Development of Supercharged Motorcycle Engines

We developed supercharged motorcycle engines as power units that meet various customer demands by utilizing our own compressor technology. By developing and fabricating supercharged engines ourselves, we pursued high-level supercharger efficiency and optimal vehicle characteristics, successfully developing a "power-type" supercharged engine, which achieves the ultimate feeling of acceleration with a size of 1, 000 cm^3, and a "balanced-type" supercharged engine, which achieves a better-than-ever balance between power and fuel economy.

Introduction

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

1 Background

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

2 Development policy

(1) Characteristics required of supercharged engines for motorcycles

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

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

(2) Selection of a supercharger

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

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

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

(3) Two supercharged engines

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

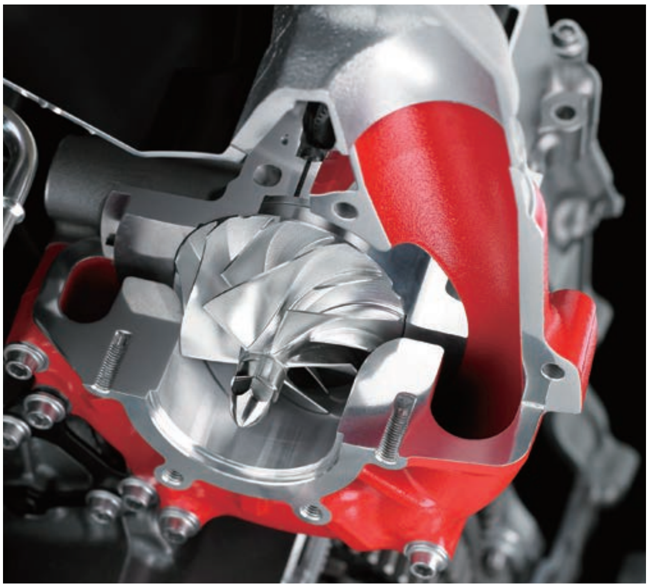


Fig. 1 Centrifugal supercharger (for Ninja H2)

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

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

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

3 Development of power supercharged engines

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

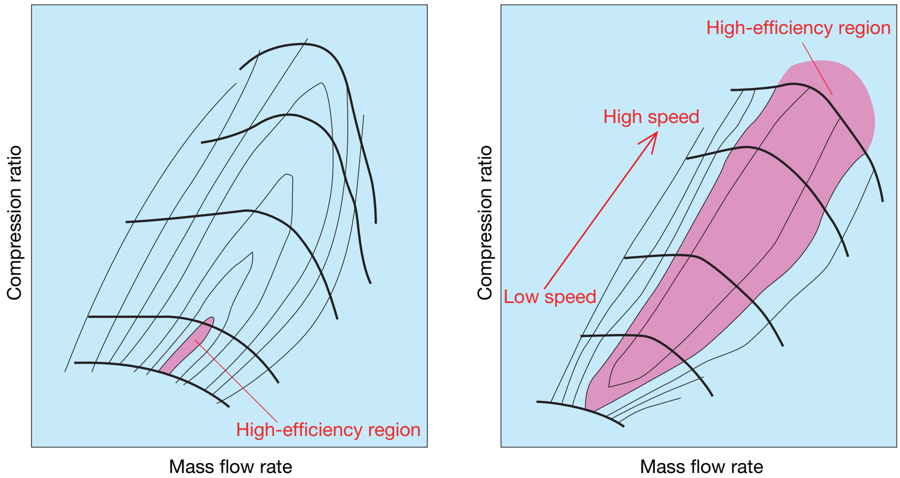
(1) Control of intake air temperature

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

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

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

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



(a) Common centrifugal supercharger

(b) Kawasaki´s supercharger

Fig. 2 Compressor map

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

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

(2) Containment in case the compressor impeller breaks

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

For this analysis, the technology used for designing the

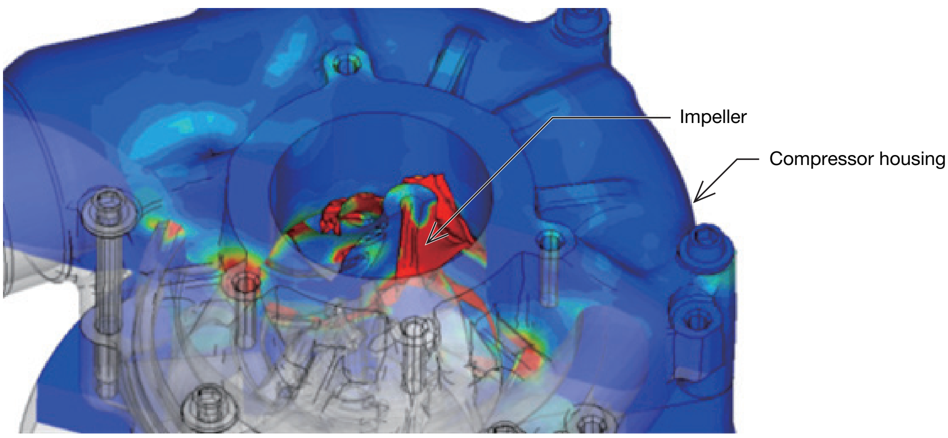


Fig. 3 Crash analysis

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

(3) Establishment of a supercharger drive system

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

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

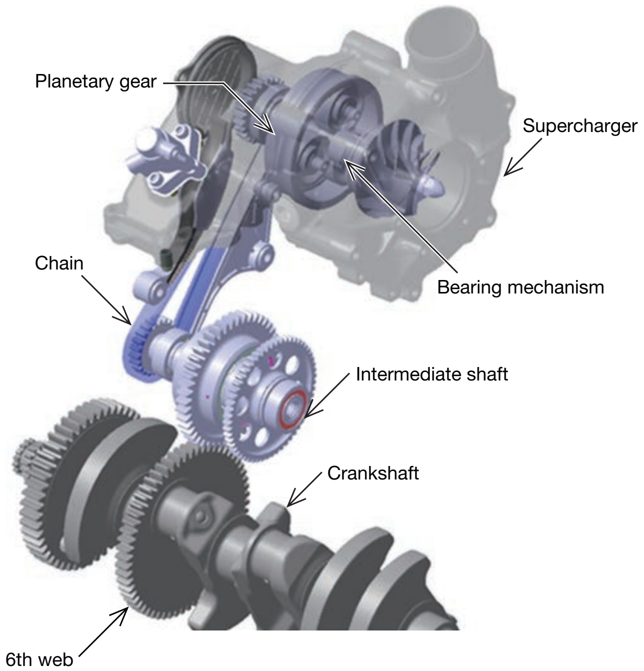


Fig. 4 Supercharger drive mechanism

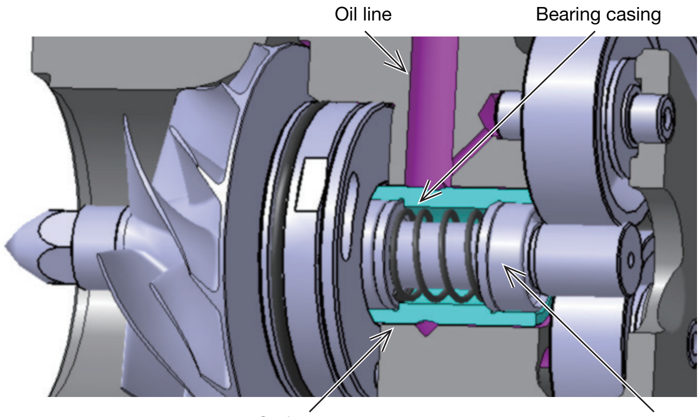


Fig. 5 Bearing structure

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

4 Development of balanced supercharged engines

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

(1) Increase of the compression ratio

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

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

(2) Optimization of the supercharger characteristics

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

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

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

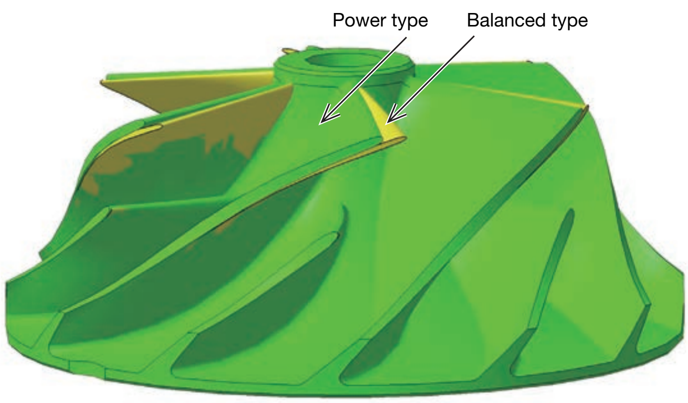
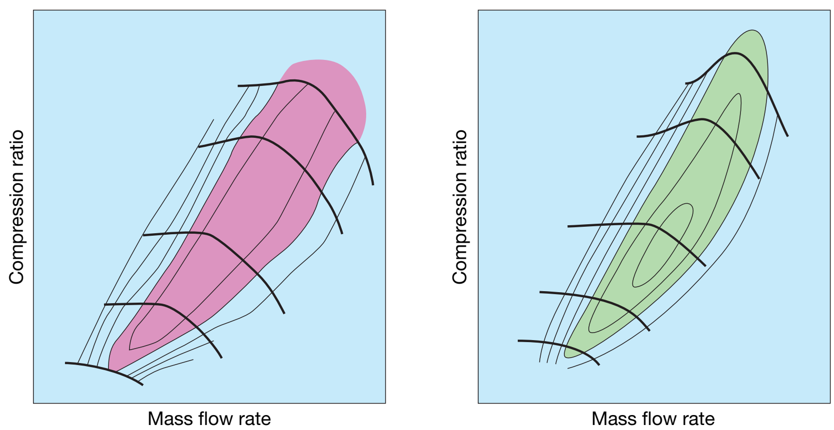


Fig. 6 Impeller blade shape



(a) Power supercharger   **(b) Balanced supercharger**

Fig. 7 Compressor map

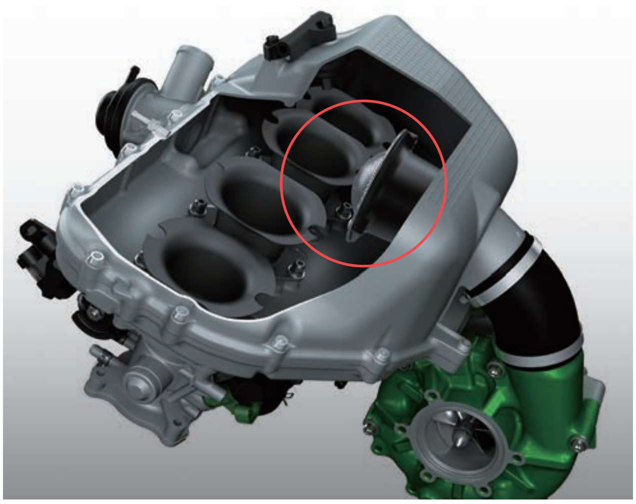


Fig. 8 Diffuser structure inside intake chamber

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

(3) Optimization of the air intake structure

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

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

Conclusion

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

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

Reference

1) Yamada: "Consumer-driven product development: strategies and execution," Kawasaki Technical Review No.174, pp. 7-12 (2014)
2) Kattwinkel: "Mechatronic Solution for Electronic Turbocharger," SAE 2003-01-0712

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