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MEASUREMENT OF AXIAL MOTIONS OF PISTON RINGS IN A TWO-STROKE ENGINE BY USING BACK LIGHT OF LED

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Abstract

In two-stroke engines of the crankcase-compression type, the piston rings slide over not only the cylinder wall but also the cylinder ports. It is important for piston ring designers to understand how piston rings behave over cylinder ports. In order to clarify the axial motion of piston rings in two-stroke engines, we established a measurement method using light-emitting diodes (LEDs). We attached LEDs inside the piston, and leaked the backlight of LEDs through the side clearance between the piston ring side face and the piston ring groove side face. From the position of the leaked backlight in the piston ring groove, we determined the axial ring position in the ring groove. Our experiments set this piston with LEDs in an experimental two-stroke engine with a transparent cylinder, and investigated the effects of intake and exhaust ports on axial ring motion under motoring operations. Results indicated that the rings moved in the axial direction by the ring projection and catching in the intake and exhaust ports.

Keywords: *two-stroke engine, piston ring, cylinder port, axial motion of piston ring, LED, transparent cylinder*

1. Introduction

Compared to four-stroke engines, two-stroke engines of the crankcase-compression type enjoy simpler construction, employing fewer parts. These two-stroke engines are widely used in outboards, snowmobiles, chainsaws, and bush cutters. Recently, these two-stroke engines have been projected as range extenders of electric vehicles [1, 2]. Their piston rings slide over, not only the cylinder wall but also the intake, scavenging, and exhaust ports. Therefore, scuffing may occur on the piston rings, as they slide over the cylinder ports, possibly disrupting the oil film on the rings. Rings may also project and catch in the cylinder ports. In order to improve the durability of the rings, it is necessary to design the rings considering their behaviour when the rings pass over the ports. Several studies have reported on axial ring motions, measured with gap sensors of electrostatic capacitance [3] or the eddy current [4] embedded in the piston ring grooves in four-stroke engines. As far as we know, the only reports on the ring behaviour of two-stroke engines have been our reports on the ring projection and catching in the ports, measured by strain gauges installed on the bottom sides of rings over the intake and exhaust ports [5, 6], and the ring behaviour in the radial and axial directions measured by gap sensors of the eddy current mounted in the ring groove [7, 8]. Recently there has been a report observing the axial behaviour of the rings in a four-stroke engine, measured by the backlight of a light-emitting diode (LED) [9]. However, there has been no report on how to mount LEDs on the piston and how to observe the ring behaviour. LEDs are less expensive than gap sensors measuring electrostatic capacitance or eddy current. Therefore, we expect the observation of the axial ring behaviour with LEDs will come into common use, as soon as measurement methods using LEDs have been established. In this study, we produced an experimental two-stroke engine with a transparent cylinder and a piston with LEDs mounted on its inside, so that we can observe the axial ring behaviour by the light leaked through the side clearance between the ring side face and the ring groove side face. Using our experimental engine, we investigated the effects of the intake and exhaust ports on axial ring motions.

2. Experimental apparatus and method

Figure 1 shows our experimental engine with its transparent cylinder. For our experimental engine, we used a two-stroke air-cooled single-cylinder gasoline engine displacing 0.175 L, with a bore of 62 mm and a stroke of 58 mm. The cylinder features an intake port on the thrust side, an exhaust port on the anti-thrust side, and scavenging ports on both the front and the rear sides. We cut the commercially available cylinder block above the exhaust port, and mounted a transparent glass cylinder between base plates (made of cast iron) on the cut cylinder block. These were fixed by nuts and bolts mounted to the crankcase.

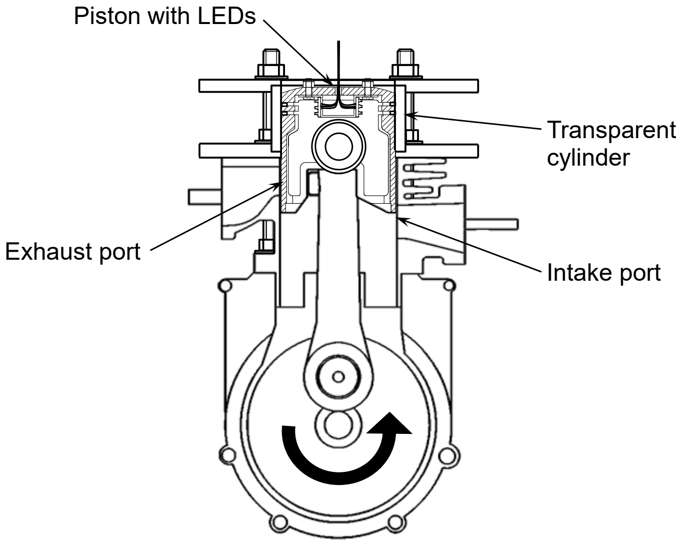


Fig. 1 Experimental engine with a transparent cylinder

For the backlights of the rings, we used a high intensity white LED chip (luminous flux of 20 lumens) with a width of 1.4 mm, a length of 3 mm, and a thickness of 0.5 mm. This LED chip is fragile and easily broken if directly attached. Therefore, we used LED chips, which were fixed with solder to a board. In order to secure an appropriate amount of light, six LED chips were attached to one board (Fig. 2). As shown in Fig. 3, we attached the boards with LEDs to the pedestal, and mounted the pedestal on the inside of the piston so that LEDs were positioned both on the thrust side (the intake portside) and on the anti-thrust side (the exhaust portside). We slotted the top and second ring grooves with a slot width of 2 mm on both the thrust side and the anti-thrust side, so that the LED light could shine through the slots (Fig. 4).

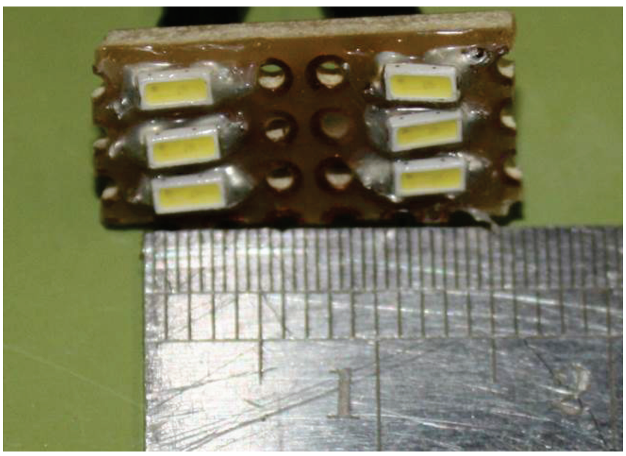


Fig. 2. Board attached LED chips

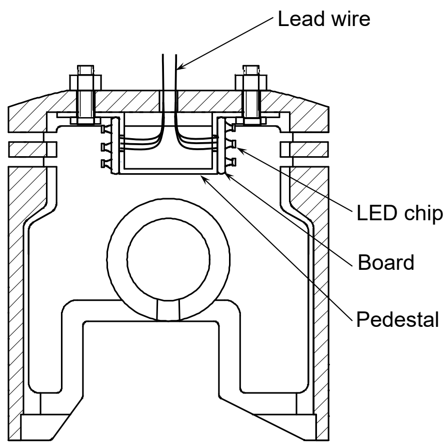
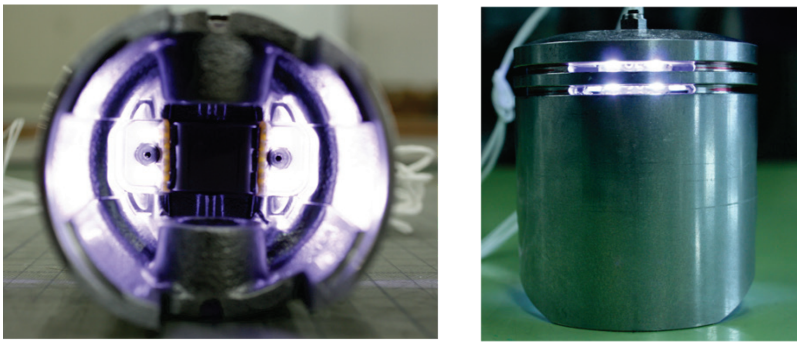


Fig. 3. Piston with LEDs



(i) Inside of piston (ii) Outside of piston

Fig. 4 Back light of LEDs

We installed the LED circuit board and its electric power source outside the engine, because there was not enough space to fit them inside the engine. Our specific goal was to investigate the axial motions of the rings, especially when the ring passed over the port. Even under a firing operation, when the exhaust port is open, minimal cylinder pressure is applied to the ring. So, without cylinder pressure, i.e., detaching the cylinder head, we drew the lead wires from the LEDs inside the piston, through the hole drilled in the piston crown, and out of the piston. In order to reduce the fluttering and breaking of the lead wires, we bound them up with tape and clamped them on the base plate.

In this commercially available engine, the barrel-faced half-keystone top ring and the taper-faced rectangular second ring are installed in the piston ring grooves. Both rings have a width of 2.0 mm, a thickness of 2.8 mm, and a tangential force of 11 N. However, our preliminary experiment found insufficient side clearance between the commercially available rings and the ring grooves: When the ring groove had sufficient lubricating oil, we were not able to observe the backlight of LEDs. Therefore, we ground the bottom faces of both the top and second rings by 0.3 mm, so the width of both top and second rings became 1.7 mm, as shown in Tab. 1. Thus, the side clearance was 0.3 mm greater in our experimental rings than in the commercially available rings.

Tab. 1. Experimental piston rings

[mm]

Top ring	2.8 7°30' 1.7	End clearance 0.27 Tension 9.0N Elastic modulus 88GPa Chrome plating Joint with side notch
Second ring	2.8 1°20' 1.7	End clearance 0.28 Tension 9.0N Elastic modulus 88GPa Phosphate Joint with side notch

Before each experiment, we applied sufficient two-stroke oil to the cylinder wall at engine bottom dead centre (BDC). We ran the engine at room temperature and a fixed engine speed, and then observed with a high-speed video camera, at a shutter speed of 1/15000 s and at a frame rate of 50 fps, on either the thrust side or the anti-thrust side, after properly arranging five incandescent lamps of 500 W on that side. In order to clearly observe the light leaked through the side clearance between the ring side face and the ring groove side face, we adjusted the installation positions of the high-speed video cameras to be the same height for each of the four locations of the transparent cylinder and the intake port on the thrust side, and the transparent cylinder and the exhaust port on the anti-thrust side.

3. Results

Figures 5 to 8 show the axial motions of the top and second rings on the thrust side (intake port side) and the anti-thrust side (the exhaust port side), while the engine runs at 300 rpm. Crank angles of 0º and 360º represent engine top dead centre (TDC), and 180º BDC. In Figs. 6 to 8, position (a) shows where the bottom of the ring passes the upper side of the port, position (b) where the upper side of the ring passes the upper side of the port, position (c) where the bottom of the ring passes the bottom of the port, and position (d) where the upper side of the ring passes the bottom of the port. Of course, when the rings pass over the transparent cylinder and the ports, we can observe the axial ring motion. Here, when light leaked only from the side clearance between the ring bottom surface and the ring groove bottom surface, we judged that the ring was positioned on the upper surface side of the ring groove. Conversely, when light leaked from the side clearance between the upper surface of the ring and the upper surface of the ring groove, we judged that the ring was positioned on the bottom surface side of the ring groove. In addition, when light leaked from both the side clearances between the ring and the upper and bottom surfaces of the ring groove, we determined that the ring was located at the centre of the ring groove.

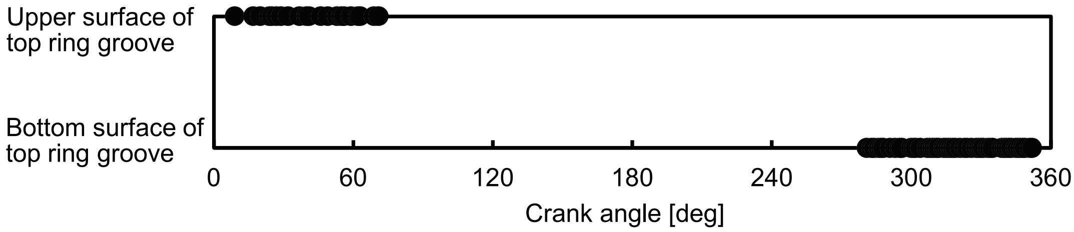


Fig. 5. Axial motion of top ring on thrust side (intake port side) at 300 rpm

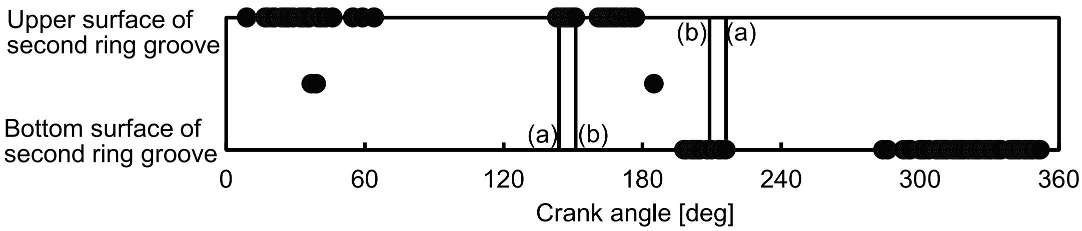


Fig. 6. Axial motion of second ring on thrust side (intake port side) at 300 rpm

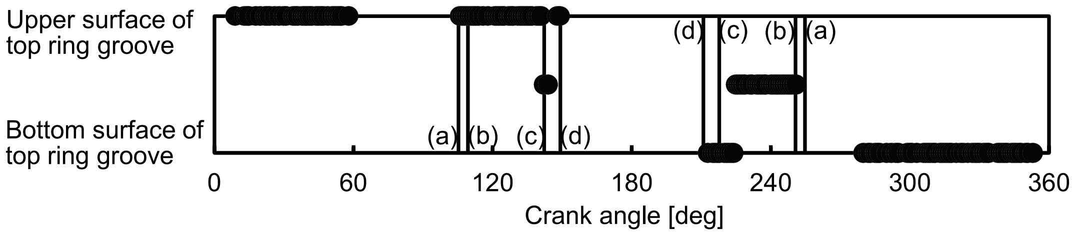


Fig. 7. Axial motion of top ring on anti-thrust side (exhaust port side) at 300 rpm

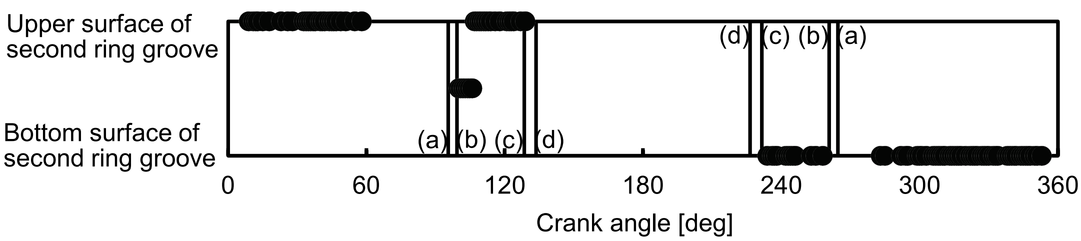


Fig. 8. Axial motion of second ring on anti-thrust side (exhaust port side) at 300 rpm

On the thrust side (the intake port side), at BDC, the top ring is adjacent to the upper edge of the intake port. Therefore, we were not able to observe the axial motion of the top ring through the intake port. In Fig. 5, through the transparent cylinder on the thrust side, the top ring was positioned on the upper surface of its ring groove during the downward stroke, and the top ring was positioned on the bottom surface of its ring groove during the upward stroke.

In Fig. 6, on the thrust side (intake port side), during the downward stroke, in many cases, from about TDC to 60º, the second ring was positioned on the upper surface of its ring groove. However, at about 40º, the second ring was occasionally positioned at the centre of its ring groove. While the second ring passed over the intake port, from about 140º to 180º, the second ring was positioned on the upper surface of its ring groove. Then, at about 180º, the second ring was positioned at the centre of its ring groove. During the upward stroke, when the second ring still passed over the intake port from about 200º to 220º, the second ring was positioned on the bottom surface of its ring groove. Even from about 280º to TDC, the second ring was still positioned on the bottom surface of its ring groove.

In Fig. 7, on the anti-thrust side (exhaust port side), during the downward stroke, from about TDC to 60º, and then from about 110º to 150º where the top ring passed over the exhaust port, the top ring was positioned on the upper surface of its ring groove. However, at about 140º where the top ring finished passing over the exhaust port, the top ring was occasionally positioned at the centre of its ring groove. On the upward stroke, while the top ring passed over the exhaust port, from about 210º to 220º, the top ring was positioned on the bottom surface of its ring groove, and from about 220º to 250º, the top ring was positioned at the centre of its ring groove. Then, from about 280º to TDC, the top ring was positioned on the bottom surface of its ring groove again.

In Fig. 8, on the anti-thrust side (exhaust port side), during the downward stroke, from about TDC to 60º, the second ring was positioned on the upper surface of its ring groove. While the second ring passed over the exhaust port, at from about 100º to 110º, the second ring was positioned at the centre of its ring groove, and from about 110º to 130º; again, the second ring was positioned on the upper surface of its ring groove. During the upward stroke, both from about 230º to 260º where the second ring passed over the exhaust port and from about 280º to TDC, the second ring was positioned on the bottom surface of its ring groove.

4. Interpretation

In this study, as we operated engine at a lower engine speed without cylinder pressure, if the piston behaviour and the cylinder ports have no effect, only the friction force on the outer sliding surface of the ring affects the axial ring motion. Thus, the ring would be positioned on the upper surface of its ring groove during the downward stroke, and the ring would be positioned on the bottom surface of its ring groove during the upward stroke. However, our results indicated that, in some cases, the ring was positioned at the centre of its ring groove. So we decided to consider our axial ring motions in Figs. 6 to 8, using our previous study on the piston behaviour analysis [5] and the measurement of the piston ring behaviour utilizing gap sensors of the eddy current [7, 8]. Figure 9 shows the calculated results of the piston radial displacement and the piston tilt angle at 300 rpm, as simulated by the "AVL EXCITE Piston and Rings" software. Again, crank angles of 0º and 360º represent TDC, and 180º BDC.

In the axial motion of the second ring on the thrust side (intake port side) in Fig. 6, during the downward stroke, from about 10º to 40º, the piston moves from the thrust side to the anti-thrust side (exhaust port side), and the piston crown leans away from the thrust side and toward the anti-thrust side, as shown in Fig. 9. It seemed that, at about 40º, the second ring was occasionally positioned at the centre of its ring groove by this piston behaviour. At about 180º, the second ring was also positioned at the centre of its ring groove. It is thought that, both by changing the piston movement from downward to upward and by the second ring projecting in the intake port [8], the second ring would move in the axial direction.

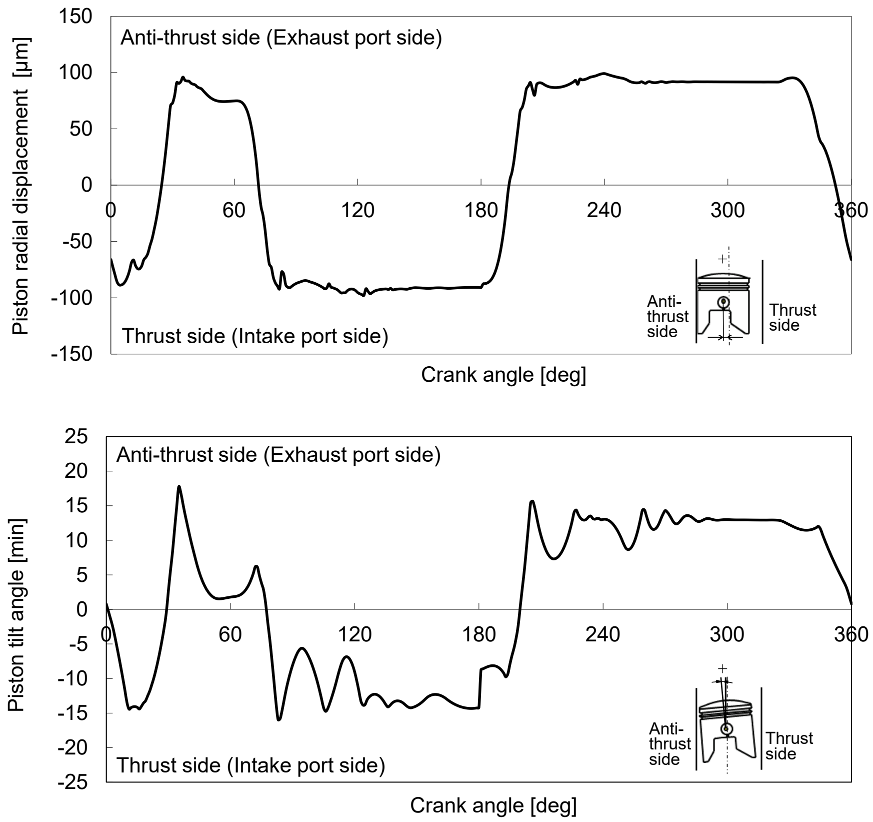


Fig. 9. Calculated results of piston radial displacement and piston tilt angle at 300 rpm

In the axial motion of the top ring on the anti-thrust side (exhaust port side) in Fig. 7, on the downward stroke, when the top ring passes over the exhaust port, the piston moves down along the thrust side (intake port side) and the piston crown leans to the thrust side, as shown in Fig. 9. It appears that, at about 140º, the top ring tends to catch the bottom surface of the exhaust port, so that the top ring would be positioned at the centre of its ring groove. On the upward stroke, the top ring begins to pass over the exhaust port, immediately after the piston moves from the thrust side to the anti-thrust side, and the piston crown leans away from the thrust side and toward the anti-thrust side, as shown in Fig. 9. Then, when the top ring passes over the exhaust port, the piston moves up along the anti-thrust side and the piston crown leans to the anti-thrust side. It seems that, from about 220º to 250º, by the second ring projecting in the exhaust port [8], the top ring would be positioned at the centre of its ring groove.

In the axial motion of the second ring on the anti-thrust side (exhaust port side) in Fig. 8, on the downward stroke, from about 100º to 110º, immediately after the piston moves from the anti-thrust side to the thrust side (intake port side) and the piston crown leans away from the anti-thrust side to the thrust side (Fig. 9), the second ring was positioned at the centre of its ring groove, when the second ring began to pass over the port. Then, it is thought that the second ring would project in the exhaust port [8]. On the upward stroke, when the second ring passes over the port, the piston moves up along the anti-thrust side and the piston crown leans to the anti-thrust side, as shown in Fig. 9. It seems that the second ring then projects in the exhaust port [8]. However, the second ring was positioned on the bottom surface of its ring groove.

5. Conclusions

In our experimental two-stroke engine with its transparent cylinder, we installed a piston with LEDs mounted inside. Then we observed the axial motions of the rings by light leaked through the side clearance between the ringside face and the ring groove side face. Ultimately, under motoring operation without cylinder pressure, we found that not only the piston behaviours, but also the ring projection and catching in the cylinder ports, affected the axial ring motions.

In the future, we will install the miniaturized circuit and power source of the LED inside the two-stroke engine, and then investigate the axial ring motions under a higher cylinder pressure.

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