

Development of 4-stroke Engine for Small Motorcycles with Low Fuel Consumption and High Performance for Use in Brazil

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ABSTRACT

A 4-stroke, 150 cm³ engine that satisfied the low fuel consumption and drivability goals was developed for the Brazilian market. To decrease the fuel consumption compared to the previous model, a tumble-port, and leaner air-fuel ratio were used to obtain a quick burning engine. In order to decrease the engine friction, a thin oil ring and a cam follower with a roller bearing was employed. Engine output at low and middle engine speed was enhanced and a high gear ratio was used to reduce the fuel consumption at the same vehicle speed. As a result, compared to the former 125 cm³ models, the fuel economy at ECE-40 mode was enhanced by 18% despite increasing displacement to 150 cm³. The maximum output was increased by 18%, while the output at low and middle engine speeds was enhanced by 37%. A EURO-2 emissions level was obtained without any devices such as secondary air induction. In addition, vibration was decreased with a primary balancer.

1. Introduction

In recent small motorcycle engines, reduction of fuel consumption and reduction of CO₂ emissions has become an important issue in consideration of the global environment. In Brazil, where 4-stroke engines are mainly used for motorcycles, further improvements in fuel economy are being demanded. Furthermore, the infrastructure, including expressways, is being built, and improvements of driving performance for traveling comfortably are expected.

Recently, an air-cooled 4-stroke 150 cm³ engine has been developed for the Brazilian market. This engine features top fuel economy and power in a 125 to 150 cm³ displacement class and also low emissions and low vibration. The concept

of the previous model, which has been popular in Brazil for many years, has been maintained. This paper describes the technology employed in this engine.

2. Development Goals

The development targets were based on the viewpoints of global energy conservation and environmental protection and the needs of the Brazilian market.

- (1) Reduced fuel consumption: Low fuel consumption that enables the user to readily see the difference between the new model and the previous model and also other manufacturers' models.
- (2) Improved engine performance: Good performance in the

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middle engine speed range, and improved cruising performance on expressways.

- (3) Environmental protection: Realization of emission performance equivalent to the EURO-2 regulation level, though this type of engine is subject to the EURO-1 regulations. (The EURO-1 regulation values are CO/HC/NO_x = 13/3/0.3 g/km, and the EURO-2 regulation values are CO/HC/NO_x = 5.5/1.2/0.3 g/km.)
- (4) Reduced vibration: Realization of pleasant high-speed cruising with reduced vibration due to the application of a primary balancer

3. Outline and Major Specifications of Engine

Figure 1 shows a cutaway model of the newly developed engine, and Table 1 shows the major specifications of the engine. The engine is an OHC 2-valve air-cooled single-cylinder 4-stroke engine, which has a cylinder inclination of 15° to the front. It was developed for the Brazilian market and is designed to run on a general gasoline-ethanol mixture. The main differences from the previous model are as follows.

- (1) The displacement was increased from 124.1 cm³ of the previous model to 149.2 cm³.
- (2) The bore × stroke was increased from the previous value of 56.5 × 49.5 (S/B = 0.88) to 57.3 × 57.8 (S/B = 1.01).
- (3) The valve drive method was changed from the OHV method, which used a push rod, to a chain driven OHC.
- (4) The included valve angle was reduced from 55° to 49°.
- (5) The intake valve diameter was left unchanged at 30 mm, and the exhaust valve diameter was increased from

25 mm to 26 mm.

(6) An oil jet was added to the underside of the piston.

(7) A primary balancer was installed.

4. Technology for Improving Engine Output, Fuel Economy and Emission

4.1. Engine Output

Figure 2 shows the engine performance curves. The output per unit displacement is the same, compared to the previous model, but the maximum output has been improved by 18%. Also, the output in the targeted middle engine speed range was improved by 37%. A higher torque compared to that of the previous model was obtained over the entire engine speed range including the low speed range, and the maximum torque was improved by 24%.

4.2. Tumble Port

Generally, when the mixture-flow in the cylinder is strengthened⁽¹⁾ in order to realize rapid combustion and the ability to run on a leaner mixture for improving fuel economy, the steady-flow performance of the port decreases. However, in order to realize both good fuel economy and



Fig. 1 Cutaway model of developed engine

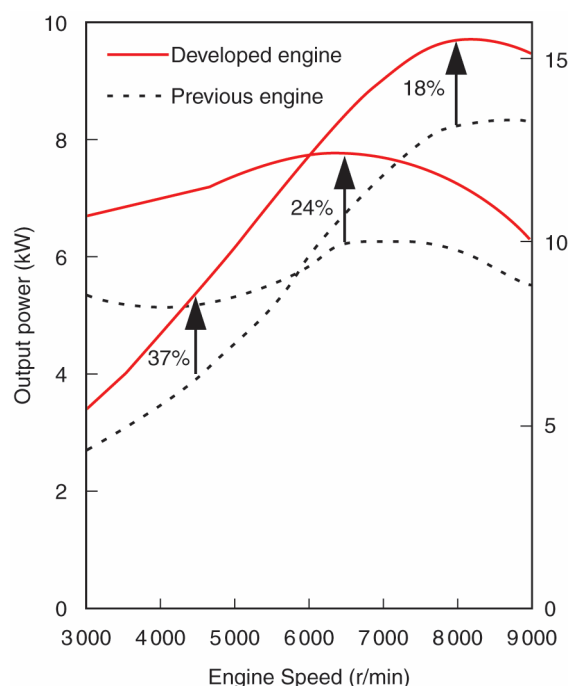


Fig. 2 Output engine performance

Table 1 Major specifications of engines

Items	Developed engine	Previous engine
Engine type	4-stroke, single-cylinder	4-stroke, single-cylinder
Displacement (cm ³)	149.2	124.1
Bore × Stroke (mm)	57.3 × 57.8	56.5 × 49.5
Compression ratio	9.5	9.2
Valve train	SOHC 2-valves	SOHC 2-valves
Valve diameter (mm)	IN 30, EX 26	IN 30, EX 25
Included valve angle (deg)	49	55
Balancer shaft	Applied	—
Transmission	5 speed constant mesh	5 speed constant mesh

power performance, it is necessary to secure high steady-flow performance at the port while generating a mixture-flow. In order to satisfy both of these requirements, a tumble port of the type shown in Fig. 3 was used as the intake port to optimize the tumble and thereby realize both tumble intensity and steady-flow performance. Figure 4 shows the shape of the intake port of the developed engine.

In order to predict and satisfy both the tumble intensity and steady-flow performance of the intake port, CFD simulation of port steady-flow was performed from an early stage of development, and the tumble was optimized. In the case of the developed engine, a study was performed with the aim of raising the tumble ratio as far as possible while maintaining the same steady-flow performance as that of the conventional port shape. Figure 5 shows the simulation results. It was found that the intake port adopted produced an increase in the blow-off flow velocity. The blow-off flow is passing through the upper part of the intake valve and flowing into the cylinder along the cylinder wall face, and

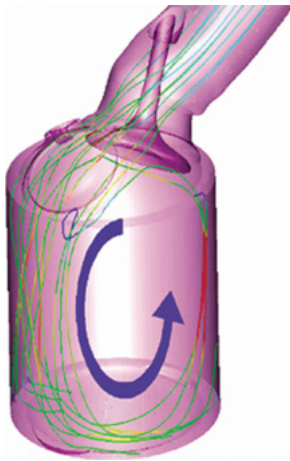


Fig. 3 Tumble flow

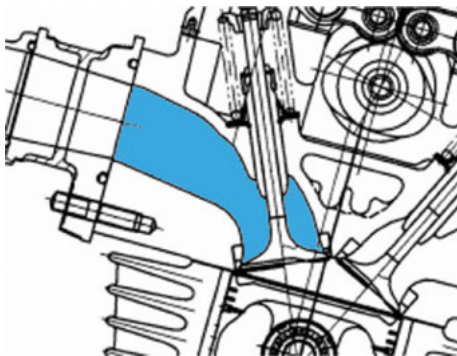


Fig. 4 Shape of intake port

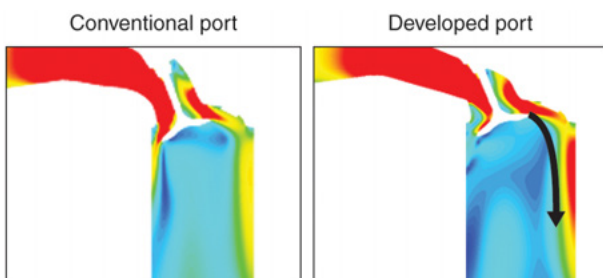


Fig. 5 Simulation result of intake port

becomes the cause⁽²⁾ of generation of tumble. At the intake port in which the tumble ratio and the steady-flow performance were optimized based on the simulation, it was possible to make the effective valve-opening area (Z) of the intake port the same as that of the previous model, as shown in Fig. 6. The percentage of fluctuations in combustion for constant speed running at 60 Km/h is shown in Fig. 7. By using a tumble intake port, it enables a leaner setting of two points on an air-fuel mixture compared to that of the previous model.

Also, in order to cope with rapid combustion, the crankshaft support rigidity was improved by using a roller bearing for the right journal bearing, as shown in Fig. 8. In the developed engine, the use of rapid combustion results in a maximum pressure increase rate ($dp/d\theta$) of 1.6 times compared with the previous model. Increase of engine noises was a concern, but the noise on rider's ears was reduced by 70% by using roller bearings compared with the ball bearing model.

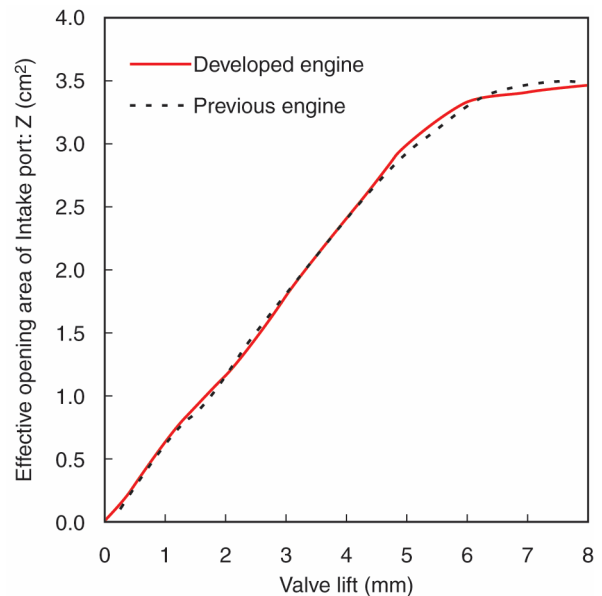


Fig. 6 Comparison of effective valve-opening area of intake port

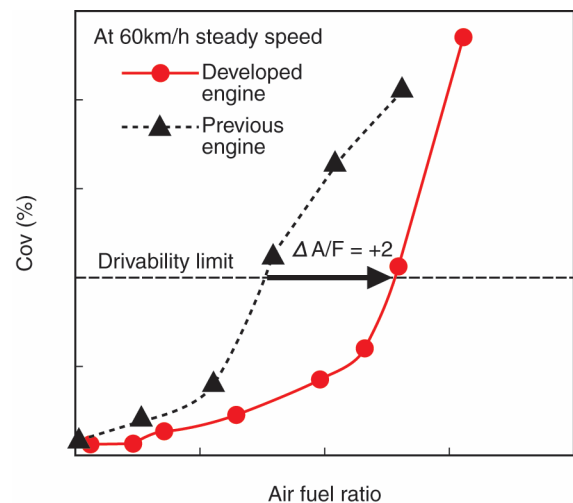


Fig. 7 COV(IMEP) at 60km/h steady speed

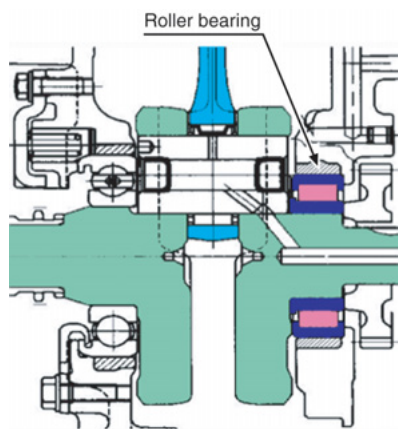


Fig. 8 Section drawing of main bearing

4.3. Compact Combustion Chamber

The bore was increased from 56.5 mm to 57.3 mm, and the valve included angle was reduced from 55° to 49° to permit a more compact combustion chamber. The combustion chamber as shown in Fig. 9 was designed by making the cylinder head hemispherical and also by making the dent on piston head like a cavity. As a result, the S/V ratio was improved by 8% compared to that of the previous model, despite the increase in the bore.

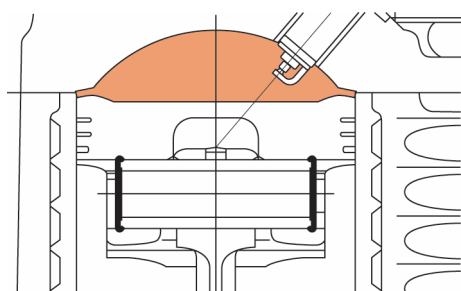


Fig. 9 Spherical combustion chamber

4.4. Improved Cooling Performance

In order to improve the anti-knocking performance of the engine, a T-shaped air jacket with cooling fins that branched toward the plug seat and also toward the rear of engine was employed. Figure 10 shows the cross-sectional diagram of the air jacket.

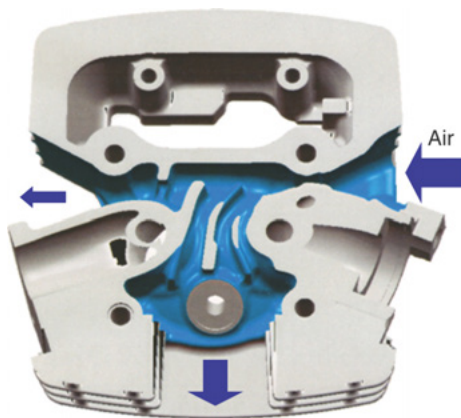


Fig. 10 Air jacket section view

Also, in order to actively oil-cool the back of the piston crown, a dedicated oil jet was arranged in the proximity of the journal, as shown in Fig. 11, in addition to the conventional oil spray from the big end thrust face of connecting rod. As a result, the maximum temperature of the piston was reduced by 10 °C.

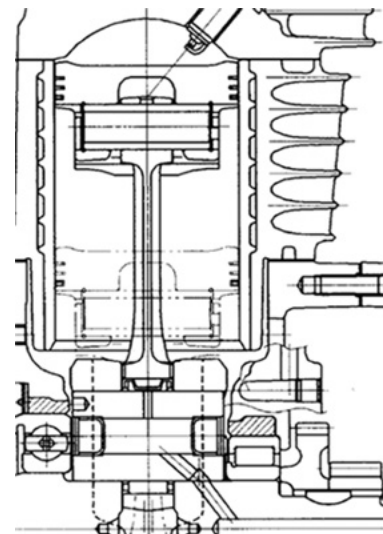


Fig. 11 Oil jet to piston

4.5. Offset Cylinder

In order to reduce friction due to pressure on the piston side in the low and middle engine speed range, an offset cylinder structure was used. As shown in Fig. 12, the center of the cylinder was offset 4 mm to the exhaust port from the center of crankshaft.

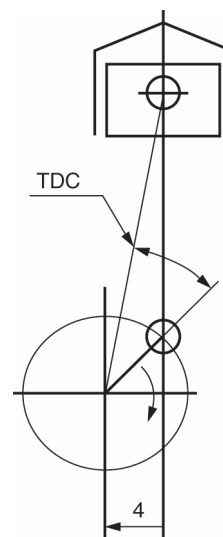


Fig. 12 Offset cylinder

4.6. Valve Drive System

In order to realize good fuel economy and power, the camshaft drive train system was changed from OHV to OHC. The OHV system of the previous model was used in the Brazilian market over a long period of time. The OHC system reduces friction and the equivalent mass of the valve train. Also, a rocker arm⁽³⁾ having a roller follower was employed in order to reduce the sliding resistance between the rocker arm and the cam profile face.

4.7. Reduction of Friction and Mass of the Piston

As shown in Fig. 13, the entire surface of the piston was tin-plated and also the piston skirt was striated⁽³⁾ in order to reduce the friction of the piston. Furthermore, in order to reduce the sliding resistance of the piston rings, the thickness of the oil ring was reduced from 2.0 mm of the previous model to 1.5 mm, resulting in a reduction of oil ring tension of 15% compared to that of the previous model. In addition, the overall height of the piston was shortened 3.3 mm and the profile was changed in order to reduce the mass of the piston. As a result, the bore was widened from 56.5 mm to 57.3 mm, but the complete piston assembly mass (mass of the piston with piston rings and piston pins) was reduced by 4%.

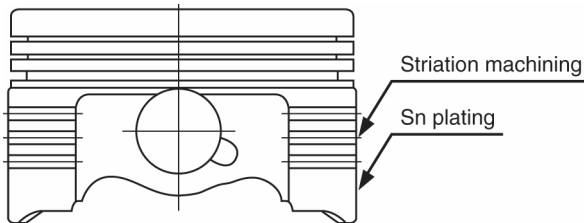


Fig. 13 Developed piston

4.8. Reduction of Fuel Consumption at the Same Vehicle Speed due to the Change in the Reduction Gear Ratio

In order to reduce friction by lowering the engine speed for the same vehicle speed, the low and middle engine speed characteristics were enhanced by increasing displacement and adopting a longer stroke. In addition, the reduction gear ratio was set on the low side, resulting in a 17% reduction of fuel consumption for 60 km/h steady speed running. Figure 14 shows the BSFC for 60 km/h steady speed running.

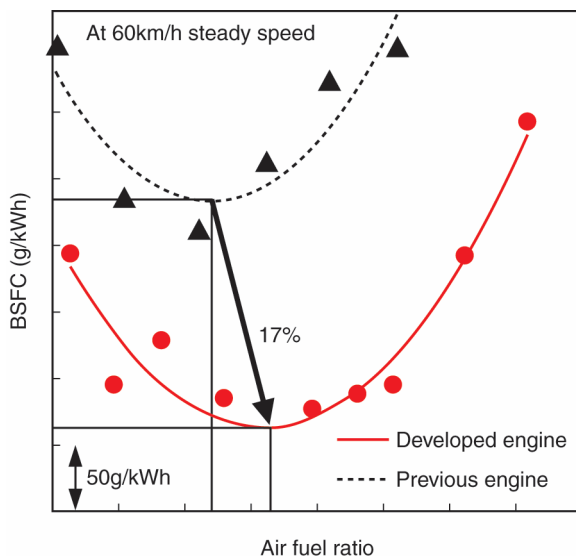


Fig. 14 BSFC at 60 km/h steady speed

5. Effectiveness of Fuel Economy Improvement and Emission Reduction

5.1. Effectiveness of Combustion Improvement

As a result of the combustion improvement mentioned in the previous chapter, the Pmi was improved by up to about 10% compared to that of the previous model, as shown in Fig. 15.

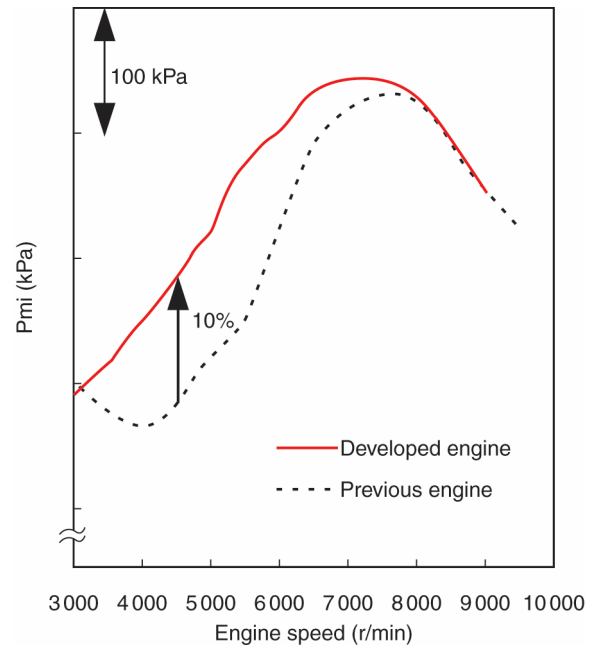


Fig. 15 Result of Pmi

5.2. Effectiveness of Friction Reduction

As a result of the adoption of friction reduction technology mentioned in the previous chapter, the Pmf in the middle engine speed range was reduced by 13% compared to that of the previous model, as shown in Fig. 16.

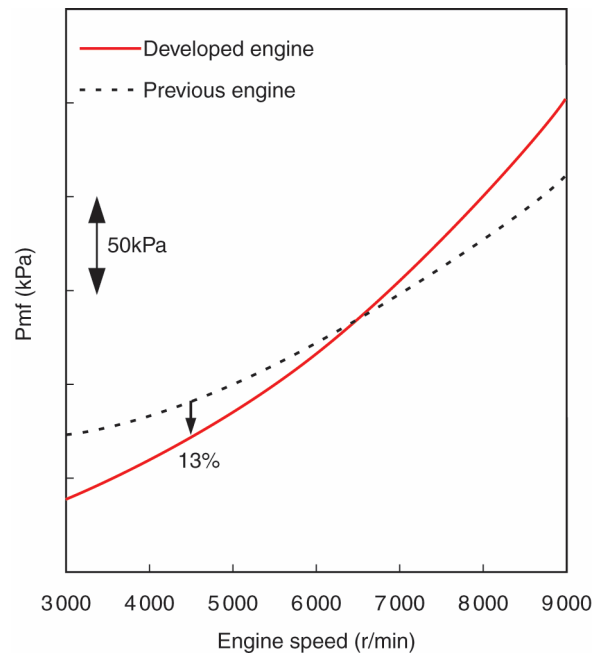


Fig. 16 Result of Pmf

5.3. Effectiveness of Fuel Economy Improvement and Emission Reduction

As a result of combustion improvement, friction reduction of each part, and the change of the reduction gear ratio due to improved engine output at low and middle engine speeds, the fuel consumption in the ECE-40 mode was improved by 18% compared to the previous model. Figure 17 shows the measured value of the fuel consumption in the ECE-40 mode. As shown in Fig. 18, the emissions decreased to the EURO-2 regulation level without applying a secondary air induction system or a three-way catalyst.

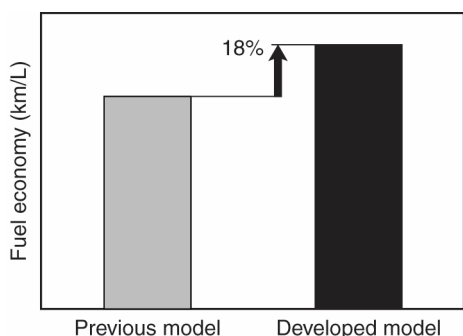


Fig. 17 Result of fuel economy in ECE-40 mode

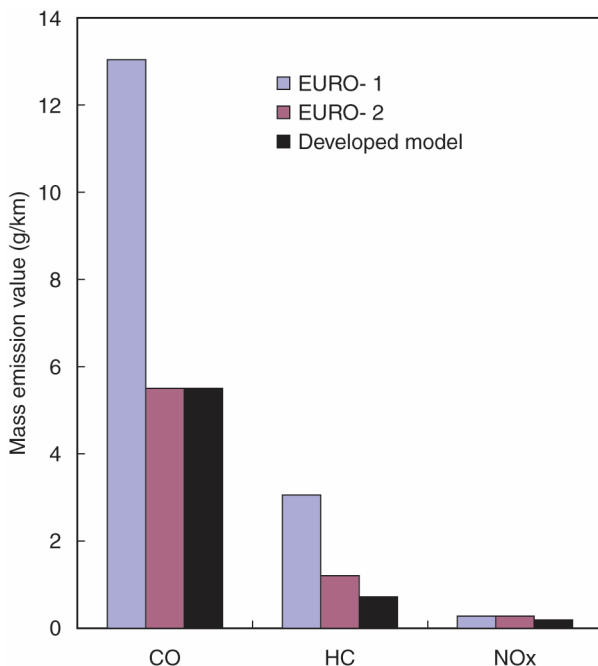


Fig. 18 Result of mass emission

6. Vibration Reduction Technology

6.1. Primary Balancer

Along with the increase in displacement, the primary balancer shown in Fig. 19 was used as a method of reducing engine vibration. As a result, the primary engine vibration of the frame head pipe was reduced about 1/2 that of the previous model.

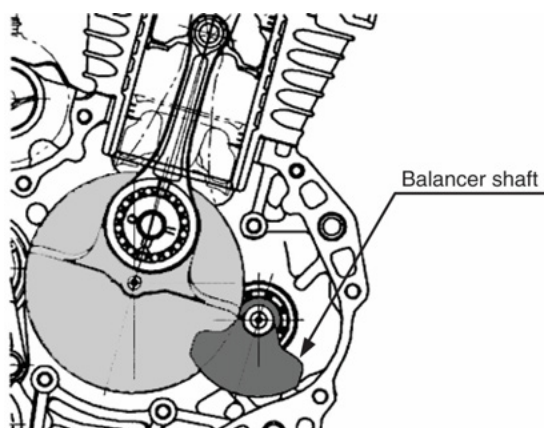


Fig. 19 Side view of balancer shaft

7. Conclusion

The combustion improvement, friction reduction, and vibration reduction technology led to the following results with the newly developed air-cooled 4-stroke 150 cm³ engine.

- (1) The fuel economy in the ECE-40 mode was improved by 18% compared to that of the previous model.
- (2) The output per unit displacement was the same as that of the previous model, and the maximum output was improved by 18%. The output in the middle engine speed range which is the target range was improved by 37%.
- (3) The emission decreased to the EURO-2 regulation level without applying special devices.
- (4) The use of a primary balancer realized the lowest level of riding vibration for this class of motorcycle.

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