

Development of a Closed Crankcase System Engine for Motorcycles

Osamu KUDO*

Yasuo SHIMURA*

Koji TERADA*

Nobuaki INUMARU*

ABSTRACT

A compact and lightweight single cylinder engine was developed for the off-road motorcycle XR650R. The engine features a closed crankcase. This engine system addresses the issue of deteriorated oil discharge prevention performance caused by pressure fluctuations in the crankcase, an issue common to single piston, large displacement engines. A construction was adopted whereby a bulkhead divides the crank chamber and the transmission chamber housed in the same housing. The pressure generated by the reciprocating motion of the piston discharges the engine oil to the transmission chamber. As a result, the pressure fluctuations in the transmission chamber were reduced, and, subsequently, so was the amount of blow-by gas discharge. Further, it was possible to reduce the breather chamber volume to 1/5 that of a conventional engine. Moreover, effects from reduced engine weight and friction loss were obtained.

1. Introduction

The strong demand for a lightweight, compact engine in our XR series off-road sports motorcycles has resulted in all models in this series being equipped with single-cylinder engines having a displacement in the range from 50 to 600 cm³. A single-cylinder engine requires a large-volume breather chamber to avoid oil discharge via the crankcase breather that is caused by large pressure fluctuations inside the crankcase. There is also a friction loss by oil agitation due to the wide variations in oil level inside the engine.

Four-stroke engines are typically provided with a deep oil pan under the crankshaft to reduce this oil agitation loss and to provide an oil level that does not result in immersion of the crankshaft in oil. However, large-displacement off-road motorcycles require a high minimum ground clearance beneath the engine, which must also be mounted as low as possible in the frame, thus precluding the use of a deep oil pan. This brings back the issue of oil friction loss.

We have addressed these issues during the course of implementing a full model change for the XR600R, the motorcycle in this series having the largest engine displacement, by developing a new engine with a sealed crankcase. The fluctuations in crankcase pressure that are caused by the reciprocating motion of the piston are accommodated within the crank chamber, rather than being transferred to the transmission chamber, due to the use of a sealed bulkhead between the two chambers. This new engine is used in the XR650R model, and this new system is called a closed crankcase system.

2. Engine Overview

The two objectives that had to be achieved in the

development of the XR650R were as follows:

- High torque at low engine speeds and high power at high engine speeds
- A significant reduction in engine weight over the previous model

These objectives were achieved by increasing the displacement by 50 cm³ to improve the torque characteristics at low engine speeds, while the change from air cooling to water cooling and an increased compression ratio improved the power output at high engine speeds. The issue of breather performance is usually encountered when attempting to increase engine displacement. The closed crankcase system was employed to address this issue. The shape and material of every engine part was reviewed with the objective of

Table 1 Engine specifications

Model	XR650R	XR600R
Engine stroke	4-stroke	4-stroke
Number of cylinder	1	1
Cooling system	Liquid-cooled	Air-cooled
Lubricating system	Dry sump	Dry sump
Bore × Stroke (mm)	100 × 82.6	97 × 80
Displacement (cm ³)	649	591
Compression ratio	10.0	9.0
Maximum engine output (kW/ r/min)	41/6750	31/6500
Maximum torque (Nm/ r/min)	64/5500	52/5000
Valve train	SOHC 4-valve	SOHC 4-valveRFVC
Fuel supply system	Carburetor	Carburetor
Engine dry weight (kg)	40	45
Crank case	Closed	Conventional

* Asaka R&D Center

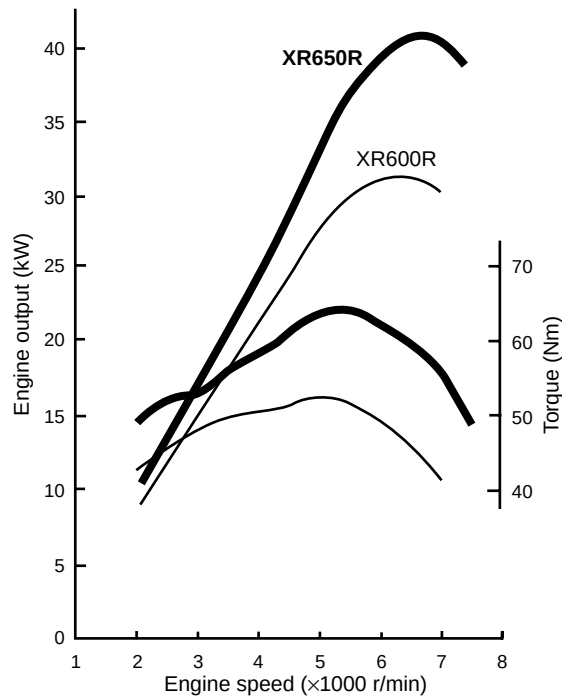


Fig.1 Engine performance curve

reducing engine weight, and a closed deck-type aluminum alloy cylinder with a nickel-cadmium-zirconium-plated bore was adopted. These changes have increased the maximum power output by about 30%, improved the low-speed torque by about 13%, and reduced the engine dry weight by about 5 kg. Even when such added parts as the water cooling radiator are included, a weight reduction of about 1 kg has

been achieved. The engine specifications are shown in Table 1, while the output characteristics are shown in Fig.1.

3. Improvement of the Breather Performance

The oil discharge prevention performance of the breather (breather performance) in a single-cylinder engine can be improved by enlarging the breather chamber or increasing the volume of the crankcase. However, both of these methods conflict with the need to reduce engine weight and size. Typical concerns that can be encountered when applying a method to separate the crank chamber and transmission chamber include crank chamber lubrication oil processing, and the effect on pressure loss inside the closed crank chamber. This method, however, is advantageous in terms of reducing the overall size of the engine. In addition, just as pumping loss is minimal for the deactivated cylinder in engines that stop operation when the intake valve and exhaust valve are closed and that have a variable number of cylinders⁽¹⁾, so is the pumping loss that occurs in a closed crank chamber. A comparative study was therefore conducted on the following concern items:

- (1) Function and settings
 - Oil discharge function
 - Pumping loss
 - Transmission chamber pressure
 - Amount of oil supplied to the crank chamber
- (2) Effects
 - Breather performance
 - Scavenging performance
 - Friction loss

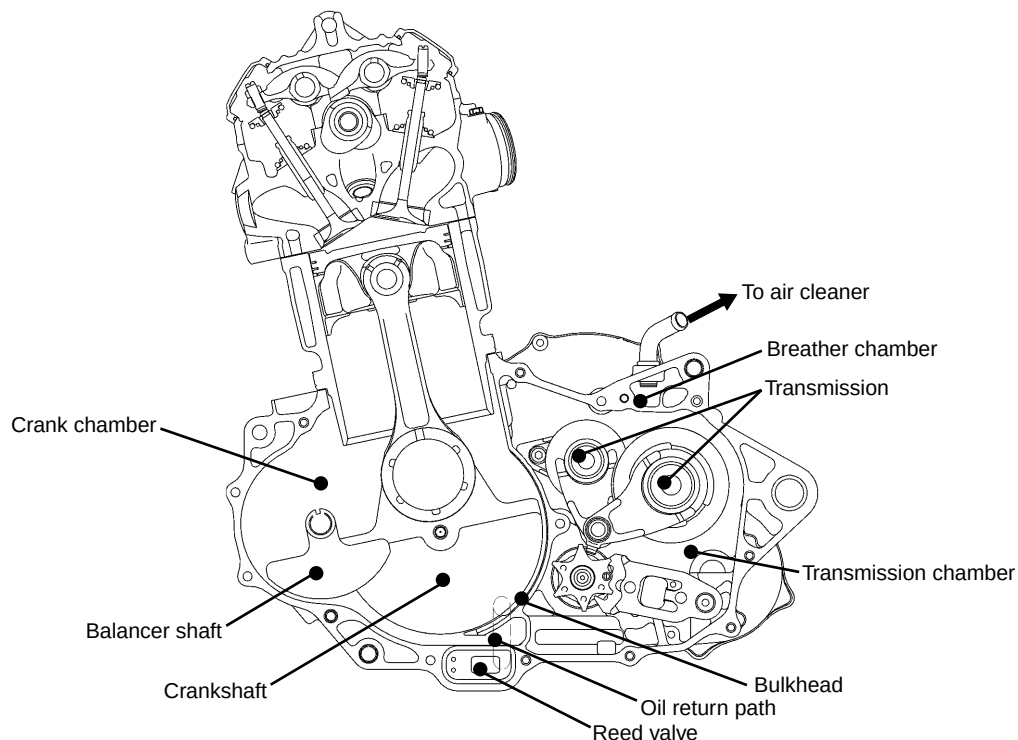


Fig.2 Section of closed crankcase

4. Construction and Action of the Closed Crankcase System

4.1. Construction

A typical motorcycle engine has the crankshaft and transmission housed within a single crankcase and lubricated with the same oil. As shown in Fig.2, the closed crankcase system (subsequently referred to as the closed type) is characterized by having the crank chamber and transmission chamber separated by a bulkhead with no pressure leakage between them. The crankshaft and primary balancer are arranged inside the crank chamber, and a bulkhead to separate the crank chamber from the transmission chamber is provided around the outside of the crank weight. An oil seal is fitted on the outside of the crankshaft bearing to maintain pressure tightness within the crank chamber.

Oil is pumped to lubricate the connecting rod big end and crankshaft bearings, and the piston is cooled by spraying oil on its underside. The oil that flows into the crank chamber is discharged into the transmission chamber from a discharge port provided beneath the bulkhead through a reed-operated check valve. A breather chamber is provided above the transmission chamber, and after condensing the oil, the blow-by gas is directed to the air cleaner.

4.2. Oil Return System

A schematic diagram of the oil return system is shown in Fig.3. During the time the piston is rising as shown in (A), a negative pressure is generated in the crank chamber, and the reed valve closes to prevent the return flow of oil and air from the transmission chamber. During the time the piston is falling as shown in (B), the crank chamber volume decreases and the pressure increases. The reed valve is opened by this pressure, allowing the oil that has flowed into the crank chamber to be returned to the transmission chamber.

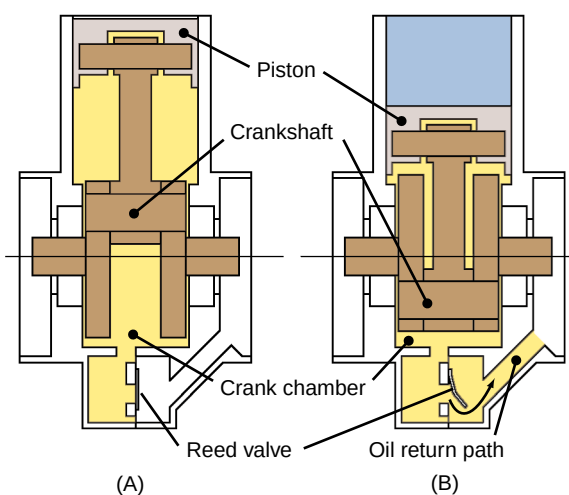


Fig.3 Schematic drawing of oil return action

4.3. Pumping Loss

Although the crank chamber is closed, it is still necessary for the oil that has been supplied to the crank chamber to be

returned to the transmission chamber. The pressures within the crank chamber and transmission chamber, and the opening and closing of the reed valve when the engine is running are shown in Fig.4.

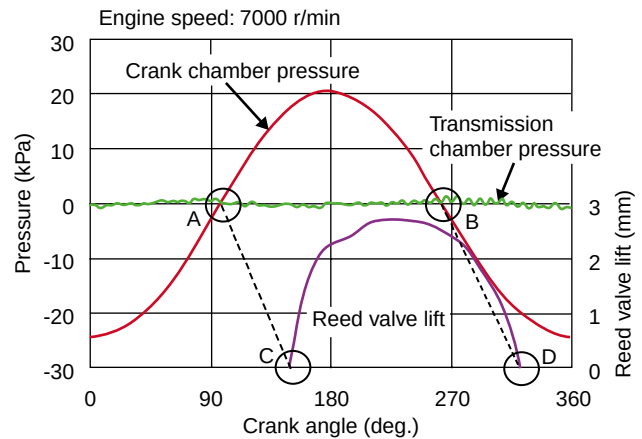


Fig.4 Pressure in crank chamber and reed valve lift

The pressure within the crank chamber exceeds that in the transmission chamber between the crank angles of 95° and 265° (A-B). This difference in pressure provides the pumping action to return the oil in the crank chamber to the transmission chamber. However, there is a time delay in the opening and closing of the reed valve with respect to the changes in pressure (A-C, B-D). The reason for this delay is believed to be the viscosity and inertia of the oil. Consequently, there is a potential concern of the back flow of oil and air into the crank chamber between the crank angles of 265° and 320° (B-D) when the pressure in the transmission chamber is higher than that in the crank chamber and the reed valve is open.

A study was made of the pumping loss that occurs in the crank chamber to identify the effects of this back flow. Supplied lubricant oil and blow-by gas that passes the piston rings flow into the crank chamber. Their combined volume is only several cm^3 for each revolution of the crankshaft, making it extremely small relative to the swept volume. Consequently, if an amount is discharged that is equivalent to the volume flowing in with each cycle, there would be hardly any change in the amounts of oil and air in the crank chamber, resulting in an extremely low pumping loss. However, as the degree of back flow increases, an excessive volume is pumped, and this is thought to contribute to an increased pumping loss. Fig.5 shows a P-V diagram for the crank chamber, with the crankcase volume indicated on the horizontal axis. For the sake of comparison, an engine was constructed without the bulkhead between the crank chamber and transmission chamber (subsequently referred to as the conventional engine type), and the same measurements were performed on that engine.

The pumping loss in the crank chamber is represented by the hatched area that is bounded by the P-V plots during the compression and expansion strokes. In contrast to the pressure difference that occurs between the compression stroke and expansion stroke in the conventional engine, no

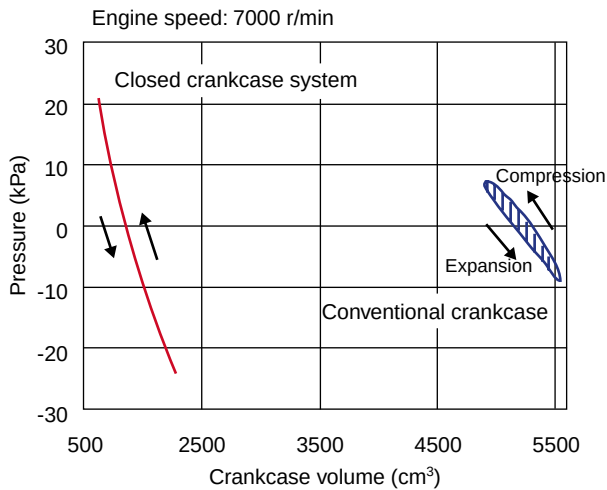


Fig.5 P-V diagram of crankcase

such pressure difference exists in the closed crankcase system engine. The pumping loss in the conventional engine is due to a cycle in which air is taken in from outside the engine when the piston rises, and then discharged with the blow-by gas when the piston falls. In contrast, there is hardly any risk of back flow from the oil discharge port in the closed crankcase system engine and, since the combined volume pumped from the crank chamber to the transmission chamber is low, the pumping loss was confirmed to be low.

4.4. Reduced Pressure Fluctuations in the Transmission Chamber

Since a very low volume is pumped between the crank chamber and transmission chamber, there were lower pressure fluctuations in the transmission chamber than that in the conventional engine. These results are shown in Fig.6. In this way, the pressure fluctuations in the crankcase of a single-cylinder engine that result from the reciprocating motion of the piston were limited to the crank chamber only. This effect was confirmed in the closed crankcase system engine as no pressure fluctuations were transferred to the

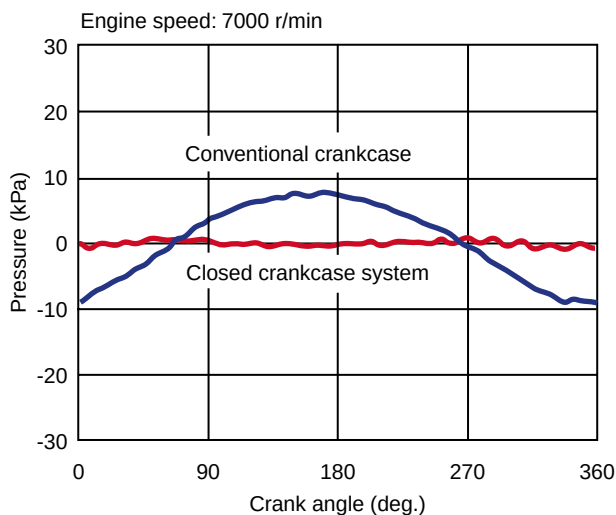


Fig.6 Comparison of transmission chamber pressure

transmission chamber. As a result of verifying the effects of engine operating conditions on pressure fluctuations, it was found that there were no differences between the intake, compression, expansion and exhaust strokes, or due to differences in engine load. Further, we verified that there were no differences between firing and motoring conditions.

4.5. Oil Feed Volume

Since oil agitation loss caused by the crankshaft tends to increase as the amount of oil fed in to the crank chamber is increased, a study was conducted to determine the optimum oil feed volume. In the case of a conventional engine, oil is pumped to the connecting rod big end, and the oil splashed from the big end is then used to cool the piston. Therefore, there is the possibility that the oil supplied could exceed the required volume for both applications. After providing a piston cooling jet to evaluate the minimum amount of oil required for both the big end bearing and for piston cooling, we modified the lubrication system. We determined the required volume of oil fed into the crank chamber to make the crank pin and piston temperatures comparable to those in the conventional engine, and thereby reduced the total feed volume by 52% as shown in Fig.7.

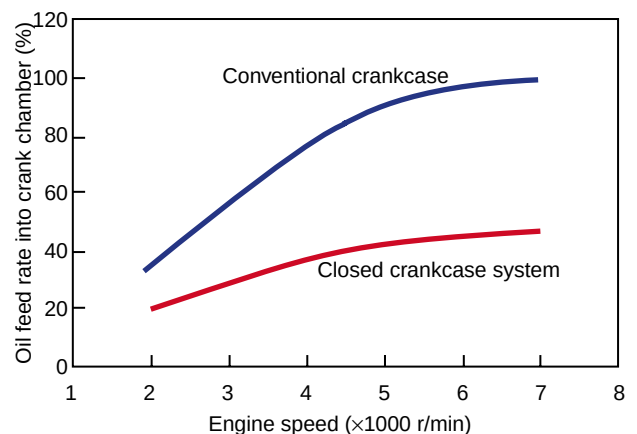


Fig.7 Oil feed rate into crank chamber

5. Closed Crankcase System Engine Performance

The performance of the closed crankcase system engine was evaluated against a conventional engine without the bulkhead between the crank chamber and transmission chamber.

5.1. Improved of Breather Performance

Since the closed crankcase system engine produced a lower pressure fluctuation in the transmission chamber, a small breather chamber with a volume in the order of 60 cm³ situated at the top of the transmission chamber was able to achieve adequate performance. In a comparative test, oil was discharged from the conventional engine when it was fitted with this small-volume breather as a result of the breathing circuit being closed. Therefore a larger breather was necessary. The breather chamber volume in the

XR600R, the previous model employing a conventional breather, was 330 cm³. This is roughly five times larger than that needed in the closed crankcase system engine of the XR650R. These figures indicate how the closed crankcase system contributed to crankcase size reduction. A comparison between the breather chambers is shown in Fig.8.

5.2. Improved Scavenging Performance of the Dry Sump System

The XR650R employs a dry sump lubrication system. An oil outlet port is provided in the base of the transmission chamber to discharge oil into an external oil tank situated within the main frame through a scavenging pump. The reduction in pressure fluctuations in the crank chamber and enhanced stability of the transmission chamber affected the scavenging performance. Since a dry sump lubrication system involves pumping oil under pressure from the external oil tank to each part of the engine, it is necessary to stabilize the oil level in the tank. The closed crankcase system engine, with its small fluctuations transmission chamber pressure, maintained a stable oil level on the outlet side when the engine was running. Further, the amount of oil that could be drawn up into the external tank was greater than that in a conventional engine. As a result, the volume of on-board oil could be decreased to 300 cm³ leading to a consequent reduction in vehicle weight. The amount of oil in the external tank with the engine running for a total oil volume of 2000 cm³ is shown in Fig.9.

5.3. Reduced Friction Loss

A comparison of the friction loss is shown in Fig.10. The friction loss mean effective pressure (Pmf) is represented on the vertical axis, and the pumping loss of the crank chamber is also shown as represented by mean effective pressure (defined as PmfP*). There are two reasons for the decrease in friction loss resulting from the closed crankcase system engine: the first is the lower pumping loss in the crank chamber as previously mentioned, and the second is the lower oil agitation loss.

In a conventional crankcase, PmfP* increases due to the movement of large volumes of air at the blow-by discharge port accompanying the reciprocating motion of the piston. In the closed crankcase system, however, PmfP* is low since no back-flow occurs to accompany the discharge of oil from the crank chamber. In addition, the oil level in a conventional

engine rises due to deteriorated dry sump scavenging performance. Pressure fluctuations also increase and, since the oil level changes, there is considerable friction loss by oil agitation. In the closed crankcase system, in addition to optimizing the oil volume, a long oil scraper that protrudes over the crankcase along the crank weight is provided as shown in Fig.11. In addition, after optimizing the clearance for the crank weight, various configuration related methods

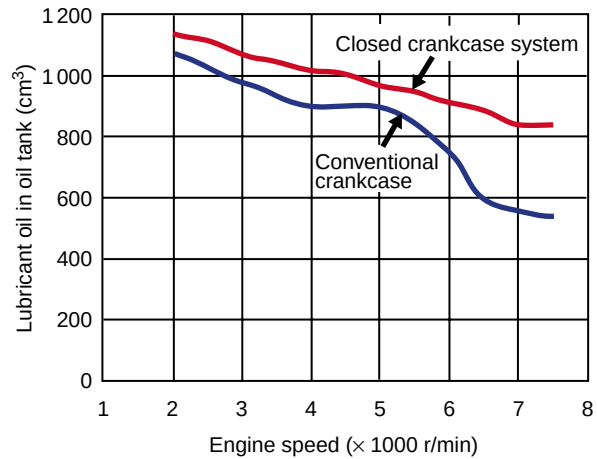


Fig.9 Lubricant oil in oil tank

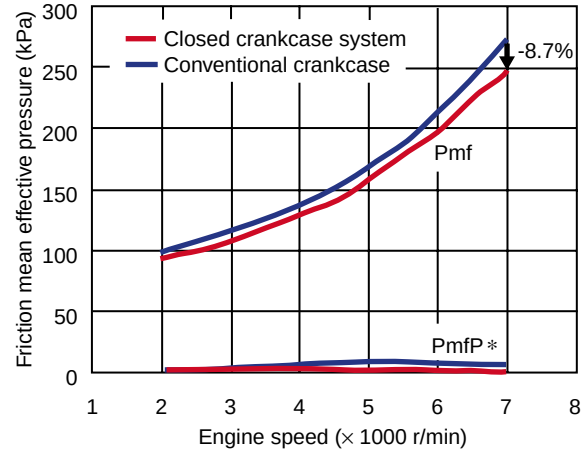


Fig.10 Friction mean effective pressure

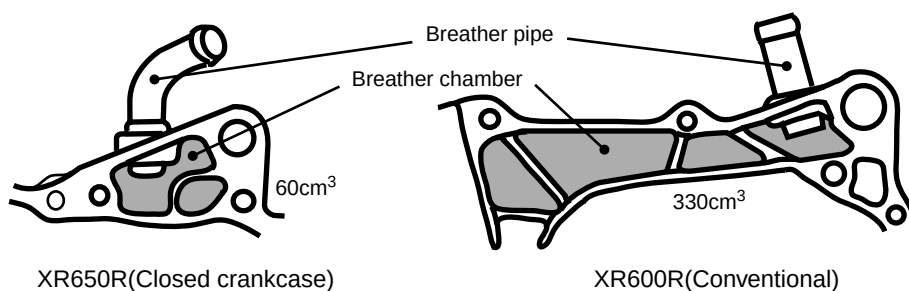


Fig.8 Comparison of breather chamber volume

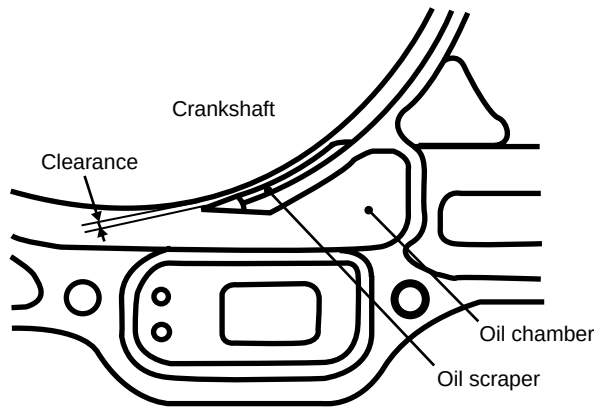


Fig.11 Detail drawing of sump part

to decrease friction loss by oil agitation were investigated including the temporary accumulation of oil in a rear oil chamber. The overall effect was to reduce the friction loss by 8.7% at an engine speed of 7000 rpm, resulting from a reduction in the pumping loss of 2.0% and a reduction in the agitation loss of 6.7%.

6. Conclusion

A closed crankcase system was devised, by which the crank chamber and transmission chamber are separated, in a 650 cm³ single-cylinder engine for use in off-road motorcycles. This system prevents the crankcase pressure fluctuations that are characteristic of a single-cylinder engine from being transferred outside the crank chamber, thereby resulting in the following advantages:

- (1) The breathing performance and scavenging performance, when applying a dry sump lubrication system, were both improved due to the reduced pressure fluctuations in the transmission chamber. This enabled the volume of the breather chamber to be reduced by 80% in comparison with the previous model, and the on-board oil volume to be reduced by 300 cm³. Both of these factors contributed to a reduced engine weight.
- (2) The friction loss by oil agitation was decreased by optimizing the lubricating oil volume, the shape of the sump part, and by stabilizing the oil level in the engine. In addition, the pumping loss due to oil being discharged from the crank chamber was reduced to a level lower than that of a conventional engine in which there is extensive movement of air at the blow-by gas discharge port. These factors combined to reduce friction loss by 8.7% at an engine speed of 7000 rpm.

References

- (1) Hatano,K., Iida,K., Higashi,H., Murata,S.: Development of A New Variable Engine Displacement and Valve Timing System, Proc. of JSAE No.924, Vol.1, p.37-40(1992) (Written in Japanese)

■ author ■



Osamu KUDO



Yasuo SHIMURA



Koji TERADA



Nobuaki INUMARU