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.

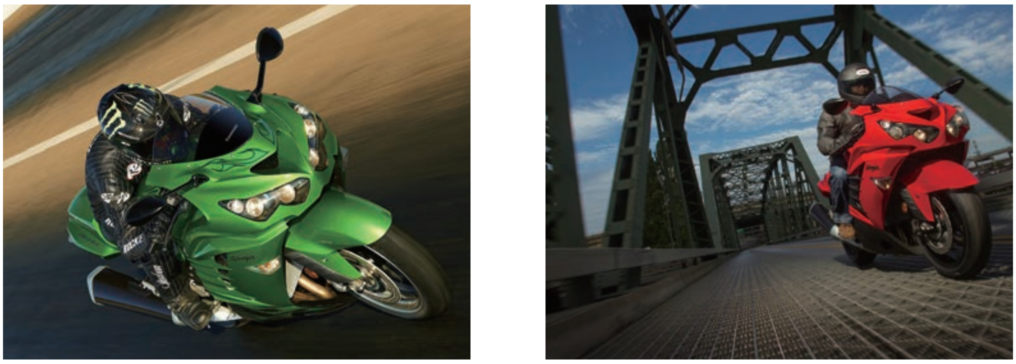
1 Concept and features

(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

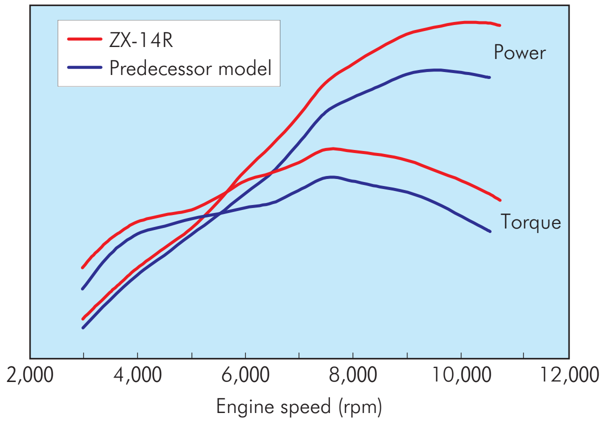
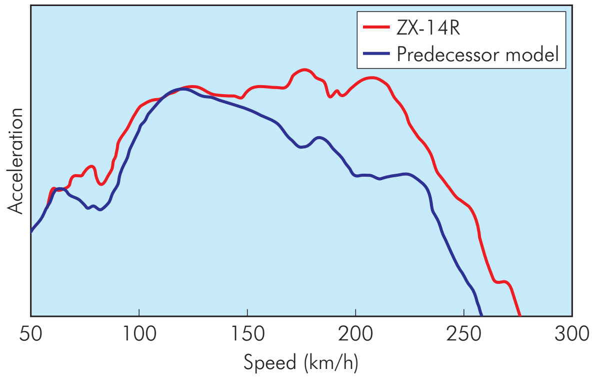


Fig. 4 Engine performance



Measurement conditions: Full acceleration in high gear

Fig. 5 Acceleration performance

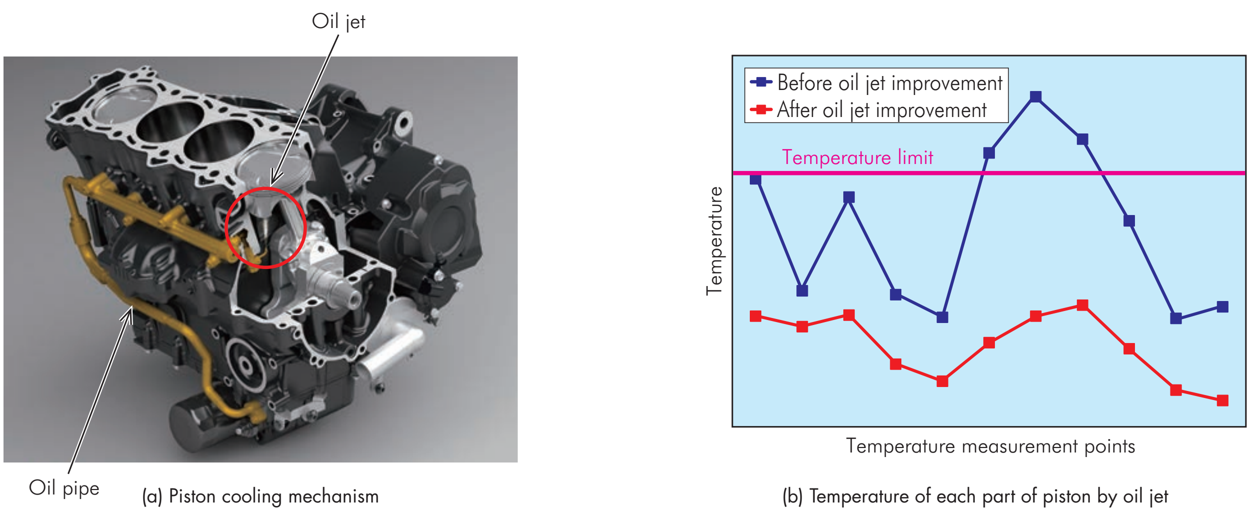
2 Engine related technology

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

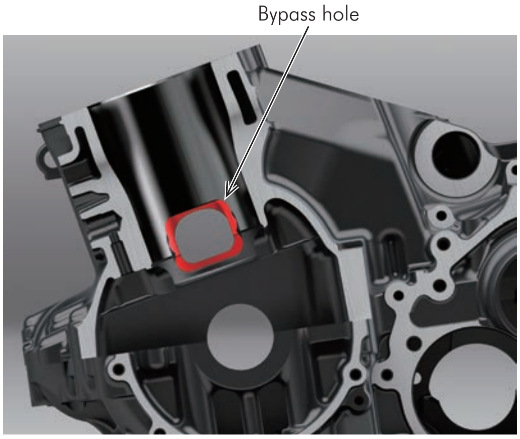
When the pistons move up and down, the pressure on the lower part of the pistons varies, which generates a pumping loss (intake and exhaust loss). The pressure can be released through the bypass hole (Fig. 7 (a)) at the bottom of the cylinder. While the pumping loss can be curbed by expanding this hole, 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

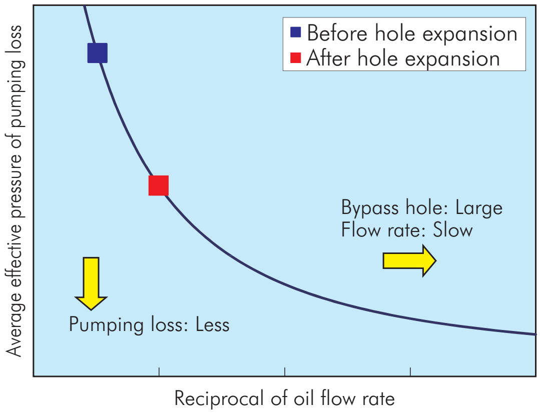
When the position of the intake and exhaust valves is raised, the amplitude (variation) of the cam chain becomes larger, the load applied to the cam chain increases, and the engagement sound also increases. In the ZX-14R, the method of the hydraulic pressure chain tensioner was changed, to optimize the 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



(a) Bypass hole at the bottom of the cylinder

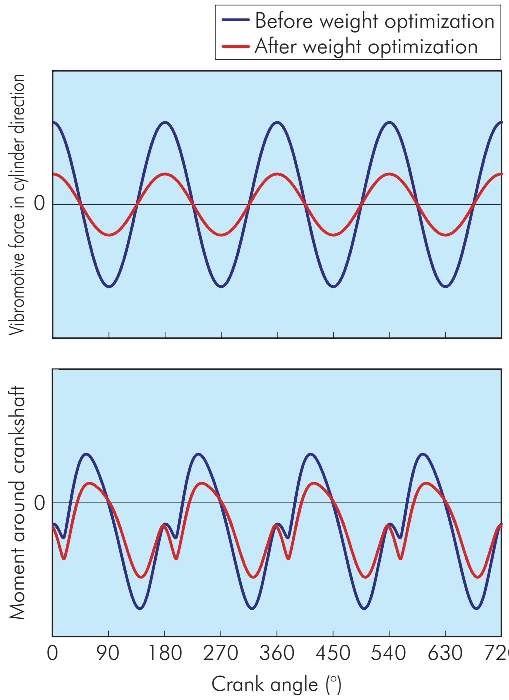


(b) Relationship between oil flow rate and pumping loss by bypass hole

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.

(a) Dual-shaft secondary balancers



(b) Effectiveness of balancer weight optimization

Fig. 8 Vibration damping through dual-shaft secondary balancers

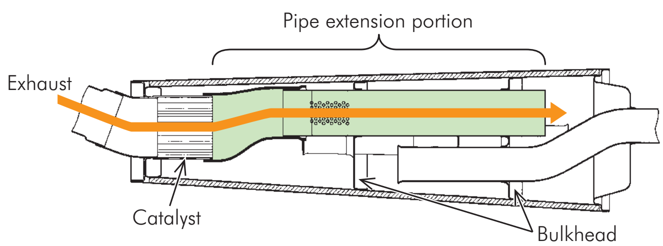
(2) Intake system

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) 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

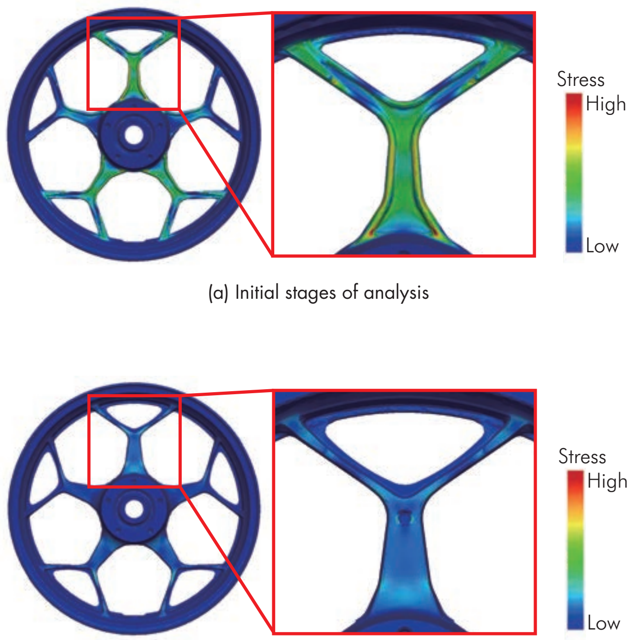
(1) Improvement in frame rigidity

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.

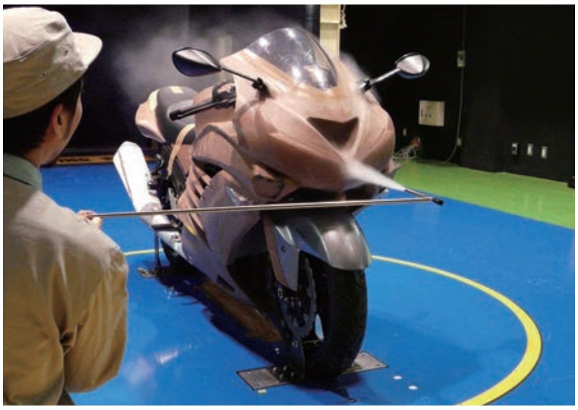


Fig. 12 Wind tunnel test

(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

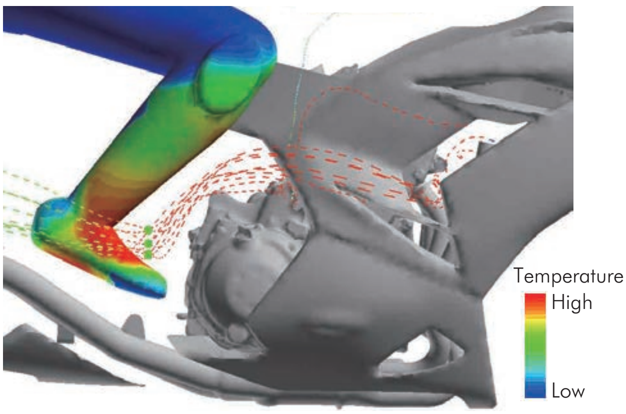
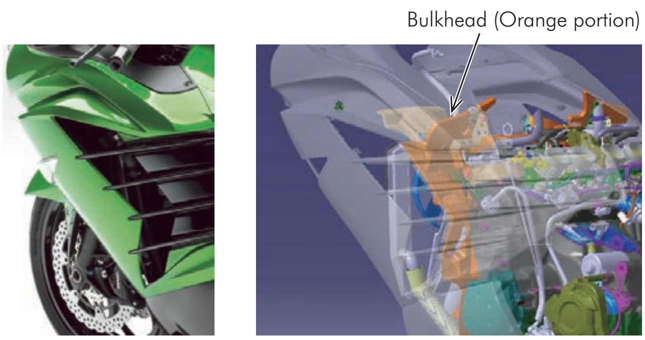


Fig. 13 Analysis of engine waste heat flow



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

Fig. 14 Side cowl and internal bulkhead structure

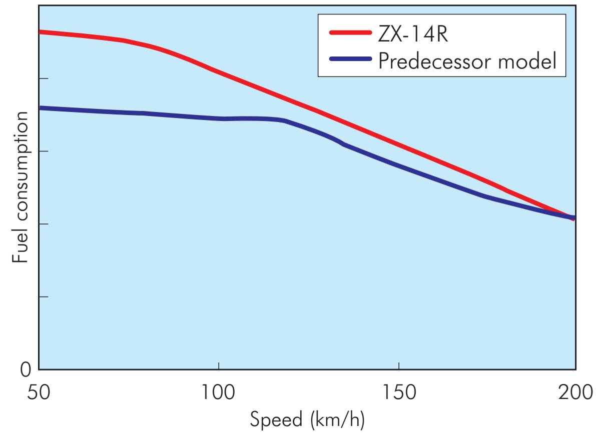


Fig. 15 Fuel consumption at cruising speed


Takeru Ohshima
Certification & Intellectual Property Department,
Research & Development Division,
Motorcycle & Engine Company


Hisatoyo Arima
Engineering Department 1,
Research & Development Division,
Motorcycle & Engine Company


Nobuyuki Nishiguchi
Kawasaki Motors Corp., U.S.A.

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)