response, the market is being supplied by high-quality products from existing motorcycle manufacturers and low-cost products from new manufacturers in countries such as India and China. In recent years, the existing manufacturers have had to work to keep improving their competitiveness against the new manufacturers, which keep improving their quality every year. In such conditions, Kawasaki is working in various ways to provide emerging countries with products that have high quality on the level of developed nations and yet are cost-competitive.

1 Strategic global models: Aluminum die cast sleeveless cylinders

(1) Background and aims of development

In developing the new Ninja 300 model, Kawasaki has gathered its powers of product development and manufacturing technology to supply a higher-performance model in a more timely manner to meet market needs. It is a strategic global model aiming to suit both emerging and developed markets.

Since the Ninja 300 has greater engine power than the previous model, the Ninja 250R, the temperature in the engine tends to rise, and the cylinders which hold the reciprocal motion of the pistons also heat up. Therefore, the efficiency of heat release to the coolant passage needs to be improved (Fig. 1).

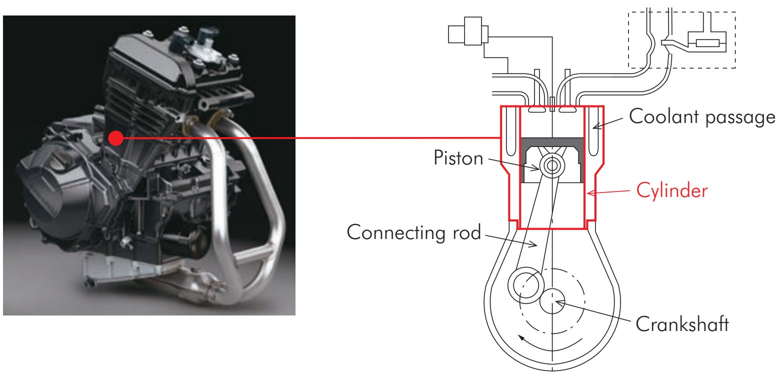


Fig. 1 Cylinder constituting an engine

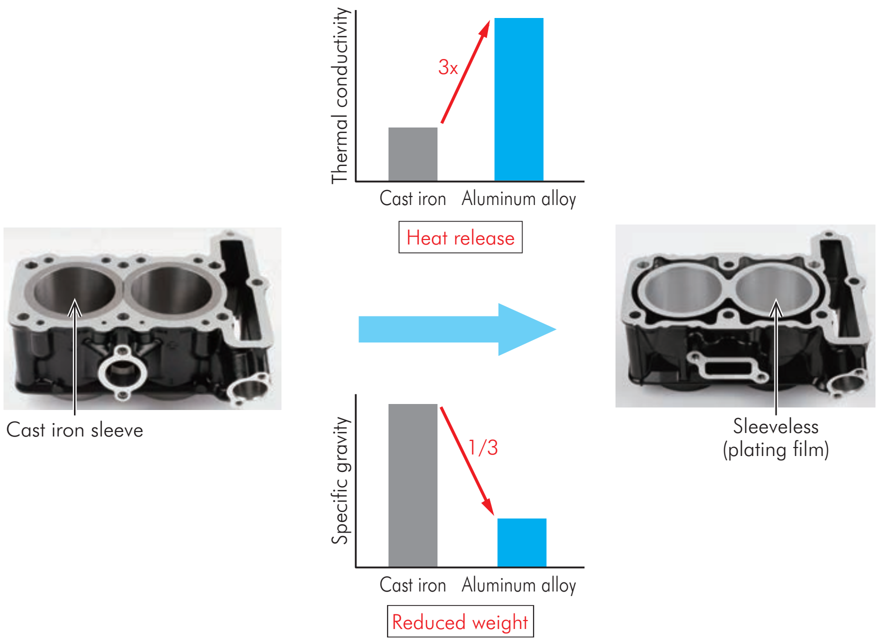


Fig. 2 Advantages of sleeveless cylinders

In the previous model, the Ninja 250R, the cylinders were structured with cast iron sleeves embedded in the aluminum alloy body for sliding performance. However, if cast iron sleeves were used likewise for the Ninja 300, there could be overheating or knocking from the rise in temperature due to the low thermal conductivity of cast iron sleeves. Also, since the specific gravity of cast iron is approximately three times that of aluminum alloy, it would increase weight.

To answer these challenges, with the Ninja 300 cylinders we improved productivity by changing the production method from gravity die casting to die casting, and we achieved excellent sliding performance, heat release, and reduced weight by applying a thin plating film to the aluminum alloy body instead of using cast iron sleeves (Fig. 2).

(2) Development of manufacturing technology

(i) Switch to aluminum die casting

To adapt production capacity to the increase in demand in emerging countries, we changed the production method of aluminum cylinders from gravity die casting, which we used to use, to die casting, which makes production five times faster. Since die casting fills dies at high speed, both high precision and high productivity can be achieved. However, high fill speed can cause casting defects due to such factors as gas entrapment and non-uniform solidification rate. This makes it challenging to apply to cylinders that require high performance (Table 1). We answered this challenge by using casting simulation to optimize the production method, including the runner and gating system and the die's internal cooling structure. Thus, we were able to achieve high quality (Fig. 3).

Table 1 Advantages and challenges of the die-casting method for gravity die casting

Advantages	・Short cycle time allows fast production ・High dimensional precision, low surface roughness ・Enables thin-wall molding
Challenges	・High fill speed can cause defects due to gas entrapment at the inner cylinder surface ・Shrinkage cavities can form at thick walls and bolt bearing surfaces, which require strength ・Mold easily damaged due to high fill speed

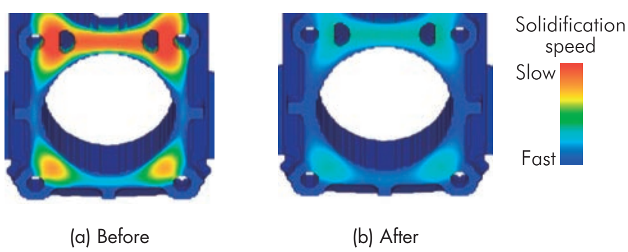


Fig. 3 Equalization of the solidification speed by the casting simulation

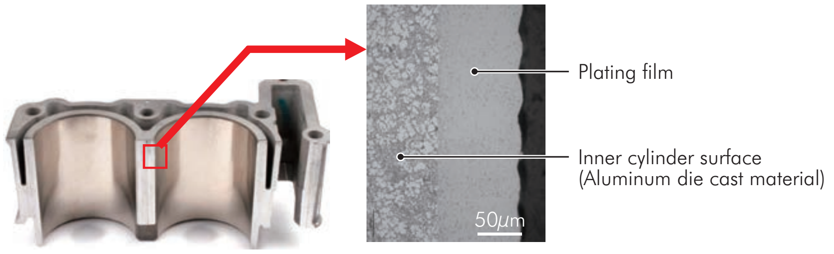


Fig. 4 Cross-section of a composite plated cylinder

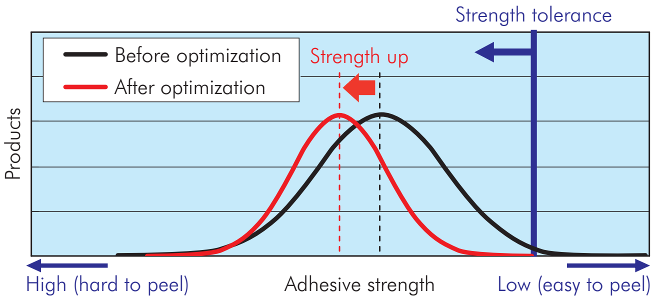


Fig. 5 Distribution of adhesive strength of plating film

Fig. 6 Ninja 300 featuring sleeveless cylinders

(ii) Replacing sleeves with composite plating

Instead of using cast iron sleeves as before, we applied composite plating to the aluminum cylinder.

This involves forming plating film with dispersed SiC (silicon carbide) particles (Fig. 4) and using this thin film to bring out sliding performance and to grant strong heat dissipation. Kawasaki has been building up the technology for this composite plating method for over 10 years for high-output engines. However, the aluminum alloy used in this case has high silicon content, giving it poor metallurgical bonding strength with the plating film. So we broadened the binding site by plating pretreatment to accelerate surface roughness of the aluminum alloy, optimized the heat treatment performed after plating, and thus formed an adequate interdiffusion layer and improved adhesion (Fig. 5).

(3) Application to new models

The new sleeveless cylinders have given the high performance, light weight, and high productivity the Ninja 300 needed to achieve function and quality with power greater than that of the previous model, the Ninja 250R (Fig. 6). At the same time, they have been adopted for the new Ninja 250 and Z250 models as well, contributing greatly to improving production capacity for the increased demand in emerging countries. We intend to continue to apply them to more models.

2 Aluminum frame welding and finishing process automation

(1) Significance of development

Automation in global production is significant not only for saving labor to reduce costs, but also for securing quality on the same level as domestic products.

Below, we introduce welding automation technology and finishing automation technology for aluminum frames for motorcycles.

(2) Aluminum frame welding automation

Aluminum frame welding requires extremely high quality in many aspects, ranging from weld strength and dimensional precision to aesthetics.

Previously, quality was secured by the high skill of individual welders. However, the motto of the last decade has been deskilling. Various automation technologies have been developed, frames have been restructured to be easy to weld automatically, etc. Some current models achieve over 90% automation of welding (Fig. 7).

(i) ServoTorch

The ServoTorch uses a servomotor inside a welding torch to accurately control feeding of aluminum welding wire, which is prone to buckling. The ServoTorch has not only reduced feed problems, but also made it possible to achieve stable weld quality between different types of

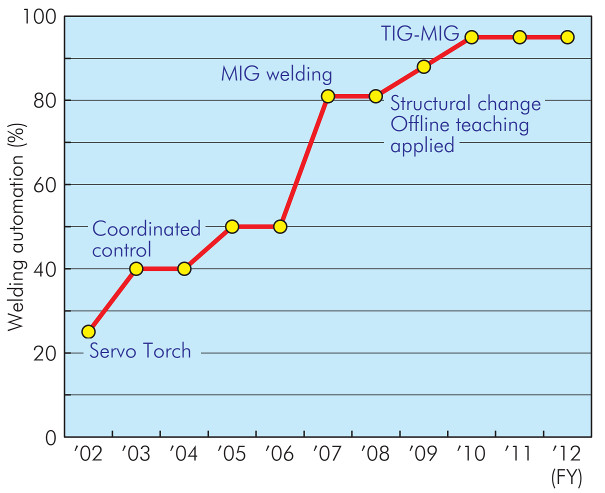


Fig. 7 Transition in rate of welding automation

materials, such as between sheet metal parts and cast metal parts with different melt forms.

(ii) Positioner-coordinated welding

To stabilize weld quality, flat-position welding is essential. Therefore, we have introduced coordinated welding technology allowing a welding torch and work positioner to work in harmony. This keeps the weld zone consistently in the flat position, even in continuous welding across the corners of a box structure, and has succeeded in stabilizing weld quality.

(iii) Offline teaching

We have sped up and deskilled work to teach welding robots with our own offline teaching software, KCONG. The challenge was applying offline teaching data to the actual robots, since discrepancies could arise between the offline teaching and the actual robot due to individual differences in robots. We minimized such discrepancies by correcting absolute position accuracy for the robots.

(iv) TIG-MIG welding

TIG-MIG welding is the automation of the process to address inadequate penetration of parts at which MIG welding is started.

In frame welding, the perimeter of a cylindrical frame material is divided into front and back semicircles which are welded one at a time. When this is done by MIG welding*, often, the penetration of the part where welding is started is not deep enough, because the welding heat input at the start of welding disperses due to aluminum's high thermal conductivity. This phenomenon especially tends to arise where parts where welding is started are put on each other. Such parts cannot achieve the penetration required. Therefore, workers have been welding them together with TIG welding**.

Now we have developed the TIG-MIG welding method, in which parts at which welding is started are preheated with TIG welding, and then MIG welding is started.

The robot cell comprises two robots, a TIG preheat robot and an MIG final weld robot, and a work positioner (Fig. 8). Right after preheating by the TIG preheat robot, the MIG final weld robot, which has been waiting nearby, starts welding. In final welding, the frame is positioned for optimal welding position, for coordinated welding with the robot.

Thus, we have achieved automation even of the joint at the part where MIG welding is started. At the same time,

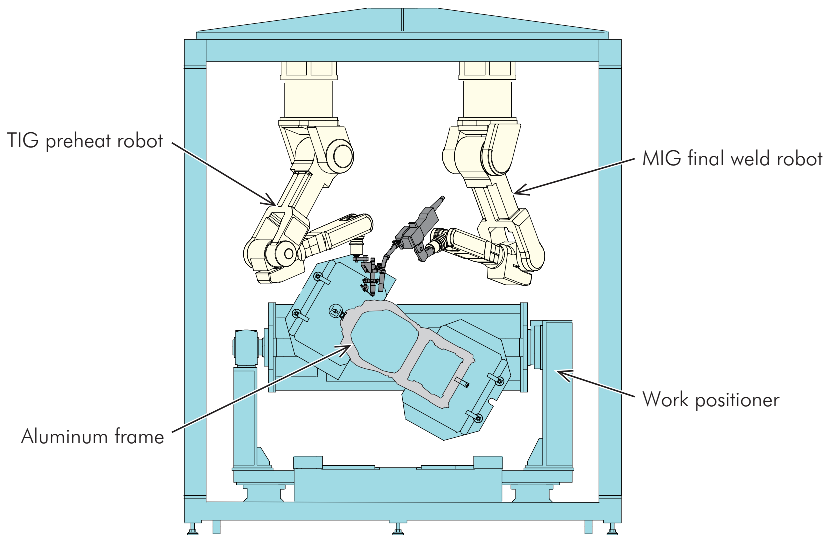
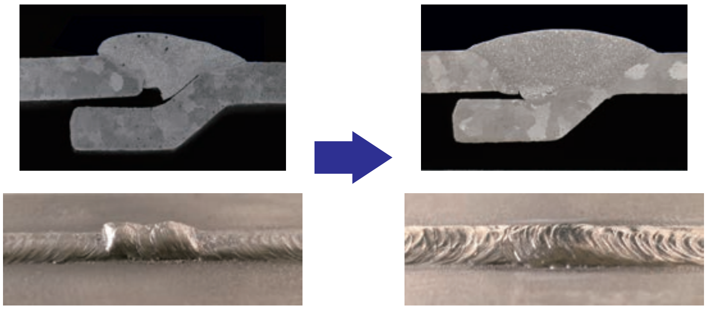


Fig. 8 TIG-MIG welding robot cell



(a) Defective MIG welding (b) TIG-MIG welding

Fig. 9 Improving penetration quality and controlling reinforcement height by TIG-MIG welding

we have secured the required weld penetration quality reliably, and we have managed to reduce the concentration of stress. In addition, we have obtained good weld bead appearance from an aesthetic perspective (Fig. 9).

*MIG (Metal Inert Gas) welding:
Inert gas arc welding using a consumable electrode. Weld beads are formed by melting welding wire as an electrode while melting the base material. An efficient welding method.

**TIG (Tungsten Inert Gas) welding:
Inert gas arc welding using a non-consumable electrode. Allows control of heat input to the base material without forming a weld bead, since the electrode does not melt.

(3) Aluminum frame finishing automation

To visually inspect for welding defects common on the weld bead toe, including fracture and incomplete fusion, it is necessary to remove the smut (black soot) remaining on the weld zone of the aluminum frame in process.

Previously, this was done by an experienced welder placed at the end of the welding line. However, the work of removing smut with a toothbrush-like brush and checking weld quality was a heavy load. On top of this, the work environment was degraded by the dust arising from the finishing work, and, as pneumatic vibrating tools were used in addition to brush finishing in the process, it was truly a 3D job (dirty, dangerous, and demanding work).

By robotizing the finishing process, including such brush finishing work, we succeeded in not only reducing the worker load in the final process of the welding line, but also reducing the amount of dust around the welding line in general.

We realized the aluminum frame brush finishing robot system (Fig. 10) by adding function to arc welding robots, and we have equipped a pneumatic brush at the end of the arm to achieve ideal bead periphery finish (Fig. 11) and improve the appearance of the bead. Since the ideal contact force between the brush and the workpiece is

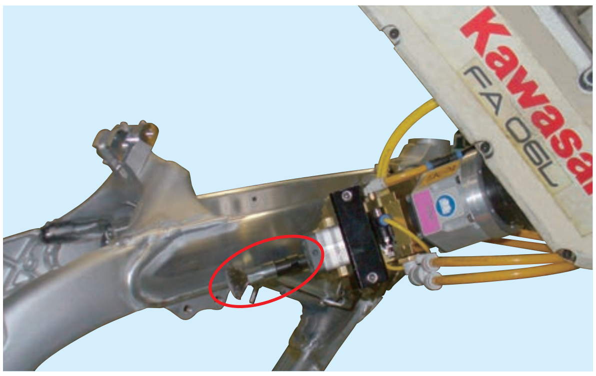
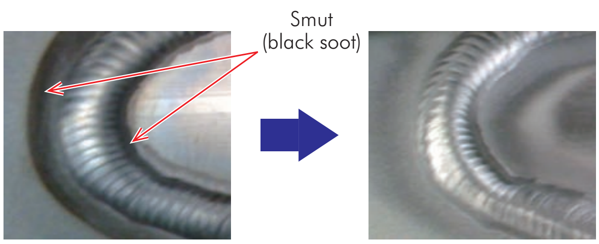


Fig. 10 Robotic system for brush finishing



(a) Before removing smut (b) After removing smut

Fig. 11 Weld bead finishing by robot

quite small relative to the mass of the pneumatic brush, we developed a suspension mechanism that resists influence from robot operation or position. Also, since the brush wears with processing time, and the wires get shorter, there was a need to modify the teaching path of the robot. Our system not only assures stable contact force using its suspension mechanism, but also applies a slight electric current between the workpiece and the brush to detect whether the current flows, to determine whether the brush and the workpiece are in contact, so that it can correct the robot arm path in real time.

In addition to this robot system for wire-brush finishing, Kawasaki has also developed and put onto the production line, for instance, a robot system that can finish aluminum frames to be shipped unpainted and give them hairlines as an appearance design feature.

It is easy for finishing processes for appearance design and quality verification to vary in work quality depending on the skill level of the workers. Automating this work allows us to stabilize its quality and to realize a production line capable of accommodating global production and drastic shifts in production volume.

Concluding remarks

This paper has introduced methods incorporating know-how in production and manufacturing technology that can be applied relatively easily even in emerging countries, but manufacturing sites in Japan have many processes that require more advanced manufacturing technology compared to overseas production bases.

We intend to respond to movement towards high-mix, variable-quantity production and to achieve better quality, timely production, and maximum cost reduction. Meanwhile, we shall push even further our multifaceted approach to improving production and manufacturing technology, including the creation of safe and comfortable workplaces and consideration for the environment.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Optimizing aerodynamic design through testing with a wind tunnel facility

A critical aspect of designing a motorcycle is to create a design that optimizes aerodynamic performance during the initial stages of development. For this purpose, a wind tunnel is an indispensable facility. Through tests conducted with a wind tunnel, engineers search for a design that optimizes the aerodynamic performance of a motorcycle.

This paper provides an overview of Kawasaki's wind tunnel testing facility that was established in 2009.

Preface

In developing a new motorcycle model, wind tunnel testing is a critical stage for optimizing aerodynamic performance and design. For this reason, in 2009, Kawasaki established an actual vehicle wind tunnel facility dedicated to motorcycles to further improve design and aerodynamic performance.

1 Wind tunnel testing facility

(1) Main facility

The specifications of the wind tunnel facility are shown in Table 1, and a general overview is shown in Fig. 1. This facility was designed and made by Kawasaki. It is a circuit with overall dimensions of length 68 m, width 29 m, and height 10 m, and it has a semi-open test section.

① The contraction ratio of before and after the nozzle, very important to airflow performance, is 1:7, securing uniform airflow.

② The standard dimensions of the outlet are width 3 m and height 2.5 m, with a maximum wind speed of 180 km/h, which can be increased further to 205 km/h by installing a nozzle onto the outlet.

③ The test section includes a boundary layer absorber and a six-component balance, and, on its turntable, measurement can be performed adjusted for motorcycle wheel bases from 1,160 to 1,960 mm.

Table 1 Specifications of the wind tunnel

Model	Semi-open circuit
Maximum wind speed (km/h)	180 (to 205)
Overall dimension (m) L × W × H	68 × 29 × 10
Test section length (m)	8
Outlet dimension (m) W × H	3 × 2.5
Contraction ratio	7
Blower	Diameter: 4.5 m; motor: 500 kW
Main equipment	Six-component balance, boundary layer absorber, traversing device

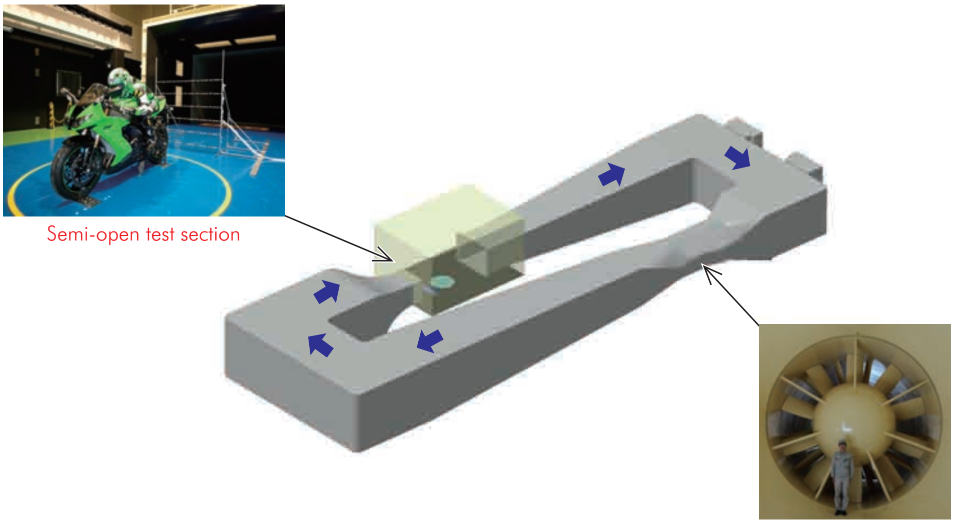


Fig.1 Overview of the wind tunnel

④ The test section has a length of 8 m, allowing slipstream measurement with two vehicles aligned in front and back, critical to aerodynamic performance when a racing vehicle is overtaking another.

⑤ Multi-Use Light Equipment (MULE) type vehicles can be evaluated for wind resistance by applying winds of 180 km/h on the turntable.

⑥ The traversing device withstands wind speeds of up to 108 km/h and supports 3D measurement using instruments such as the hot-wire anemometer and the pitot tube. Also, a smoke generator can be equipped for visualization using smoke blown from a selected position.

(2) Wind tunnel performance

The airflow performance of the facility is shown in Table 2. The tunnel outlet has wind speed fluctuations of within ±0.67%, and the turbulence intensity stays within 0.25%, assuring satisfactory precision. The boundary layer properties are shown in Fig. 2. To simulate actual motorcycle riding, the flow near the ground must be close to the main flow. A boundary layer absorber is used to reduce the thickness of the boundary layer at the center of the turntable from 180 mm to around 30 mm, making the effectiveness of the boundary layer absorber evident.

Table 2 Airflow performance

Item	Performance
Wind speed distribution	Within ±0.67%: tunnel outlet
Turbulence intensity	≤ 0.25%: tunnel outlet
Boundary layer thickness	31.3 mm: turntable center

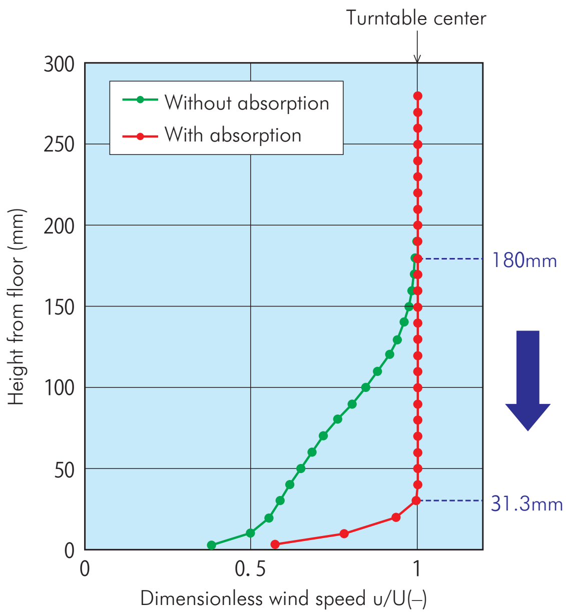


Fig.2 Effect of boundary layer absorber on boundary layer properties

2 Wind tunnel measurement

(1) Motorcycle measurement method and wind tunnel dummy rider development

Motorcycles differ from automobiles in that wind hits the rider directly, making the rider an aerodynamic part extremely consequential to aerodynamic performance. Therefore, we have an actual human rider get on a motorcycle for wind tunnel testing as we make measurements at a wind speed of 180 km/h.

However, with the long duration of the wind speed and pressure distribution measurements using the traversing device, it is difficult for a rider to hold a fixed position. With laser measurement, safety prohibits measurement with a rider on the vehicle. Therefore, we have developed a wind tunnel dummy rider and are deploying it for measurements that are difficult with an actual rider (Fig. 3).

(2) Visual measurement

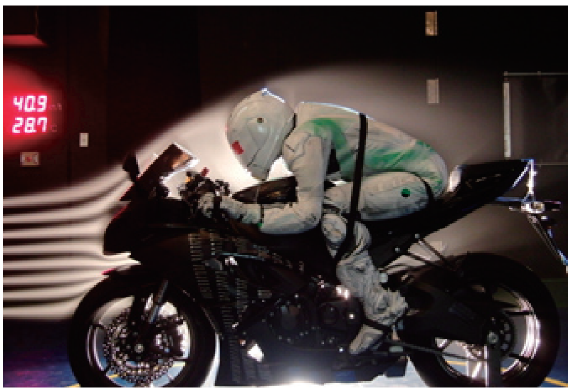
We use multiple streams of smoke from comb-shaped nozzles to visualize the flow around the motorcycle. Using the traversing device, smoke can be blown at a selected position from comb-shaped nozzles installed horizontally or vertically. The results of measurement visualizing flow onto the helmet and onto the front radiator are shown in Fig. 3.

(3) Wind speed and pressure measurement

Wind speed can be measured with pitot tubes and with small hot-wire anemometers. The hot-wire anemometer has a probe as small as a matchstick and is capable of measurement at multiple points. Attaching probes to multiple points on the radiator allows simultaneous measurement of six aerodynamic components and wind speed through the radiator, which is useful for optimizing the wind tunnel aerodynamics and engine cooling.

Pressure is measured using a multi-point electronic scanner gauge, capable of detailed measurement of the motorcycle body, the rider, and the space around the vehicle.

(a) Flow onto helmet



(b) Flow onto radiator

Fig. 3 Visualization measurement using comb-shaped nozzles (measurement taken with a dummy rider)

3 Use as a general-purpose wind tunnel

This facility was made mainly for motorcycle measurements, but it is semi-open and is useful as a general-purpose wind tunnel, with its ability for detailed measurement with a multi-point pressure gauge and anemometers attached to the traversing device, etc. In fact, we have already adopted a system so that all of Kawasaki can utilize it to address aerodynamic issues. It has proven useful for aerodynamic performance testing of watercraft, for example (Fig. 4).

Concluding remarks

To improve product marketability, motorcycle development will increasingly demand rider comfort, etc., such as through wind protection. We hope to use this wind tunnel testing facility to send into the world products with new added value.

Reference

1) K. Sakagawa, E. Ihara, Y. Ustumi, T. Haraguchi, M. Morikawa, Y. Horinouchi: "Engineering riding comfort and aerodynamic and cooling performance in the sketching stage," Kawasaki Technical Review No. 174, pp. 51-56 (2014)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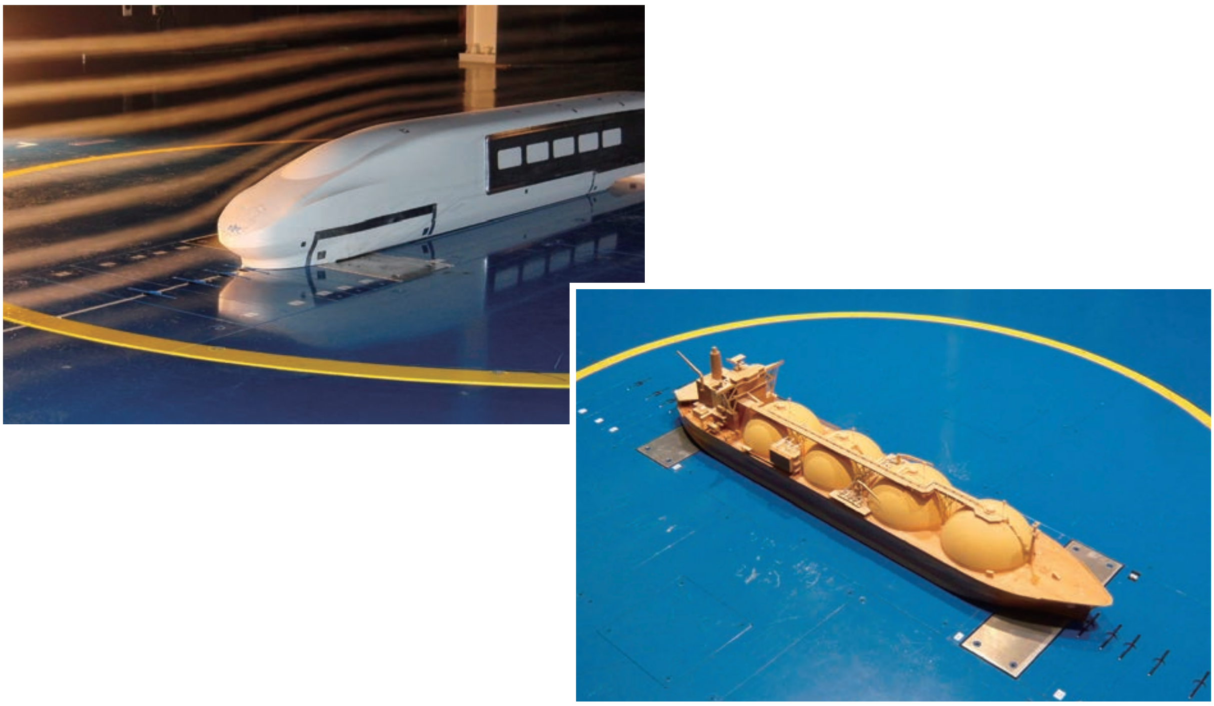

Fig.4 Aerodynamic performance testing

Side × Side vehicle Teryx4 for family use

The Side × Side vehicle category continues to expand in the North American off-road vehicle market. For family use in this category, we have released the Teryx4 four-seater recreational UV (Utility Vehicle) with superior dependability, comfort, and stability.

Preface

Lately, the North American market for off-road vehicles, used for leisure and agriculture, is moving from saddle-type ATVs (All Terrain Vehicles) to the growing market of Side × Side vehicles (vehicles on which the driver and passenger can sit next to each other). Kawasaki released the MULE (Multi-Use Light Equipment) four-wheel multipurpose vehicle for utility-oriented users in 1987, and since has been rolling out variations with different displacement, seat arrangement, etc. Also, we have offered the Teryx* for recreation-oriented users since 2008. Now we have released the Teryx4, focusing on family use, a four-seater recreational UV (Utility Vehicle) with superior dependability, comfort, and stability.

* Teryx: An invented name combining "T. rex" (for the powerful image of the tyrannosaurus) and "Terra" (Earth).

1 Product concept

North America has trail areas (Fig. 1) here and there offering opportunities for leisure such as recreational driving and hunting. With this in mind, we have developed a four-seater UV, with family use as the product concept, which enables the experiences of "Fun to Ride" and "Ease of Riding."

2 Product appeal and marketability

(1) Main specifications

The Teryx4's main specifications are shown in Table 1.

(2) Engine, drivetrain

The exterior of the engine is shown in Fig. 2. It realizes pleasant handling with smooth drive at all speed ranges, through the combination of a high-torque engine, allowing

Fig. 1 Riding image in a trail-area

Table 1 Main specifications of Teryx4

Engine	4 st, V2, SOHC, water-cooled
Displacement (cm^3)	783
Bore x Stroke (mm)	85 x 69
Maximum output (kW/rpm)	43/6,750
Maximum torque (N·m/rpm)	64/5,500
Length x Width x Height (mm)	3,171 × 1,564 × 1,964
Drive method	Shaft, motor-selectable 4 × 4
Transmission	CVT automatic HIGH, LOW, REV
Wheelbase (mm)	2,177
Minimum ground clearance (mm)	281
Cargo bed capacity (kg)	113
Minimum turning radius (m)	5.1
Dry mass (kg)	687

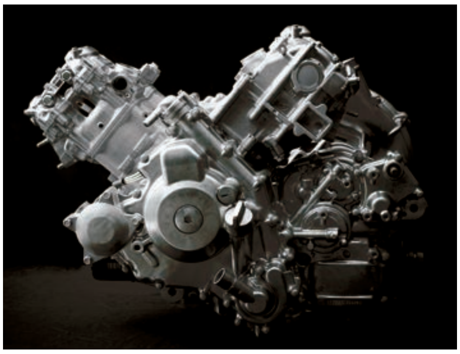

Fig. 2 Engine exterior

Fig. 4 FOX suspensions

riders to feel powerful acceleration, a centrifugal clutch*, our first in a four-wheel vehicle, and continuously variable transmission (CVT). Its characteristics are exhibited in full force on rocky stretches of trail areas. Also, it has engine braking responsive to road conditions, offering riding stability on rough roads that repeatedly go up and down, as well as a feeling of security going downhill.

Furthermore, it is equipped with a centrifugal clutch, which reduces load on the CVT belt, dramatically cutting belt maintenance frequency and improving dependability.

*Centrifugal clutch: A mechanism which activates a clutch shoe according to the engine speed to transfer or cut off drive by contact with the housing on the receiving side.

Fig. 5 Two-seater Teryx model

(3) Body

We have made the frame structure more compact, such as by shortening the wheelbase and securing ground clearance, and in so doing improved performance in tight turns and climbing over obstacles, enhancing handling on trail areas. At the same time, we have designed the living space in the cabin to have more than enough room for four adults to ride, making the vehicle very comfortable. The structure involves a double X frame (Fig. 3), and we applied FEM analysis to optimize rigidity and lower weight. This further enhances riding performance and stability.

Also, to improve shock-absorbing performance, we adopted suspension from Fox, a company boasting some of the best technology in the off-road industry (Fig. 4). On top of that, we combined radial tires and bucket seats with improved shape and thickness to realize soft, pleasant riding comfort in action.

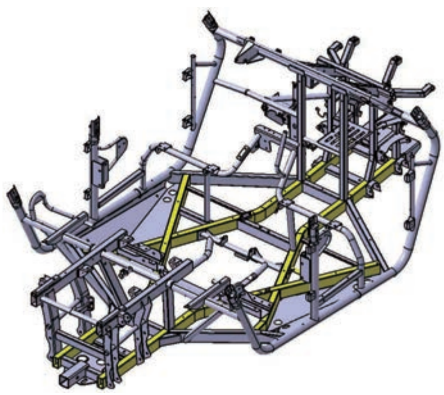

Fig. 3 Double X frame (Yellow colored parts)

3 Variation deployment

We simultaneously released a new two-seater Teryx model with the same engine, drivetrain, and frame structure (Fig. 5).

Postscript

We will continue to accurately identify diversifying user demands in the North American Side × Side market and to develop attractive models that answer these demands while emphasizing dependability, comfort, and stability.

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4-stroke horizontal FJ series engine delivers lower vibration at lower cost

The 4-stroke horizontal general-purpose engine FJ series has been developed afresh and released to the market as the successor to the FE series, which has been popular with OEMs for over 20 years to drive all sorts of machines.

The FJ series maintains the best-in-industry low vibration that sets us apart from competitors technically, while reducing cost through a development process in which almost all parts are procured in China from the prototype stage.

Preface

We have developed the 4-stroke horizontal general-purpose engine FJ series for the commercial market (e.g. agricultural equipment, carts and other work equipment, lawn equipment), especially for professional applications in OEMs' work machines, and also for the residential market (e.g. generators, power sprayers), especially for general users.

The preceding FE series has been popular with OEMs and users for over 20 years, set apart by its best-in-industry low vibration which has given Kawasaki a reputation for low-vibration engines.

The development objective of our new FJ series has been to modify the structure from the FE series to maintain its low vibration while reducing cost, allowing us to hold our own in price competition, to expand our market share in 4-stroke horizontal general-purpose engines.

To fulfill the paradox of low vibration and low cost, we established a new production base in China, CK&K*, and managed to procure almost all parts in China from the prototype stage.

*CK&K: Changzhou Kawasaki and Kwang Yang Engine Co., Ltd.
A general-purpose engine manufacturing company set up by 50:50 investment between KYMCO (Kwang Yang Motor Co., Ltd.) and Kawasaki.

1 Main specifications

As the development policy for the horizontal general-purpose engine FJ series (FJ130/180/220D) in general, we used the bore-up and bore-down method, while keeping in mind to keep parts shared throughout the series, to speed up development and design and to reduce workload. The FJ series' main specifications are shown in Table 1.

Table 1 Main specifications

Item \ Model	FJ130D	FJ180D	FJ220D
Engine	Air-cooled, horizontal, 4-stroke OHV, 1-cylinder		
Displacement (cm^3)	133	179	220
Bore × Stroke (mm)	56 × 54	65 × 54	72 × 54
Maximum output (kW/rpm)	2.8/3,600	4.1/3,600	4.8/3,600
Maximum torque (N•m/rpm)	7.9/2,800	11/3,200	13.7/3,200
External dimensions (mm)	L302 × W360 × H353	L304 × W365 × H370	L304 × W365 × H370
Dry mass (kg)	16.5	18.6	19.0

In particular, the basic FJ180D model inherited the basic specs of our vertical engine for lawnmowers, which boasts about 650,000 units of sales, and at the same time reduced cost by sharing basic parts such as the piston and intake and exhaust valves. Also, we gave our horizontal output engine the new features of a 2-axis balancer and a V-valve spherical combustion chamber, obtaining the lowest vibration in the industry, while also conforming to strict exhaust gas regulations.

2 Features

(1) Low vibration (adoption of a 2-axis balancer)

In the FJ180/220, we adopted a 2-axis balancer to cancel out vibration from the vertical movement of the piston, dramatically reducing the vibration felt. A conceptual diagram of the 2-axis balancer is shown in Fig. 1. Levels of

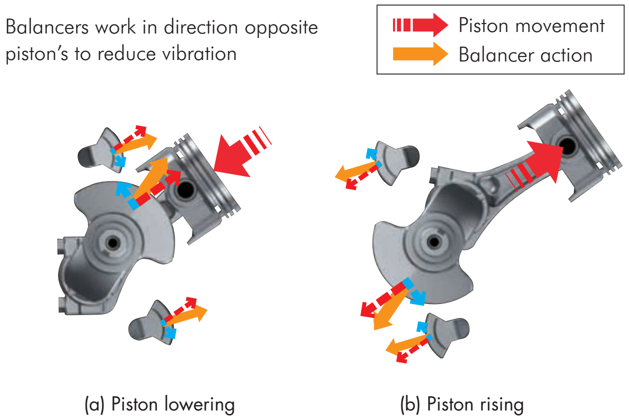

Fig. 1 Conceptual diagram of 2-axis balancer

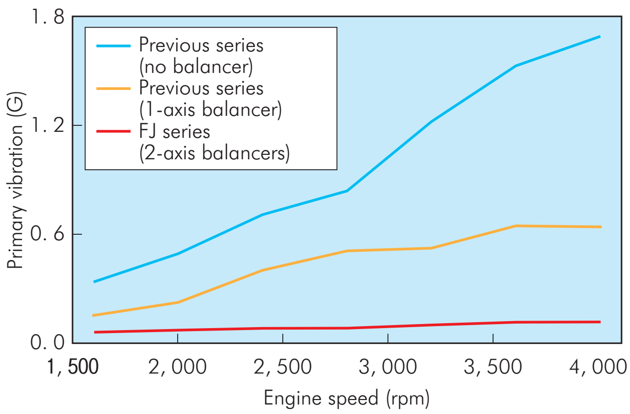

Fig. 2 Comparison of vibration levels

vibration are compared in Fig. 2.

Thus, we achieved a vibration level that compares favorably to the preceding FE series, making a product that secures the industry's lowest vibration, to uphold Kawasaki's reputation for low-vibration engines.

(2) Achieving a competitive price range

The following design methods and approaches were introduced to improve price competitiveness.

① We worked with vendors to advance low-cost design, with design methods suitable for procurement and manufacturing in China and compatible with Chinese vendors' production methods.

② We reduced part cost by sharing parts within the series.

③ We promoted part preparation from the prototype stage of the mass production process, helping to identify mass production problems at an early stage and to grasp non-obvious problems.

(3) Product design considerate of customer needs

(i) Light startability

We achieved top-class light startability by improving the precision of the auto-decompressor (a mechanism that reduces the power needed to start the engine by opening the exhaust valve when the engine starts to prevent compression pressure from the piston rising) and using ball bearings to reduce bearing friction.

(ii) Low noise

We improved the muffler to reduce explosive noise and make the engine sound powerful, but not unpleasant.

(iii) High performance and output

We placed the intake and exhaust valves in a V shape (Kawasaki V valves) (Fig. 3), adopted a spherical combustion chamber with the spark plug in the center (Fig. 4), and used a high-lift, large-diameter cam to raise output and torque yet another step higher compared to the previous model.

(iv) High durability and reliability

We used iron gears, a forged crankshaft, and a cast-iron cylinder liner and ball bearings to secure excellent durability.

(v) Appearance

We gave the engine compact external dimensions for easy installation, along with a sharp, advanced appearance design that is easy to handle and maintain.


Fig. 3 Kawasaki V-valve

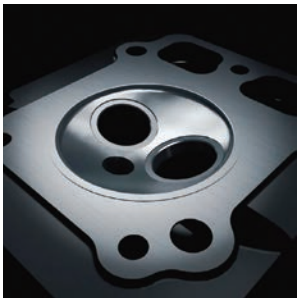
Fig. 4 Spherical combustion chamber

Postscript

CK&K, as Kawasaki's first general-purpose engine plant in China, has been assembling the 2-stroke engine TJ and TK series in addition to the FJ series, altogether reaching a total production of about 320,000 units in the period from FY 2010 to FY 2012.

With the completion of the FJ series, with its best-in-industry low-vibration high performance and the price competitiveness of Chinese procurement, we have confidence that OEMs will choose our 4-stroke horizontal general-purpose engines.

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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, offshore structures	Kobe Works (Kobe) Sakaide Works (Sakaide, Kagawa Prefecture) Estaleiro Enseada do Paraguacu S.A. (Brazil) Nantong COSCO KHI Ship Engineering Co., Ltd. (China)* Dalian COSCO KHI Ship Engineering Co., Ltd. (China)*
Rolling Stock	• Train cars, integrated transit systems, monorail cars, platform screen door systems • Gigacell (nickel metal-hydride battery)	Hyogo Works (Kobe) 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, dual mode vehicles (DMV) • Rail cars, heavy lift cars	Nichijo Manufacturing Co., Ltd. Head Office (Main Plant) (Sapporo, Hokkaido) Nichijo Manufacturing Co., Ltd. Akebono Plant (Sapporo, Hokkaido)
Aerospace	• 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)
	• Aircraft components, rocket components, space equipment, target systems • Aircraft servicing, remodeling	NIPPI Corporation Aerospace Division (Yokohama) and Aircraft Maintenance Division (Yamato, Kanagawa Prefecture)
Gas Turbines & Machinery	• Gas turbine engines for aircraft and ships, peripheral equipment • Gas turbine generators, gas turbine cogeneration systems	Akashi Works (Akashi, Hyogo Prefecture) Seishin Works (Kobe)
	• Steam turbines for ground and maritime applications, 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) 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) Tongfang Kawasaki Advanced Energy-saving Machine Co., Ltd. (China)
Plant & Infrastructure Engineering	• Cement, chemical, conveyers, and other industrial plant systems • Flue gas desulphurization and denitrification plants • 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)*
	• Crushers, processing equipment for recycling	EarthTechnica Co., Ltd. Yachiyo Works (Yachiyo, Chiba Prefecture)
Motorcycle & Engine	• Motorcycles, ATVs (all-terrain 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) KHITKAN Co., Ltd. (Thailand) Kawasaki Motors Enterprise (Thailand) Co., Ltd. (Thailand) P.T. Kawasaki Motor Indonesia (Indonesia) Kawasaki Motors (Phils.) Corporation (Philippines) Changzhou Kawasaki and Kwang Yang Engine Co., Ltd. (China)*
Precision Machinery	• Hydraulic equipment for construction machines, hydraulic equipment and systems for industrial machines • Marine application machines, deck cranes and other marine deck equipment • Industrial robots	Akashi Works (Akashi, Hyogo Prefecture) Nishi-Kobe Works (Kobe) 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) Flutek, Ltd. (Korea)
Other	• Wheel loaders, snowdozers, load haul damps, concrete paving equipment, and other construction machinery	KCM Corporation(Main Plant) (Inami-cho, Hyogo Prefecture) KCMA Corporation (U.S.A.)

*Affiliated company-equity method

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