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.

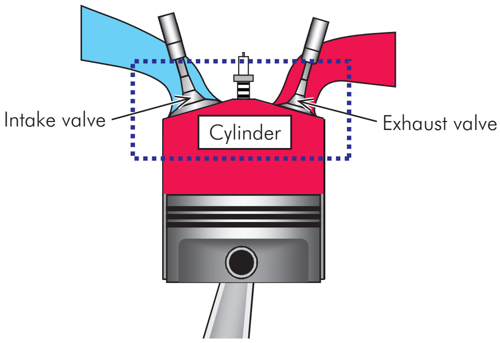
Figure 1 and Fig. 2 show examples of analysis of cylinder flow speed and exhaust gas residual ratio in cases with long valve overlap time and with short valve overlap time.

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.

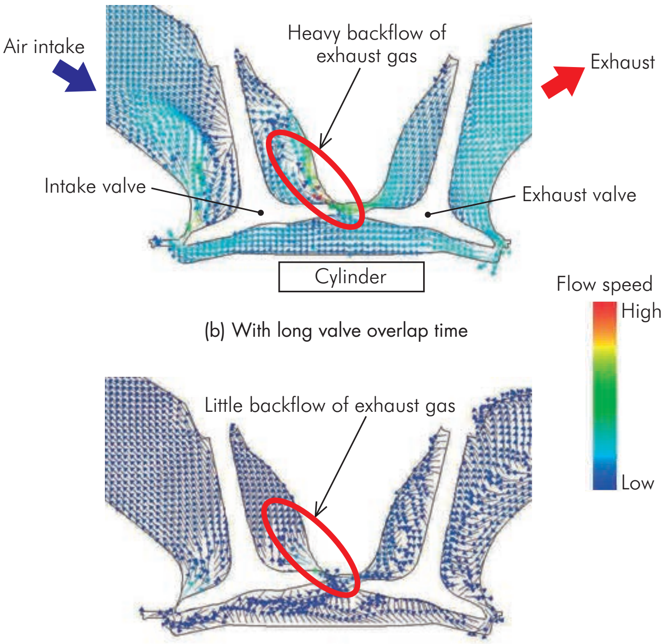


Fig. 1 Predicted flow fields

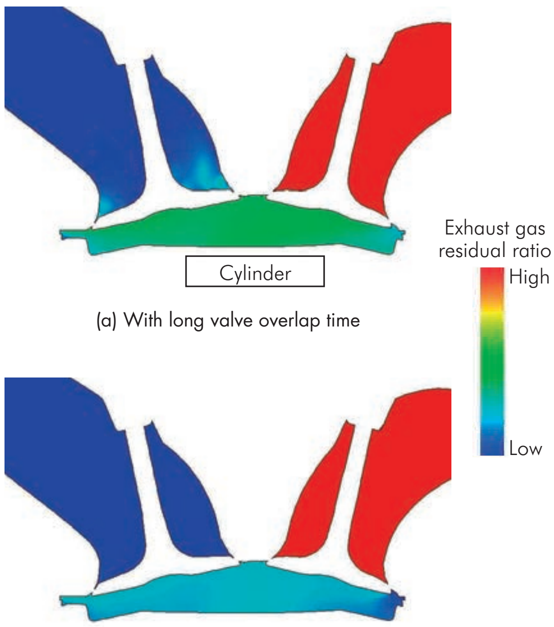


Fig. 2 Predicted residual ratio of exhaust gas

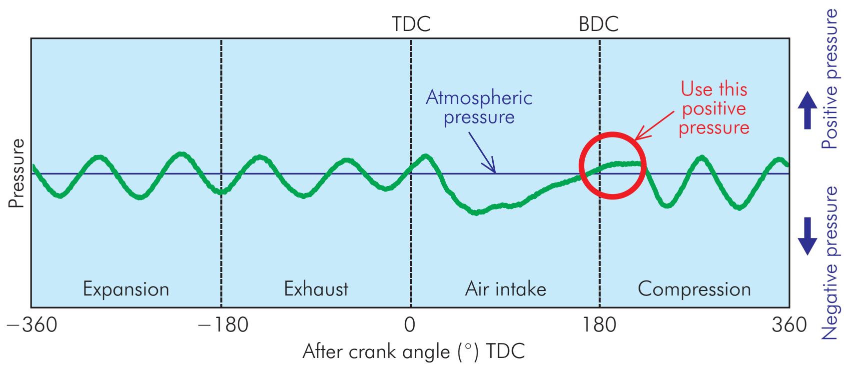


Fig. 3 Intake pressure pulsation of intake port

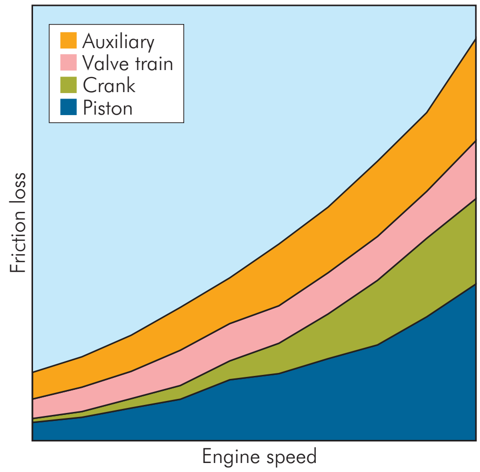


Fig. 4 Friction loss of each engine part

(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.

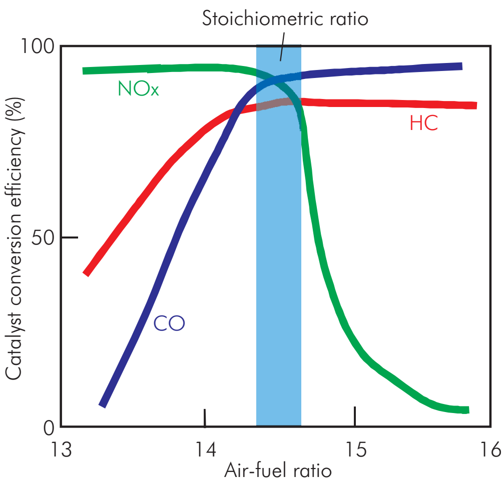


Fig. 5 Conversion of catalyst

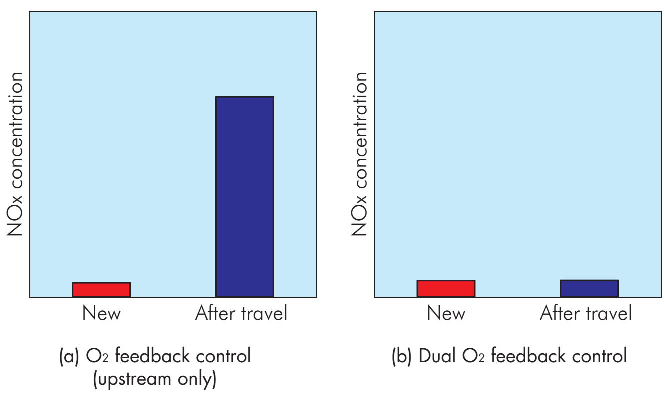


Fig. 6 NOx concentration in emission gas

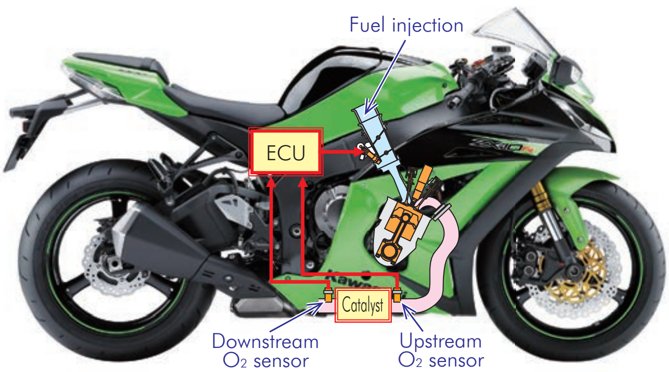


Fig. 7 Dual O_2 feedback system

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)).

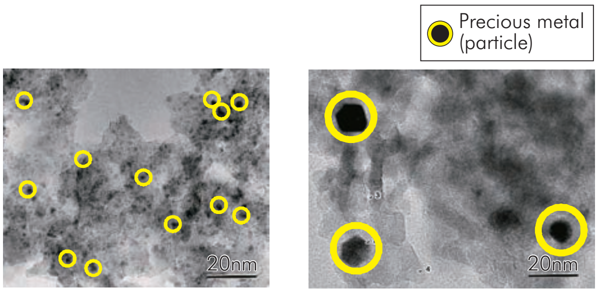
* Stoichiometric ratio: The air-fuel ratio at which the air and the fuel can react with each other with no shortage or surplus of either

(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)



(a) Fresh (b) After degradation

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

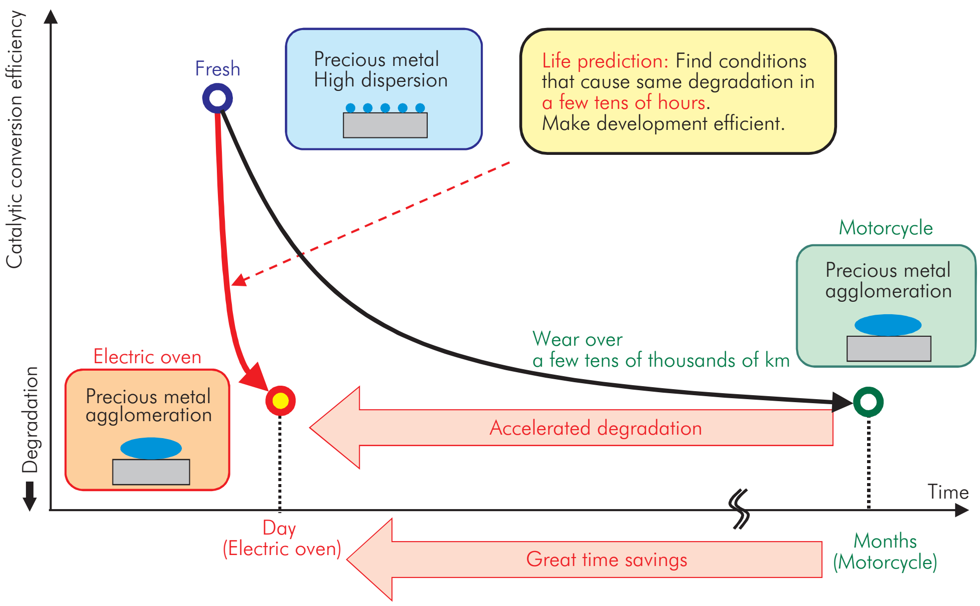


Fig. 10 The images of catalyst life predicting method

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.

Reference

1) T. Abe, S. Kuratani, Y. Mori and D. Yanase: "Application of Air Fuel Ratio Control to a Motorcycle with Dual Oxygen Sensor," Proc. of Small Engine Technology Conference. SETC, 2011-32-0629, SAE (2011)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