

Development of Horizontally-opposed Six-cylinder Engine for 2018 Gold Wing

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ABSTRACT

On the basis of the concept of new Gold Wing, the new horizontally-opposed six-cylinder power unit was developed with the theme “smooth yet aggressive at times, light weight and compact flat-six power unit.” To achieve weight reduction and compactness of the power unit, the materials and the shapes of the crankshaft and the connecting rods were redesigned. To realize lightweight and compact power unit, the Unicam valve train having finger follower rocker arms for the intake valves and the single throttle body were applied. To enhance combustion efficiency, the combustion chamber was changed from bathtub type for two valves, to the pent roof type for four valves. In addition, the compression ratio was increased and the intake ports were applied with a shape generating a strong tumbling of intake air. To enhance maneuvering qualities, which was derived from the set concept of the developed motorcycle, a throttle-by-wire system was adopted. To the drive system of the Integrated Starter Generator, a damper of revised configuration and a rubber coupling were implemented and the requirements for tranquil riding were fulfilled. A comfortable exhaust sound was also provided by reassessing the design of the exhaust system. With all the measures mentioned above, weight reduction, together with downsizing, was successfully achieved by 7.1 kg for the DCT equipped model and by 9.5 kg for the MT equipped model compared to the previous model. Furthermore, the peak output power was increased by 6 kW and, yet, the fuel economy was improved by 24% (in the case of the model sold in Japanese market) in the WMTC mode (class 3-2). As mentioned above, the enjoyably deep and pulsated exhaust sound was also achieved while offering the mild and high quality sounds of mechanical operations.

1. Introduction

Ever since the first introduction of the GL1000 in 1975, the Gold Wing evolved and its model lineup was strengthened as Honda's grand tourer model for long-distance touring. From the first model, the horizontally-opposed engine configuration has been applied featuring low center of gravity, small vibration and lower mechanical noise. In the early four cylinder engines, the displacement was increased from 1000 cc to 1100 cc, then to 1200 cc. While modifying further to six cylinders, 1500 cc, and to 1800 cc, the horizontally-opposed engine configuration stays alive for more than 40 years.

In this paper, the horizontally-opposed six-cylinder (hereafter F6) power unit for the sixth generation Gold Wing - GL 1800 is introduced. This model has been totally updated and its mass production started in 2018. This power unit is based on the former F6 engine, the only

one in motorcycles, with modifications applied to reduce weight and achieve compactness by applying advanced technologies such as the latest valve train mechanism, the Throttle by Wire (hereafter TBW), the Integrated Starter Generator (hereafter ISG), the Dual Clutch Transmission (hereafter DCT), etc. Compared to the previous model, the power output is increased, the throttle response is enhanced as well as improving the fuel consumption. With its deep and enjoyably pulsated exhaust sound along with the lower mechanical noise, the new power unit is intended to be “fun to ride” for the rider.

The power unit comes in two types; the seven-speed DCT type and the six-speed manual transmission (hereafter MT) type. Unless otherwise mentioned, this paper refers to the DCT type. The details of DCT are discussed in the separate paper titled “Development of 7-speed Dual Clutch Transmission for 2018 Gold Wing”⁽¹⁾.

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2. Goals of Power Unit Development

Considering changes of the market and the customer demands, the target of complete motorcycle was set at a leap from the gorgeous & luxurious, massive and heavy line and to regain youthfulness, aiming at a “fun to ride, fun to control” motorcycle. Keeping that in mind, the new power unit has been developed with the theme “smooth yet aggressive at times, light-weight and compact flat-six power unit.” The major goals were set as per the following.

- 1) Reduce weight by 6.5 kg in DCT type, 9.0 kg in MT type
- 2) Reduce length from the front of engine to the rear end of the left cylinder head by 30 mm
- 3) Same or more power output as the previous model. Improve fuel consumption by 20% in WMTC mode (class 3-2)
- 4) Deep and pulsated exhaust sound and high-quality engine start sound

To contribute to the concept of new Gold Wing “light-weight and highly dense packaging that allows the rider to fully use the motorcycle in various conditions,” the key goal of the power unit was set at light weight and compactness. Despite the valve train modifications from the two-valve to the four-valve and the employment of seven-speed DCT, the target weight reduction of power unit was set at 6.5 kg in DCT type, 9.0 kg in MT type from target of complete motorcycle.

To shift the riding position further to the front of motorcycle to enhance maneuverability, a target was set to reduce the length from the front of engine to the rear end of left cylinder head by 30 mm.

While maintaining and evolving such features of the previous model as the adequate torque in low engine speeds, strong acceleration, low vibrations and quietness, a target was set to improve fuel consumption by 20% in the WMTC mode (class 3-2).

It was also aimed to realize deep and pulsated exhaust sound appropriate for a motorcycle with a large displacement engine along with high-quality engine start sounds suitable for a top-end model.

The overview of the power unit is shown in Fig. 1.



Fig. 1 Overview of power unit

Table 1 Power unit specifications

	Developed model		Previous model
	DCT type	MT type	
Cylinder arrangement	F6-cylinder		F6-cylinder
Bore x Stroke (mm)	73 x 73		74 x 71
Displacement (cm ³)	1833		1832
Compression ratio	10.5 : 1		9.8 : 1
Maximum power	94 kW / 5500 rpm		88 kW / 5500 rpm
Maximum torque	171 Nm / 4500 rpm		169 Nm / 4000 rpm
Valve train	Unicam - 4 valve		SOHC - 2 valve
Combustion chamber configuration	Pent roof		Bathtub
Diameter (mm) / Number of throttle body	φ 50 / 1		φ 40 / 2
Generator	Integrated Starter Generator (ISG)		Dedicated generator
Starter			Dedicated motor
Transmission	7-speed DCT	6-speed MT	5-speed MT
Reverse system	Engine drive	Motor drive	Motor drive
Engine weight (kg)	114.3	111.9	118.1
Engine length x width x height (mm)	617 x 702 x 503		633 x 706 x 513

*The engine weight includes the intake system, starting system, charging system and the transmission. The intake system consists of the throttle body and the downstream parts. Exhaust system not included.

*The engine length does not include the final shaft.

3. Power Unit Specifications and Other Major Specifications

Major specifications of the new Gold Wing (North America type) and the previous model are compared in Table 1.

While maintaining the same longitudinal, water-cooled 4-stroke, F6 configuration and 1800 cc displacement from the previous model, the engine has been totally redesigned. For weight reduction and compactness, the bore/stroke and the number of throttle bodies are modified. To enhance combustion efficiency, the compression ratio is raised, and the combustion chamber is redesigned from the two-valve bathtub type to the four-valve, pent-roof type. For easy operation of motorcycle, the seven-speed DCT type is provided in addition to the six-speed MT type. Moreover, the ISG and the engine-driven reverse system are newly employed.

4. Basic Engine Configuration

4.1. Crankshaft and Connecting Rod

To enhance motorcycle maneuverability and rider comfort, the longitudinal length of the engine was reduced. The crank shaft is compared to the previous model in Fig. 2.

As well as changing the bore from previous model's

$\phi 74$ mm to $\phi 73$ mm, the crankshaft material was changed from the steel with soft nitriding to the alloy steel having a high internal hardness. With the change of material and the choice of optimum shapes, the crank journal width was reduced by 1 mm, the crank pin width by 2 mm, and the crank web width by 1~2 mm, thus reducing the overall length of crank shaft (the length between the front and rear journals) was reduced by 22.6 mm. Consequently the length between cylinders (bore pitch) was reduced by 9 mm, and the right and left cylinder offset by 4 mm. The crank pin diameter was increased by 4 mm to deal with the increase of contact pressure in the connecting rod big end bearing from the reduced crank pin width and the lowering of crankshaft stiffness from the increased stroke. The crank pulse rotor was relocated from the front of crankshaft in the previous model to the rear of crankshaft, reducing the length from the engine front cover to the crankshaft by approximately 7 mm.

With all these measures taken, the length from the front of engine up to the rear end of left cylinder head was reduced by 29 mm from the previous model as shown in Fig. 3, allowing shifting of riding position more to the front of motorcycle to increase weight on the front wheel while maintaining rider's leg spaces, contributing to an enhancement of maneuverability of the motorcycle.

Regarding the connecting rod, the length was reduced by 7 mm by the change of material from the microalloyed steel to the high-strength carburized steel to help prevent increase of engine width from the increase of stroke as well as reducing the weight. Regarding the tightening of the rod and the cap, the nut-less design was applied using M6 bolt tightened in the plastic region while the previous model uses M8 bolt tightened in the elastic region. This design contributed to the above-mentioned reduction of crank pin

width. The connecting rod is compared to the previous model in Fig. 4.

With these modifications applied, the total weight of the crankshaft and six connecting rods was reduced by 1.1 kg.

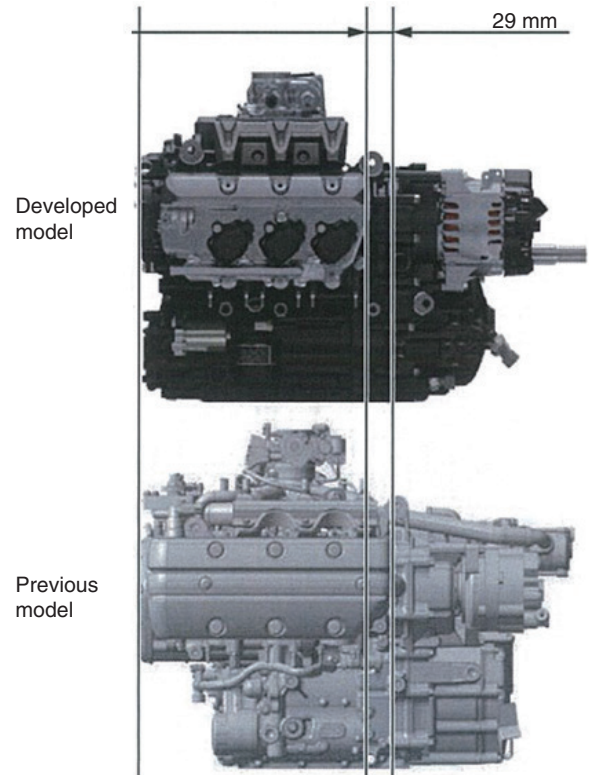


Fig. 3 Left view of power unit

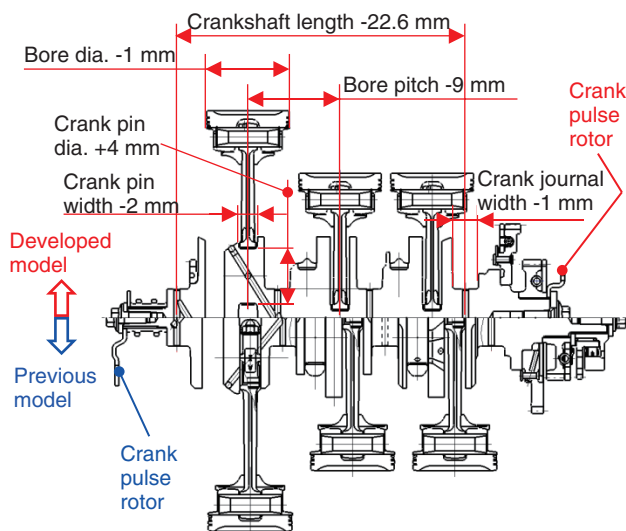


Fig. 2 Crank shaft (comparison in the left cylinder)

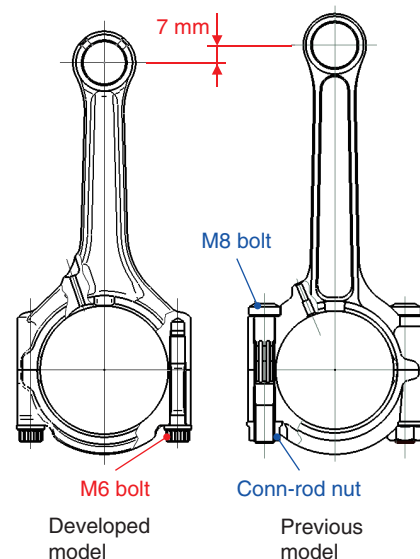


Fig. 4 Connecting rod

4.2. Valve Train and Cylinder Head

The Unicam valve train having the finger follower rocker arms in the intake side was applied for weight reduction and compactness. The construction is shown in Fig. 5.

To maintain adequate lean angle of the vehicle, which is an inherent issue in a horizontally-opposed engine, a single camshaft is laid in the upper part (intake side) just as in the previous model, applying the Unicam design in which the exhaust valve is activated by the roller rocker arm to deal with the modification from the two-valve to the four-valve design. With the finger follower rocker arm applied in the intake side, the valve lifter holding part, which is located in the intake side of cylinder head in the previous model or conventional Unicam system⁽²⁾, is eliminated. Thus, the total weight of right and left cylinder heads is reduced by 2.8 kg.

Furthermore, several weight reductions in the valve train system, such as applying the coaxial shaft which supports the inlet and exhaust rocker arms commonly, employing the thin-wall camshaft by using the high-strength material, removing material from behind the cam lobe, were conducted. With all these measures taken, a total of 1.3 kg was reduced from the valve train system despite the weight-increasing factors such as the change from the two-valve design to the four-valve system, and the addition of rocker arm parts.

4.3. Engine Weight Reduction

In addition to the measures mentioned in Section 4.1. and 4.2., the engine weight was reduced by various other means in the entire engine. Some typical examples are discussed hereafter.

The change of cylinder sleeve material from the cast iron to the composite aluminum material⁽³⁾ reduced 2.2 kg. The modified parts layout in the cooling system reduced 0.7 kg. The elimination of starter motor and related parts in the starting system and the charging system from the application of the ISG reduced 2.4 kg (discussed in Chapter 5). The

modification of the throttle body from the twin throttle type to the single throttle type reduced 1.1 kg (discussed in Chapter 7). The application of the transmission construction integrating the reverse system⁽¹⁾ allowed elimination of reverse-related parts, reducing 1.3 kg (DCT type only).

With all these measures taken, the engine weight was reduced by 3.8 kg in the DCT type from the previous model despite the weight-increase from the application of DCT and the increased number of speed from five to seven. In the MT type, 6.2 kg was saved despite the weight increase from the change to six speeds from the five speeds.

* The engine weight includes the parts in the intake system in and under the throttle body, those in the starting and charging systems, and the transmission.

4.4. Main Bearing Cap

In the Gold Wing, the iron-based sintered material was employed in the main bearing cap to reduce crankshaft knocking noises since the previous model from which the six-cylinder engine became 1800 cc⁽⁴⁾. Due to the increase of power output in the new model from the previous model, there was an issue of fretting in the bearing cap mating surfaces on the crankcase of this model.

To deal with this issue, we focused our attention on the reduction of stress amplitude on the bearing cap mating surfaces, the microscopically small slip occurring on the mating surfaces (hereafter as relative slip), which are the main causes of fretting fatigue⁽⁵⁾. It was also considered that an equalization of surface pressure distribution on the contact surfaces and a prevention of lowering of surface pressure in the outside of the bearing cap at the time of load application would be effective to reduce the said stress amplitude and the slip. It was based on such a consideration that an excessively small surface pressure tends to increase relative slip.

Effective measures to deal with the said issues include an increase of retaining stiffness such as an increase of bearing cap stiffness, use of four retainer bolts and/or an increase of journal bolt pitch. Any of such measures, however, causes an increase of engine weight and size. Accordingly, taking into account achieving weight reduction and compactness, the construction in which the bearing cap pressed in the crankcase was applied. The construction is shown in Fig. 6.

As well as press-fitting the outsides of bearing cap into the crankcase, the journal bolt was downsized from M12 to M10 by applying the high-strength material. Furthermore, the bolt pitch was increased to equalize pressures on the mating surfaces.

The analyzed surface pressure distribution on the bearing cap mating surfaces of the crankcase at the time of tightening and when the load is applied is shown in Fig. 7. The diagrams indicate surface pressure distribution on the mating surface "A" in the lower side of the crankcase shown in Fig. 6. The data at the time of load application are those taken when the relative slip in the outside is at its

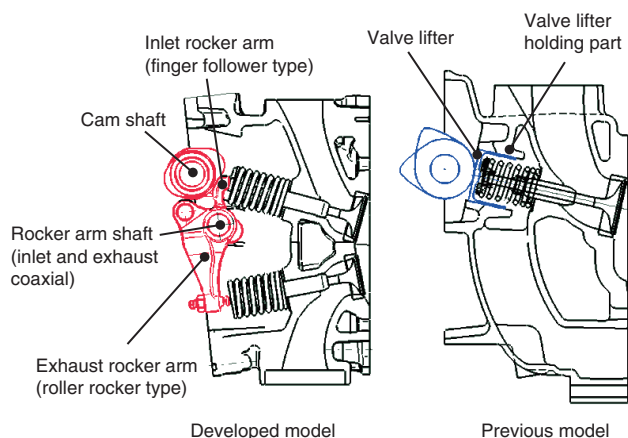


Fig. 5 Cross section of valve system

maximum. In the previous model, the surface pressure is high in the inside (journal side) and low in the outside when tightened. When the load is applied, the surface pressure lowers significantly near the outside end of the bearing cap. With the press-fitting applied, the surface pressure at the time of tightening is equalized, and the lowering of surface pressure near the outside end at the time of load application is no longer apparent.

It should be noted that while the lowering of surface pressure is seen in the inside (journal side) when the load is applied, as the relative slip in the inside is small in this bearing cap retaining design, the fretting is no longer a concern nor seen in the actual test engine.

The stress amplitude and the relative slip on the bearing cap mating surface of the crankcase are shown in Fig. 8. The stress amplitude is compared at the maximum part in the entire mating surface. Compared to the previous model, the stress amplitude and the relative slip are reduced.

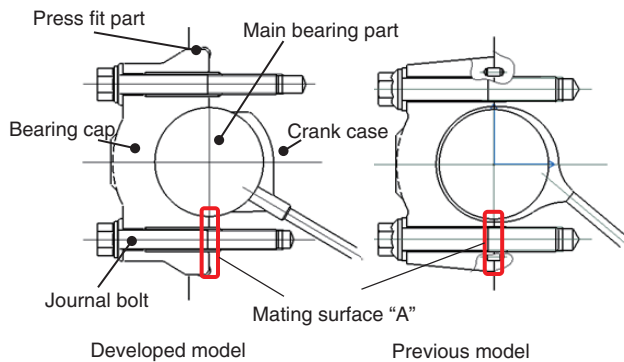


Fig. 6 Bearing cap

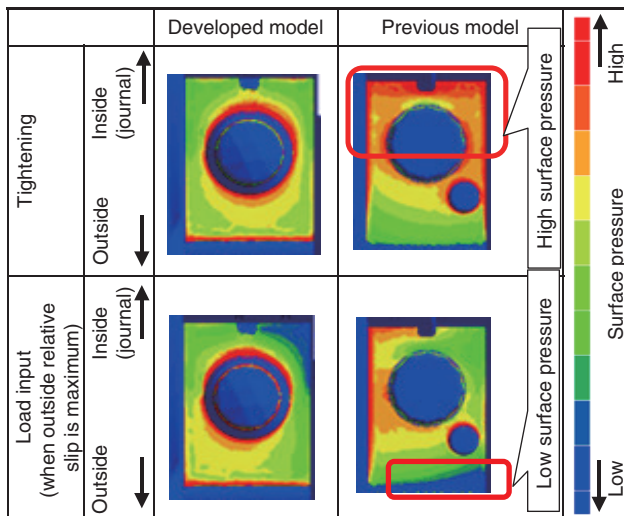
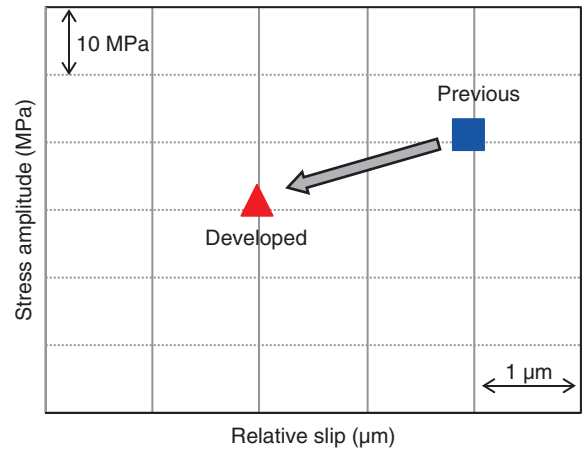


Fig. 7 Results of crank case surface pressure analysis

With all these measures taken, there is no fretting in the mating surface of the test engine, contributing to the weight reduction and compactness of the engine.



Analysis condition

Journal bolt axis power: lower limit

Combustion pressure: maximum

Press fit interference: center

Fig. 8 Results of stress and relative slip analysis

5. Integrated Starter Generator (ISG)

5.1. Mechanical Construction

In the development of the engine starting system and the charging system of the new Goldwing, the highest priority was given to weight reduction and lower mechanical noise.

To achieve the goals, the ISG, which performs as a starter motor and an alternator, was first applied in a large motorcycle. The shape of ISG is shown in Fig. 9. In the previous model, the starter motor was used in the starting system and the excitation-type alternator was used in the charging system separately. The employment of ISG permitted elimination of the starter motor, starting reduction gear, the starter magnetic switch and related electric wires, etc. In that way, the weight in the starting and charging systems was reduced by 2.4 kg (-20%).

The construction of ISG and its drive train of this model are shown in Fig. 10. The alternator, starter motor and their drive train of the previous model are shown in Fig. 11.

5.2. Starting and Charging Performance

The ISG is already applied widely in automobiles. When the ISG for automobiles is applied as it is, an electric current 2.2 times more than the previous model will be required at the time of starting, requiring a larger battery than the previous model.

To deal with the said issue, the electrical control system



Fig. 9 Shape of ISG for developed Gold Wing

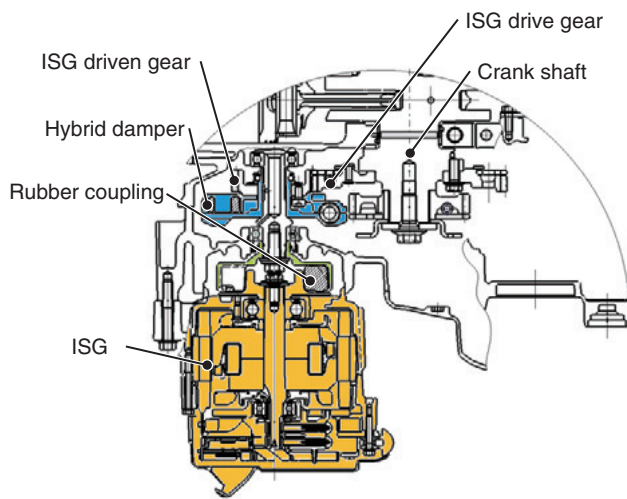


Fig. 10 Gear and couplings to drive ISG

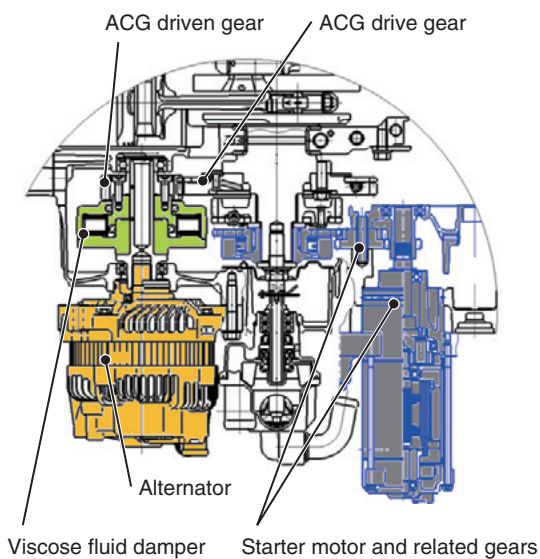


Fig. 11 Gears and couplings to drive starter motor and alternator

for starting was reviewed and the optimized, allowing reduction of required starting current to less than 1.5 times of the previous model. Thus the starting performance required for this model was satisfied without modifying the capacity and size of the battery.

Meanwhile in the charging system, the alternator capacity necessary for this model is approximately 1.2 times more than the previous model. However, as the rated alternator output of the ISG is approximately 1.7 times more than the previous model, the power exceeds the allowance of the component parts in the charging system such as the wire harness, fuses, etc. used in the previous model. This causes an increase of weight from use of large diameter wires, etc. and requires redesigning of fuses and fuse box.

To obtain alternator output 1.2 times as much as the previous model, the cooperative control was incorporated to maintain the exciting current of ISG at an appropriate level at each engine speed by commands from the PGM-FI unit. The output current characteristics of the ISG of this model and the alternator of the previous model are shown in Fig. 12. While obtaining approximately 2.9 times (a in the graph) more power output than the previous model near the idling, it is approximately 1.2 times near 4000 rpm (b in the graph), helping ensure steady power output in the wide engine speed range.

5.3. Drive System and Noises

While the ISG in automobiles is usually belt-driven, the direct drive via the gears is applied in this model. As the characteristics of a motorcycle having a longitudinal engine, the roll moment that shakes the motorcycle right and left occurs when the spinning of crankshaft is accelerated or decelerated. These shaking motions are uncomfortable for the rider when the motorcycle is standing still. To cancel the roll moment, the gear drive system was applied so that the ISG spins in the opposite direction of the crankshaft.

The helical gears were applied to drive the ISG to further reduce the gear whine noise of the previous model

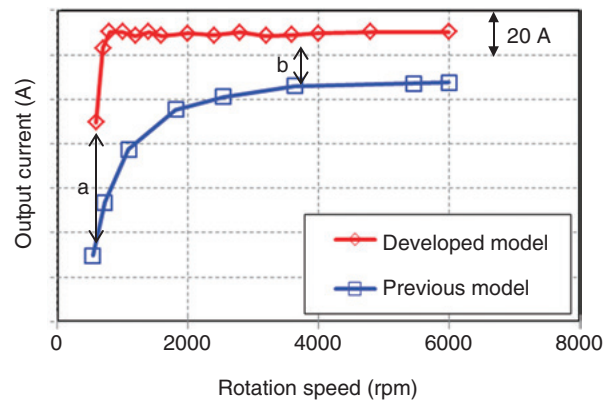


Fig. 12 Characteristics of output current to rotation speed

in which the alternator was driven by spur gears, thus enhancing high-quality feel. The comparison of noise level of the helical gear and the spur gear is shown in Fig. 13. The horizontal axis refers to the engine speed. The vertical axis represents the sound pressure measured at rider's ears. The solid lines indicate overall sound pressure level. The dotted lines indicate the sound pressure level of the order component (first order) of ISG gear meshing. In the spur gear, the order component sound pressure of ISG gear is especially high near 1700 rpm (corresponds to 80 km/h in top gear), lifting the overall sound pressure level. Meanwhile in the helical gear, there is no surge of

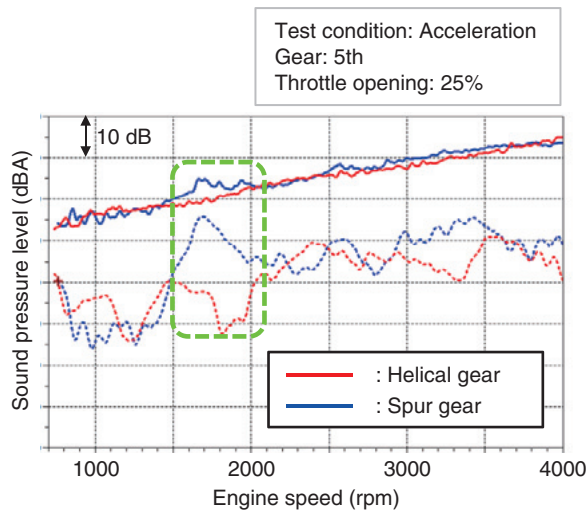


Fig. 13 Comparison of ISG gear noise

gear noise that lifts the overall sound pressure level, thus enhancing the high quality feel.

In the ISG drive train, a shock absorbing device (hereafter as damper) was necessary to reduce gear rush noise from crankshaft rotational variation. The ISG starts the engine in addition to power generation. In the viscous damper applied in the previous model, as slippage occurred from the cranking torque, it did not allow starting of the engine. In the new model, the newly-designed damper composing of the spring and the rubber was applied along with the rubber coupling. The construction of new damper is shown in Fig. 14.

The newly-designed damper is composed of the arc spring that maintains the damping stroke and the highly impact- absorbing damper rubber. The application of this construction helps ensure necessary working angle of damper and the maximum load capacity in the limited space. The rubber coupling is applied for easy coupling and reduction of coupling rush noises. As the drive shaft and the alternator were connected by the spline without using coupling in the previous model, noises occurred from the backrush in the spline connection. The application of rubber coupling eliminates the factor in occurring of rush noise.

The use of ISG for starting of engine reduces engine start noise from the previous model. In the previous model, as the starter motor torque was much lower than the required cranking torque, a large reduction gear ratio was required (total reduction ratio 28.3, internal reduction ratio 6.4).

Meanwhile in the ISG, since the power output as a starter motor was increased to approximately 4.4 times more than the previous model, the reduction gear ratio was lowered to 2.5. Accordingly, the rotating speed of ISG

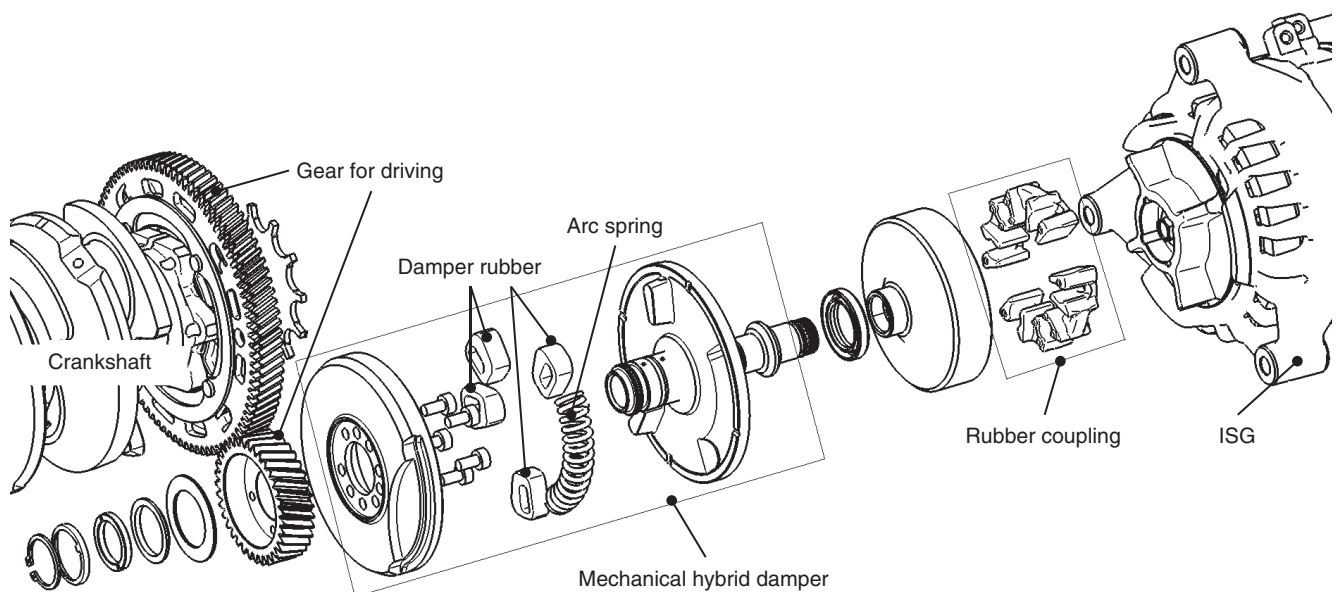


Fig. 14 Structure of ISG damper and coupling

when starting the engine was lower than the rotating speed of the starter motor and the reduction gear of the previous model. The wide and large-module helical gears were applied for starting of engine (=ISG drive gear) because the gears had to be strong enough to withstand the driving torque variation of the ISG. Accordingly, the tooth stiffness became higher than the starter gear of the previous model. Furthermore, the small reduction ratio permitted reduction only by a single stage rather than the two-stage reduction in the previous model. This also increased stiffness of the entire gear train. Consequently the sound pressure variation resulting from the deformation of the starter power train was reduced, contributing to the sound quality enhancement. The sound pressures at the time of starting in this model and the previous model are compared in Fig. 15. The horizontal axis refers to the time and the sound pressure in the vertical axis. The overall sound pressure and its fluctuation are lower in this model than in the previous model.

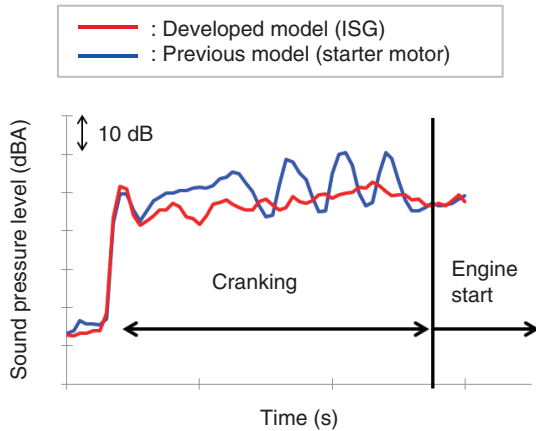


Fig. 15 Comparison of engine starting noise

6. Engine Performance

To achieve both the required engine power and the fuel consumption, the combustion efficiency was enhanced. And this has brought about the higher engine performance than the previous model.

In the cylinder head, the camshaft was located closer to the intake side in the same way as the previous model to help ensure lean angle and to maintain rider's leg space. In the previous model, an intake and an exhaust valve were laid parallel and activated by the direct valve lifting system using the SOHC design. In the new Gold Wing, the newly-applied Unicam valve train allowed the four-valve configuration while maintaining the same SOHC design having the camshaft close to the intake side just like the previous model. The volumetric efficiency was thus enhanced by the modification from the two-valve to the four-valve design while using the high-tumble intake

port design to strengthen turbulence in the cylinder. The measured volumetric efficiency is shown in Fig. 16. It is the same or higher than the previous model across the entire engine speed range. With the application of four-valve design, the combustion chamber was changed from the bathtub type of the previous model to the pent roof type, and the compression ratio was raised from 9.8 to 10.5.

The engine power output and the torque (converted on the crank shaft) are shown in Fig. 17. The indicated specific fuel consumption (ISFC) in the ordinary operation zone is shown in Fig. 18. The power output is achieved the same or higher level than the previous model across the entire engine speed zone. The ISFC is improved in the low-load zone.

The friction loss is compared to the previous model in Fig. 19. In the DCT type, despite the increase of

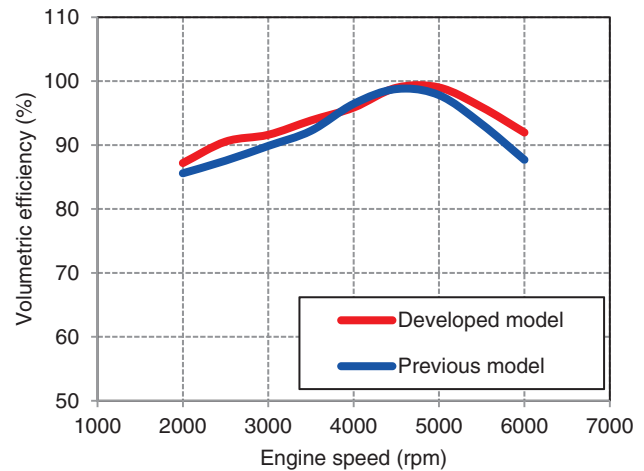


Fig. 16 Volumetric efficiency

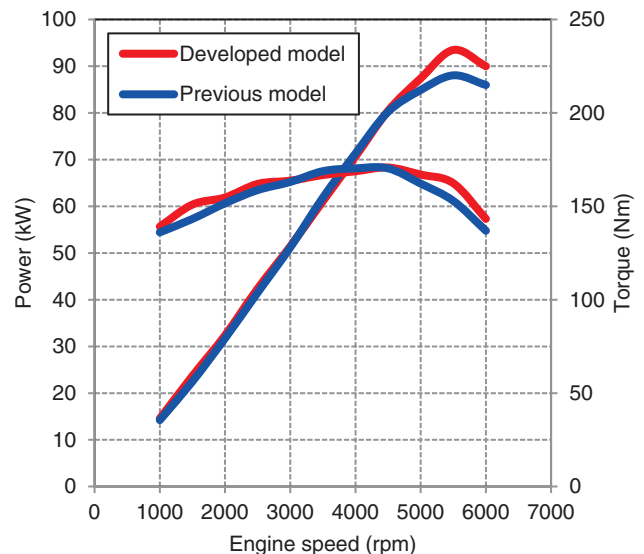


Fig. 17 Engine performance

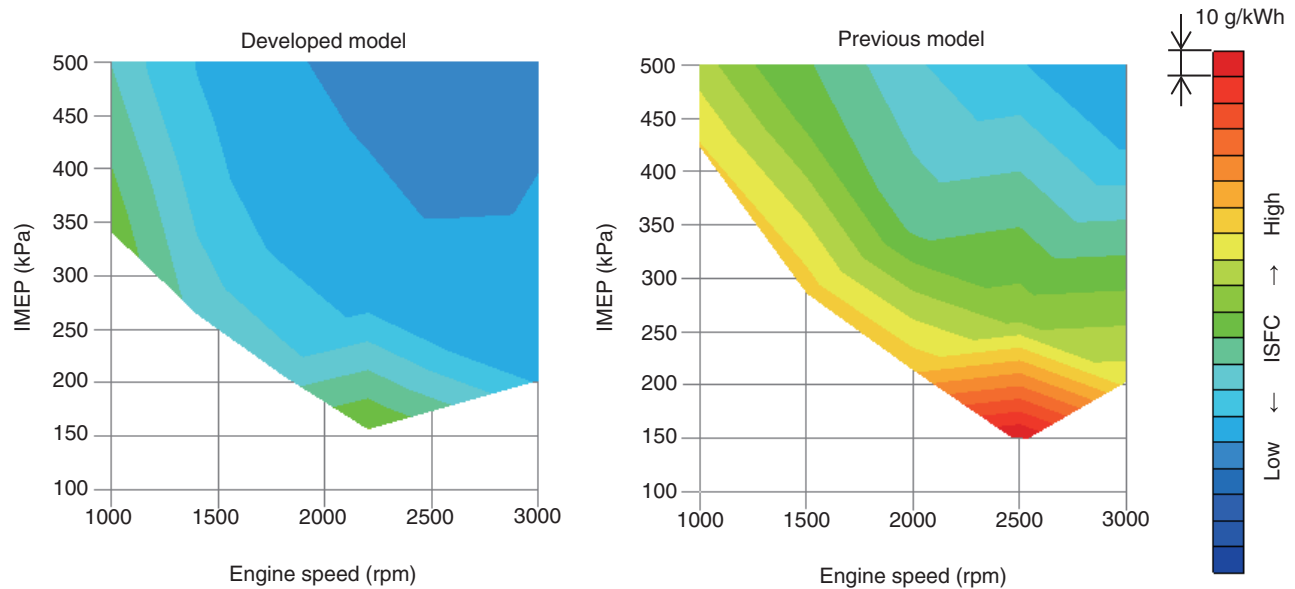


Fig. 18 ISFC map

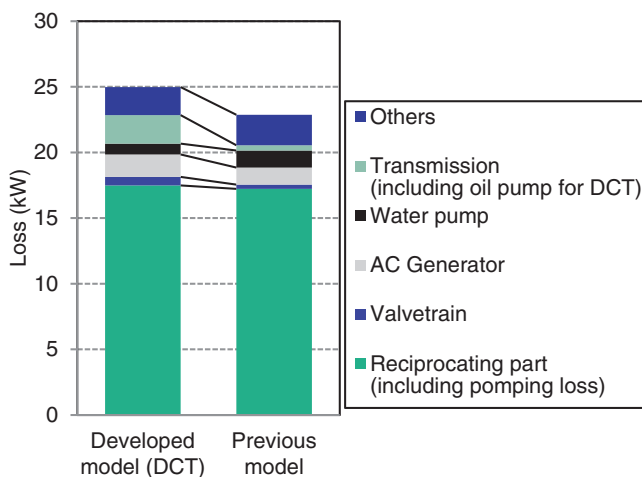


Fig. 19 Breakdown of loss at 6000 rpm

friction loss from the previous model due to the addition of exclusive oil pump for DCT, the fuel consumption in the WMTC mode (class 3-2) is improved from 14.7 km/L to 18.2 km/L (in the case of the model sold in Japanese market) due to the ISFC improvement, the weight reduction, the increase of gear step in transmission, etc.

7. Intake System

7.1. TBW

To provide the rider with high riding quality by precise control of the throttle, the TBW was applied in the throttle body. The controls using the TBW are as per the following.

- Simplified cruise control system
- Honda selectable torque control system
- Ride modes selection system
- Control of rapid engine torque increase when the throttle is opened quickly
- Walking speed mode - forward and reverse (DCT type only)
- Reduction of shift shock [moderating of inertia torque in the crankshaft system occurring at the time of gear shift (DCT type only)]
- Control of idle speed
- Maximum speed limiter
- Control of throttle opening when the idle stop is canceled

As such, the TBW allows addition of various functions in addition to the simplification of the cruise control system applied from the previous model.

7.2. Single-throttle Body

To offset an increase of weight and space with the addition of the motor to operate the TBW, the single throttle design was applied instead of the twin throttle type of the previous model.

The throttle body and the intake manifold of the previous model and the developed model are shown in Figs. 20 and 21.

In automobiles, the single throttle design is common in multi-cylinder engines. When the previous model was developed, the idea of single throttle was abandoned because the required throttle response was unattainable. In this model, the volume in downstream of the throttle valve (the volume of intake manifolds and intake ports) was reduced by 8% from the previous model. Coupled with the change of valve train from the two-valve to the four-valve

design and the improvement of combustion by the optimum valve timing, etc., the throttle response was achieved the same or better level than the previous model.

The changes of geometric opening area of throttle valve relative to the throttle valve angle are shown in Fig. 22. The changes of volumetric efficiency relative to the throttle valve angle calculated by CAE are shown in Fig. 23. For the calculation, the commercially-available one-dimensional analysis software was used (Simulation conditions: engine speed 1000 rpm, throttle twist speed 80 deg/sec).

Compared to the previous model, the rate of change of volumetric efficiency is higher in this model despite the low rate of change of geometric opening area.

The changes of driving force relative to the throttle opening angle measured from the actual motorcycle are shown in Fig. 24 (Measurement conditions: engine speed 1000 rpm, throttle opening speed 6.7 deg/sec). It has been confirmed from these findings that the throttle response is better in this model than the previous model.

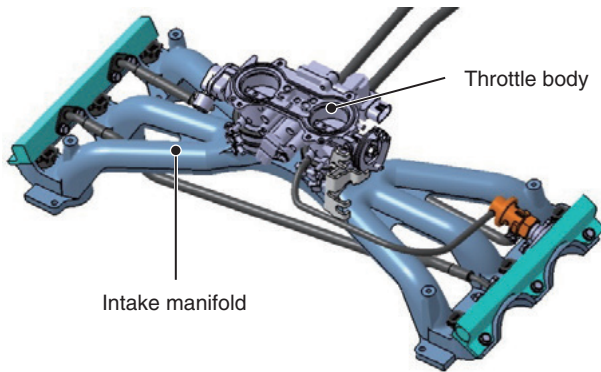


Fig. 20 Throttle body and intake manifold of previous model

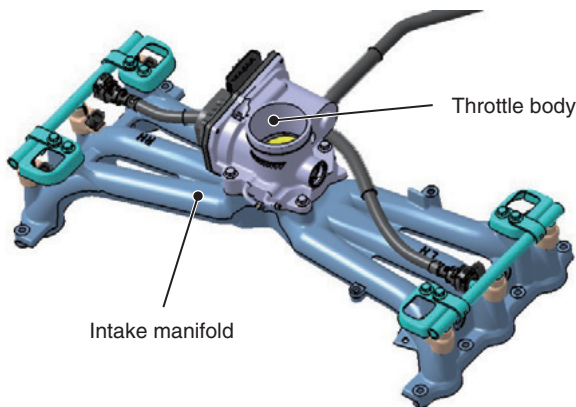


Fig. 21 Throttle body and intake manifold of developed model

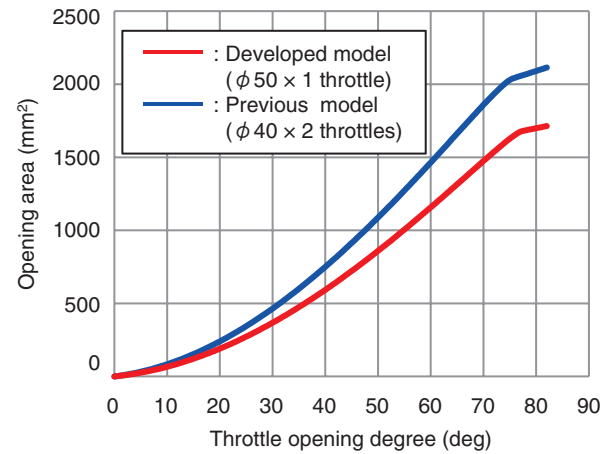


Fig. 22 Throttle opening characteristic

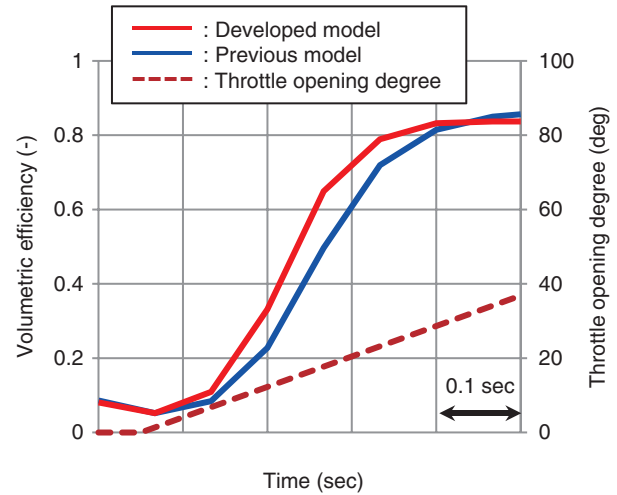


Fig. 23 Transition of volumetric efficiency in degree of throttle opening

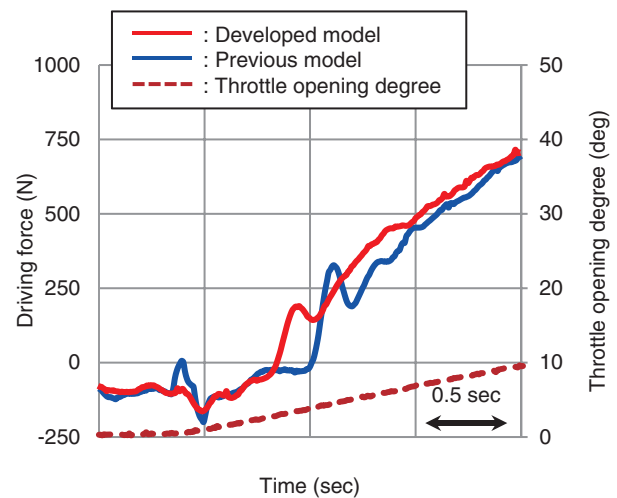


Fig. 24 Driving force (actual measurement)

7.3. Air Duct Layout

The electrical components such as the airbag module, ABS modulator, ECU were laid around the air box just like in the previous model. The double wishbone front suspension was applied in this model for realization of the concept of complete motorcycle. It is therefore necessary to contain the air box in the limited space.

Although the same 6.6-liter air box volume as the previous model was eventually maintained, the air filter surface area had to be reduced by 3%. Accordingly, the air duct layout was reviewed for effective use of the air filter surface area to achieve the maximum suction efficiency. The design specifications such as one of the two air ducts was facing to the front and the other facing to the rear were determined while analyzing flow of intake air.

The air cleaner box having two air ducts facing to the front just like the previous model is shown in Fig. 25 (Type A). The one with an air duct facing to the front and the other facing to the rear is shown in Fig. 26 (Type B).

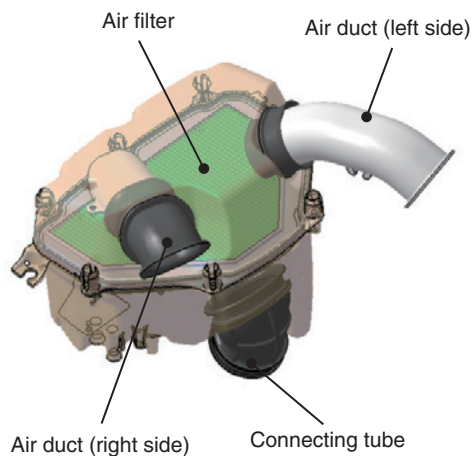


Fig. 25 Air cleaner box Type A

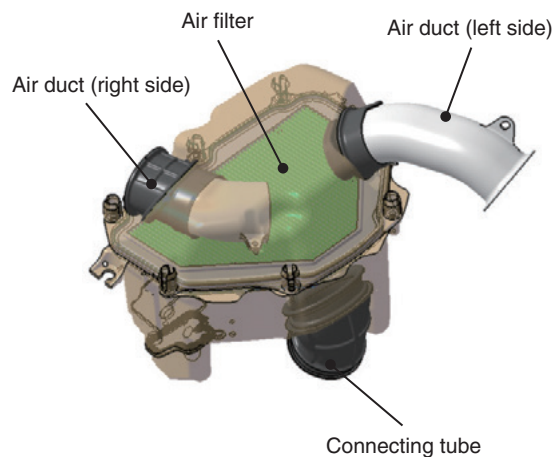


Fig. 26 Air cleaner box Type B

The average pressures on the cross section of the inlet and outlet of the air duct and the connecting tube and on the projected surface of upstream and downstream of the air filter calculated by CFD are shown in Fig. 27. Note that the commercially-available fluid dynamics analysis software was used for the calculation (conditions: steady flow when engine speed corresponds to 5500 rpm). Compared to Type A, the average pressure in various parts is higher in the Type B air box.

The internal pressure of air cleaner box (downstream of the air filter) measured from the actual motorcycle is shown in Fig. 28 (measurement conditions: engine speed 1000-6000 rpm, throttle fully open).

Also in the measurement, a higher air pressure is seen

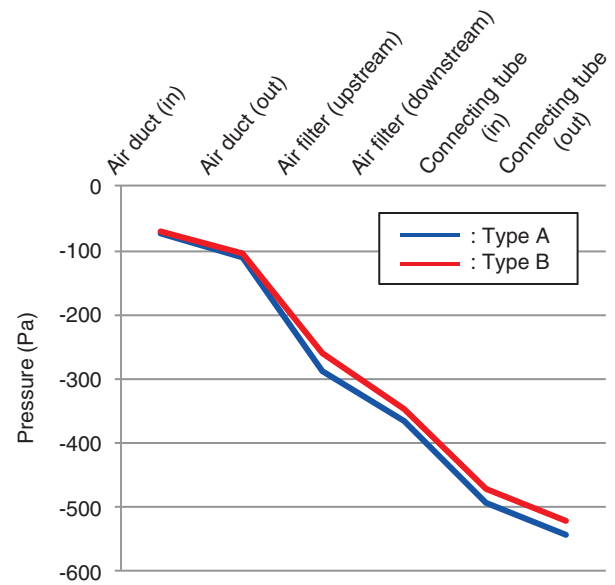


Fig. 27 Average pressure of each part

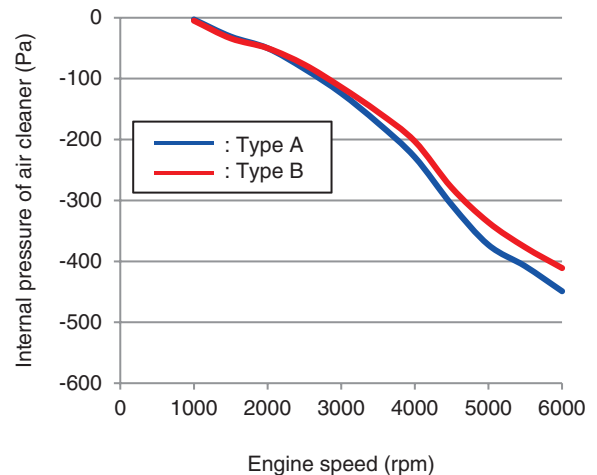


Fig. 28 Internal pressure of air cleaner box

in Type B than in type A, which is an indication of small pressure loss. From the said findings, the Type B air duct layout was applied in this model.

7.4. Reduction of Weight in Intake System

In the intake system, the weight was reduced by 1.1 kg from the previous model by the redesigning of the cruise control system, the throttle body and the intake manifold to deal with the application of single throttle system.

8. Exhaust System

In the exhaust system, a target was set to achieve exhaust sounds appropriate for the new Gold Wing as well as reducing the weight. As this new model requires high-quality image, the exhaust sounds have to be deep. A target was also set to create pulse feeling even from the F6 engine. The means to enhance deepness and pulse feeling is explained in the followings.

The internal construction of the muffler is compared to the previous model in Fig. 29. The inside of muffler is of such a construction that has a resonating chamber to attenuate sounds in addition to the same two-chamber construction as the previous model. Compared to the single tail pipe design of the previous model, two tail pipes are provided to obtain crisp sounds. The first tail pipe is open to the atmosphere from the first expansion chamber without passing the second chamber. This construction is aimed at

achievement of crisp sounds linked with the combustion by directing the high pressure exhaust gas directly to the tail pipe.

In the studies of construction, the attenuating characteristics of the muffler were set as an indicator of assessment. The acoustic characteristics were calculated from the sound pressures measured at the entrance and exit of the muffler using the test rig as shown in Fig. 30. The attenuating characteristics are compared to the previous model in Fig. 31. The horizontal axis refers to the frequency, the vertical axis represents attenuation. The red lines refer to this model and the blue lines the previous model.

To enhance deepness of exhaust sounds, it is necessary to emphasize sound pressures in low frequencies under 200 Hz. In the previous model, the construction was of a Helmholtz resonator composed of the connecting pipe that connects the first expansion chamber to the resonance chamber. The resonating frequency (the frequency of high attenuation) was near 150 Hz. Meanwhile in this model, the resonating frequency was set near 350 Hz by applying punched holes having 3 mm diameter and 5 mm pitch to the tube that connects the first expansion chamber to the second expansion chamber in addition to the tube that connects the first expansion chamber to the resonance chamber, thus controlling the attenuation under 200 Hz (green-framed part in Fig. 31). Consequently, the sound pressures in the low frequencies increased from the previous model, contributing

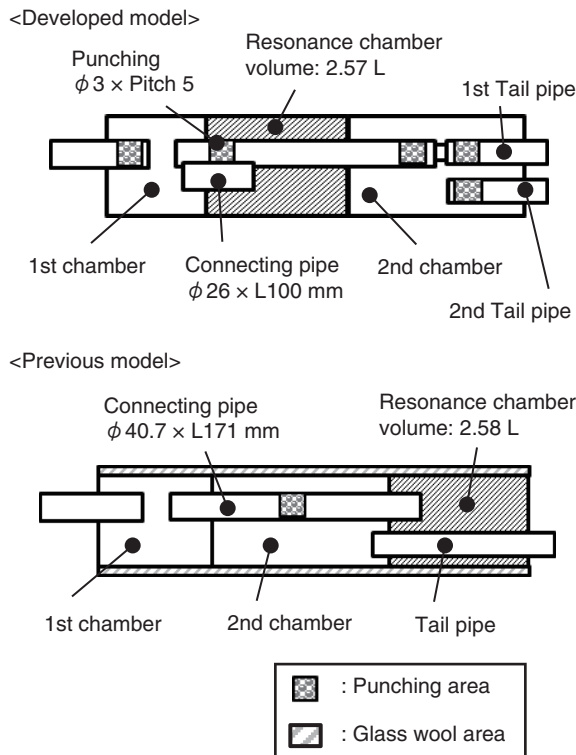


Fig. 29 Comparison of muffler structures

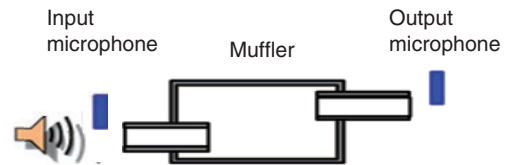


Fig. 30 Schematic diagram of test rig

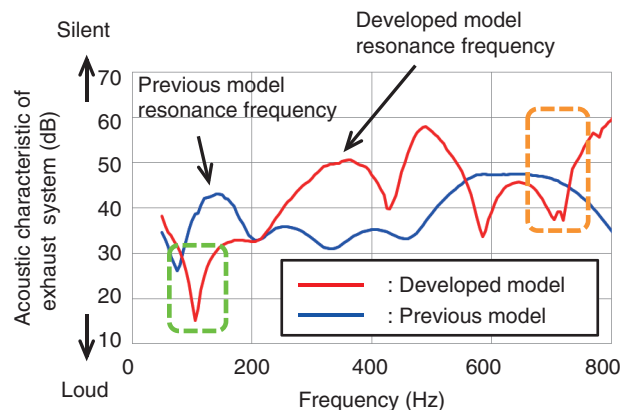


Fig. 31 Acoustic characteristic of exhaust system

to the enhancement of deepness of exhaust sound. Figure 32 shows the graph comparing, between this model and the previous model, the sound pressures in the low frequency band after adopting low pass filter under 200 Hz to the actual exhaust noise measurement results. The horizontal axis shows the engine speed and the vertical axis shows the sound pressure level of 200 Hz or less. It was confirmed that the sound pressure in the low frequency band of this model exceeds that of the previous model, proving the deepness of sound is enhanced at all the engine speed range.

Also, the increased attenuation of high frequency sound (orange-framed part of Fig. 31) permitted elimination of the glass wool in the outer canister applied in the previous model. With these measures taken, 2.1 kg has been reduced from the right and left mufflers.

It is commonly known that people feel pulse feeling when the frequency of sound pressure fluctuation is less than 30 Hz. In a six cylinder engine having evenly split combustion intervals, the frequency of exhaust sound fluctuation is three times per a full turn of the crankshaft (third order). As the frequency becomes higher than 30 Hz when the engine speed is above 600 rpm (10 Hz), the exhaust sounds are heard as continuous and constant. Accordingly in the Gold Wing in which the idle speed is 730 rpm, pulse feeling is usually unattainable.

To deal with the said issue, such an exhaust pipe construction was applied that creates difference in the sound volume by reducing the cross-sectional area of the inner pipe by 20% when compared to other pipes from the entrance of exhaust pipe up to the collector only in No.2 and No.3 cylinders (Fig. 33). It was considered that the amplitude of exhaust sound pressure variation becomes small in the cylinders having a small exhaust pipe diameter, and the sound volume appears as changing once in two full turns of the crankshaft (0.5th order).

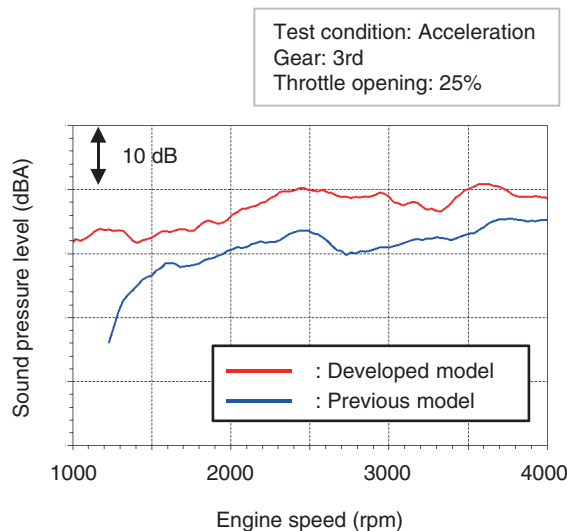


Fig. 32 Sound pressure level (under 200 Hz)

The images of exhaust sound pressure fluctuations at a constant engine speed are shown in Fig. 34. The upper diagram refers to the conventional, equal diameter exhaust pipe. The lower one is of the exhaust pipe having the cross sectional area reduced only in two cylinders.

The exhaust sound pressure level measured from the actual motorcycle is shown in Fig. 35. It can be understood from the data of developed model that the sound pressure fluctuates at the frequency of 0.5th order (16 Hz=0.06 sec interval at 2000 rpm). Meanwhile from the sound pressure data of the previous model, the sound pressure fluctuates at the third order frequency (100 Hz=0.01 sec interval at 2000 rpm). From these data, an enhancement of pulse feeling as

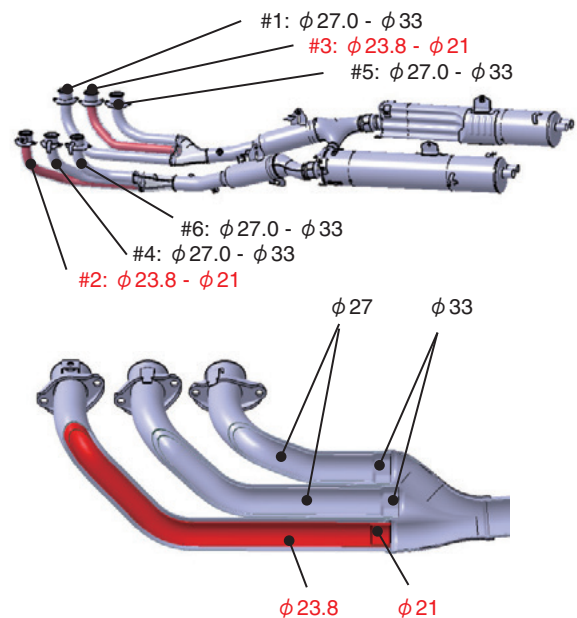


Fig. 33 Configuration of exhaust system

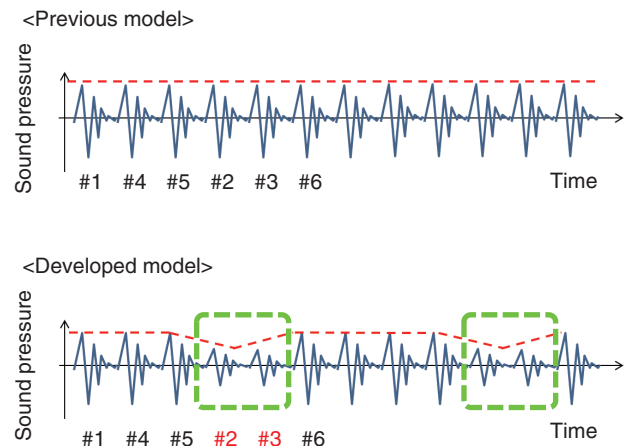


Fig. 34 Comparison of sound pressure waves (image)

intended was confirmed. As the frequency of 0.5th order sound pressure fluctuation stays below 30 Hz up to 3600 rpm, the pulse feeling is attainable in the developed model also at regular engine speeds.

In Fig. 36, the evaluation results of deepness and pulse feeling are shown using the index that Tanaka et al. have defined in their research⁽⁶⁾. Compared to previous model,

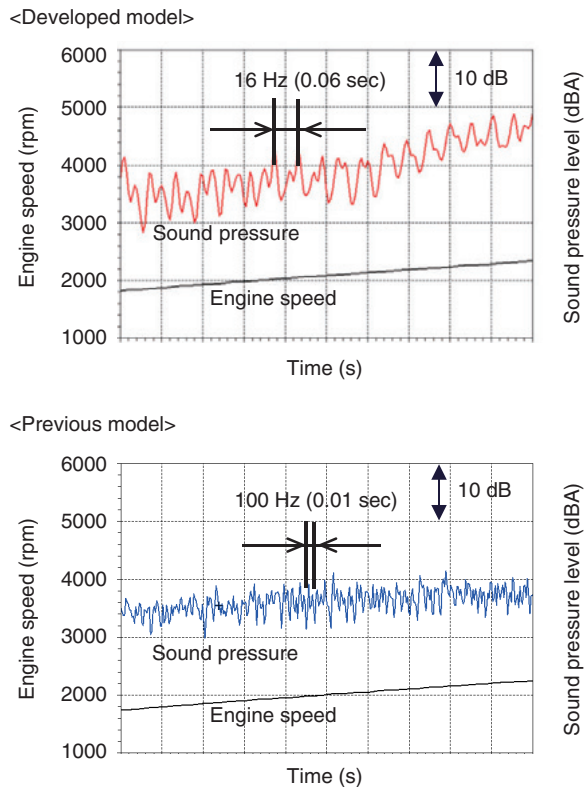


Fig. 35 Comparison of exhaust sound pressure

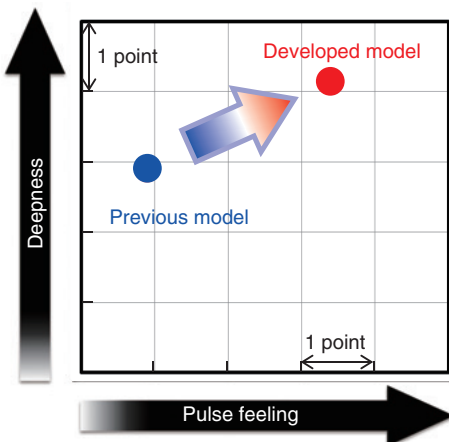


Fig. 36 Quantitative evaluation of exhaust sound

the deepness is enhanced by 1.2 points and the pulse feeling is enhanced by 2.5 points. These results illustrate that the exhaust sound desirable for the new Gold Wing was successfully created.

In addition to the earlier-mentioned muffler weight reduction, the muffler cover was downsized to balance the styling design and the function, allowing reduction of the weight of entire exhaust system by 3.3 kg. With this weight saving added to the earlier-mentioned engine weight, the weight reduction as a power unit is 7.1 kg in the DCT type and 9.5 kg in the MT type.

9. Conclusion

Through the development of the horizontally-opposed six-cylinder power unit for the new Gold Wing upon the concept “smooth yet aggressive at times, light weight and compact flat-six power unit,” the following goals have been achieved.

- (1) In the entire power unit, the weight is reduced by 7.1 kg in DCT type, 9.5 kg in MT type.
- (2) The length from the front of engine to the rear end of the left cylinder head is reduced by 29 mm, reducing the overall length, width and height of the engine for compactness.
- (3) The maximum power output is increased by 6 kW. The output is same or more in the entire engine speed range. Fuel consumption is improved by 24% (in the case of the model sold in Japanese market) in the WMTC mode (class 3-2).
- (4) The enjoyably deep and pulsated exhaust sound was also achieved while offering the mild and high quality sounds of mechanical operations.

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