

Visualization of Oil Behavior when Piston Pin Noise Occurs

Takashi KONDO* Hisayuki OHBAYASHI**

ABSTRACT

Piston pin behavior was measured on occurrence of conspicuous piston pin noise when using a semi-floating support system, and oil behavior around the piston pin was visualized.

Piston pin behavior was measured by the linkage method using a gap sensor. This clarified the behavior of the piston pin using a semi-floating support system when the noise occurred.

Visualization of the oil behavior was performed by the linkage method using optical fiber. Particle images of oil droplets were captured with a high-speed camera. Processing those images with particle tracking velocimetry (PTV) successfully vectorized the oil behavior inside the engine.

1. Introduction

As the development of hybrid, fuel cell, and other such new power plants progresses rapidly, development of conventional gasoline engines is also advancing in order to further enhance their performance. In addition to greater compactness and lighter weight, as well as greater fuel economy, higher power, and greater reliability performance, there is also demand for engines that are quieter and lower in cost. Major moving parts, in particular, are crucial parts that have a direct influence on those aspects of performance, and this is true of the pistons most of all. Piston support systems generally belong to two kinds, the full-floating support systems and semi-floating support systems. Mini-sized and compact vehicles more frequently adopt the semi-floating system due to its cost advantages. This support method, however, involves the issue of greater likelihood of piston pin noise occurring.

This issue is thought to arise because of differences in the clearance between each part in this support system. It is further known through experience, however, that lubrication conditions can also have an effect on the noise. Consequently, in order to reduce piston pin noise, it will be important to ascertain the mechanism that results in piston

pin noise and to grasp the oil behavior that is thought to be an influential factor.

2. Research Aims

It is crucial that the mechanism of piston pin noise be clarified in order to reduce the noise. As a first step to that end, the below actions were taken to grasp the phenomena that take place when piston pin noise occurs, which had not previously been made clear.

- (1) Measured piston and piston pin behavior
- (2) Visualized oil behavior

3. Test Engine

Table 1 shows the basic specifications of the test engine. A 1.5-L engine with the semi-floating support was used. In order to clarify the phenomenon of piston pin noise, the piston pin clearance was configured so that piston pin noise would be more likely to occur. The testing was then conducted with the engine operating in a state in which piston pin noise occurs. The test conditions, which are typical of that state, were that the engine was hot and running at 1850 rpm at no load.

* Automobile R&D Center

** Honda Foundry Co.,Ltd

Table 1 Engine specifications

Item	Specifications
Engine type	In-line 4-cylinder
Injection type	Port injection
Bore × stroke (mm)	73 × 89.4
Displacement (cm ³)	1497
Compression ratio	10.4
Valve train	SOHC i-VTEC
Number of valves	4 per cylinder
Valve diameter (mm)	IN: $\phi 28 \times 2$ EX: $\phi 23 \times 2$
Gasoline	Regular (RON91)
Max. power (kW/rpm)	88/6600
Max. torque (Nm/rpm)	145/4800

Table 2 Occurrence conditions of piston pin noise

	(a) Steady operation	(b) After snap
Frequency	2-3 kHz	2-3 kHz
Engine load	No load, Light load	No load
Timing	Around BTDC20°	Not only BTDC20°
Expansion stroke	With combustion	Without combustion
Imitative sounds	"Kata", "kara"	"Jyara", "Jya-"

4. Piston Support System and Piston Pin Noise

Figure 1 shows the piston support systems employed in Honda automobiles. There are two types, the full-floating and the semi-floating, and piston pin noise occurs primarily with the semi-floating type. The full-floating type has clearance between the piston pin and the connecting rod, which are both made of steel. The semi-floating type has clearance between a piston made of aluminum alloy and a piston pin made of steel. Consequently, the semi-floating type is considered to be more subject to piston pin noise because the clearance increases, especially when the engine is hot, due to the different linear thermal expansion coefficients.

Piston pin noise occurs during two engine operating states. The characteristics of each are shown in Table 2. Piston pin noise and the piston pin behavior accompanying

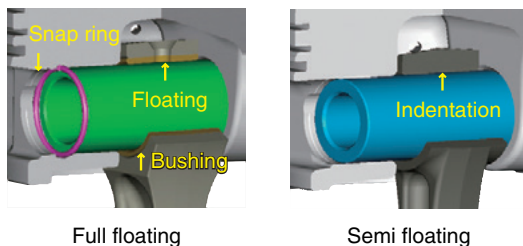


Fig. 1 Two types of floating support

it have been described in numerous reports of research and instances of measurement^{(1), (2)}.

For this research, the focus was first placed on piston pin noise that occurs during steady-state operation (Table 2(a)). The various phenomena that occur when the noise occurs were measured and analyzed.

5. Measurement of Piston and Piston Pin Behavior

5.1. Overview of Measurement System

Figure 2 shows a diagram of the measurement system. The piston pin behavior was measured using two gap sensors (Model PU-02A by the Applied Electronics Corporation) affixed orthogonally to the piston pin boss. The sensors were of the eddy current type. They were made with a ceramic portion on the tip to allow a margin for trimming, enabling round chamfering along the piston pin hole after installation to the piston.

The speed and vibrational acceleration of the piston and piston pin were measured using accelerometers (Model 352C22 by PCB Piezotronics, Inc.). Since the piston pin is press-fitted into the connecting rod, the measurements were made on the connecting rod near the piston pin. The measurement output signal was fed to the outside for retrieval by a link mechanism⁽³⁾. The link had three joints and extended from the big end of the connecting rod with one end attached to the connecting rod and the other end to a case affixed to the engine. The path of the wiring leading out from the measurement point is indicated by the dotted arrow.

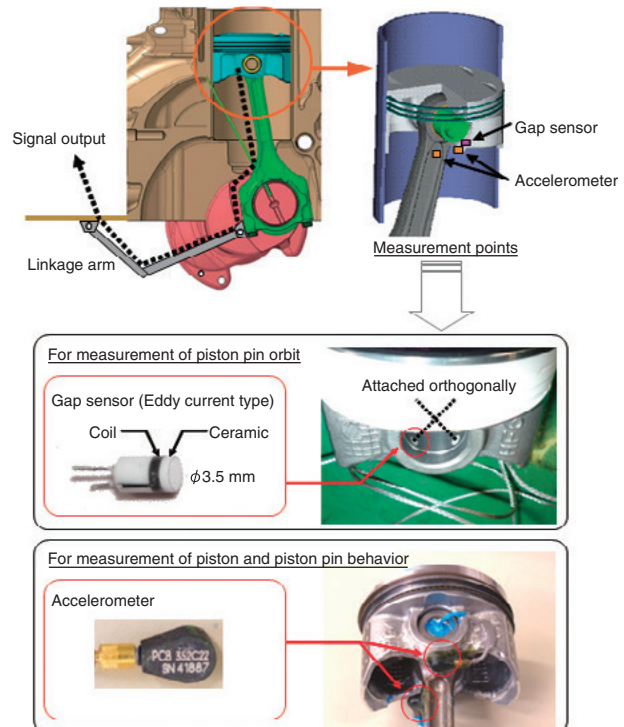


Fig. 2 Configuration of measurement system

5.2. Measurement of the Behaviors Involved

5.2.1. Piston and piston pin behavior in the vertical direction

Figure 3 shows the cylinder pressure together with the vertical component of the velocity and acceleration of the piston and piston pin when piston pin noise occurs. As shown in Table 2, piston pin noise occurs near BTDC 20°. Attention was therefore focused on this vicinity.

First of all, regarding the cylinder pressure, since the engine is operating under no load, the pressure changes from negative to positive near BTDC 40°. The pressure then increases further because of combustion.

At this time, the increase in cylinder pressure exerts a braking force against the vertical rise of the piston. Meanwhile, the relative velocity of the piston pin has increased so that the piston pin rises and hits the surface of the piston pin hole. The result is that the piston and piston pin impact against each other at a point from BTDC 30° to BTDC 20°. This impact phenomenon can also be discerned in the acceleration graph.

5.2.2. Piston pin axis center behavior

Next the behavior of the piston pin axis center inside the piston pin hole was measured in order to clarify the piston pin behavior when piston pin noise occurs. The results are shown in Fig. 4. The solid line drawn in the figure represents the axis center behavior from BTDC 90° to TDC. The open circles drawn on that line represent the position of the axis center at each 1° of crank angle.

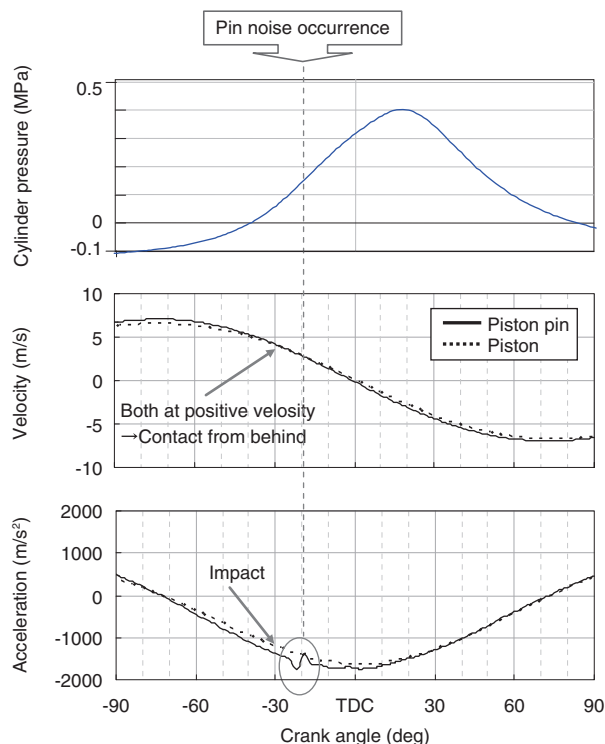


Fig. 3 Vertical behavior of piston and piston pin (1850 rpm, No load)

It can be inferred from the confirmation results in the previous paragraph that piston pin noise is a phenomenon of impact in a vertical direction between the piston and piston pin that occurs as the cylinder pressure increases. However, the results from measurement of piston pin axis center behavior made it clear that the piston pin is not just displaying simple vertical behavior.

It was observed that as the piston pin heads toward BTDC 20°, where piston pin noise occurs, it makes a large, circular motion inside the piston pin hole toward the counter-thrust side (this movement will be referred to hereafter as a circular motion) while rapidly traveling in an upward direction. Figure 5 shows the findings to this point organized in the form of a flow chart. The behavior of the

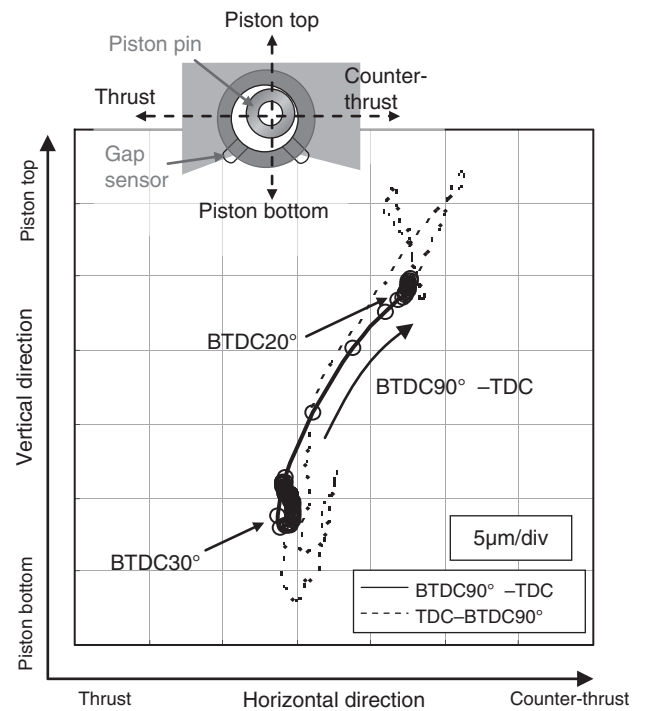


Fig. 4 Piston pin center orbit of semi floating system at steady operation (1850 rpm, No load)

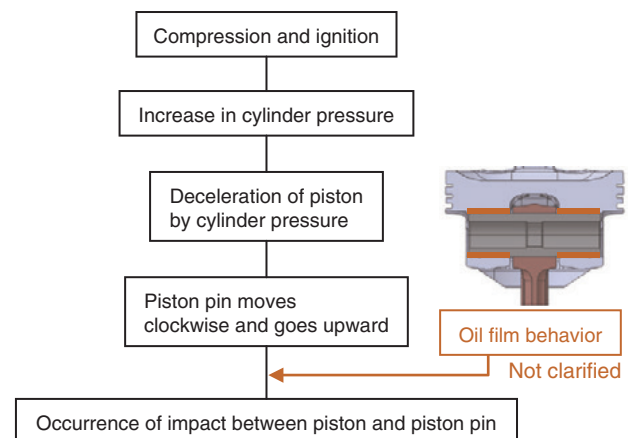


Fig. 5 Flow of piston pin noise phenomena

Table 3 Comparison of oil behavior visualizations

Method	Developed method	Conventional methods	
	Direct view by fiber scope PTV	Direct view (fluorescent paint)	Neutron radiography
Observation point	Inside of engine Moving with linkage Very near to target	Outside of engine View from static point Visible via quartz/sapphire glass port	Outside of engine View from static point Permeation by neutron beam
Difficulty	Easy	Easy	Difficult
Cost	Low cost	Low cost	Expensive
Safety consideration	None	None	Radiation exposure
Advantages	• Viewable from moving point • Viewable inside/reverse side of parts • No influence for flow • PTV possible by oil mist	• Easy to install	• Viewable wide area
Disadvantages	• Depends on fiber scope spec (because of mass product model)	• Expensive fluorescent paint • Difficult to view inside/reverse side • Different deformation at window from actual engine	• Limited equipment only • Significant cost • Significant safety considerations • Depends on permeability of parts

piston and piston pin has become clear, but the state of the oil that is interposed between those parts has not been made clear. Therefore, this will be done in the next section.

6. Oil Behavior Visualization

The state of the lubrication when piston pin noise occurs will be made clear. It would be ideal to directly observe the oil inside the piston pin hole. Since there was no method for doing so, however, the state of the oil that flows into and out of the piston pin hole was observed by visualization and the state of the lubrication inside the piston pin hole was inferred from that.

6.1. Overview of the Measurement System

Particle tracking velocimetry (PTV) was used to measure oil behavior. Figure 6 shows the visualization of

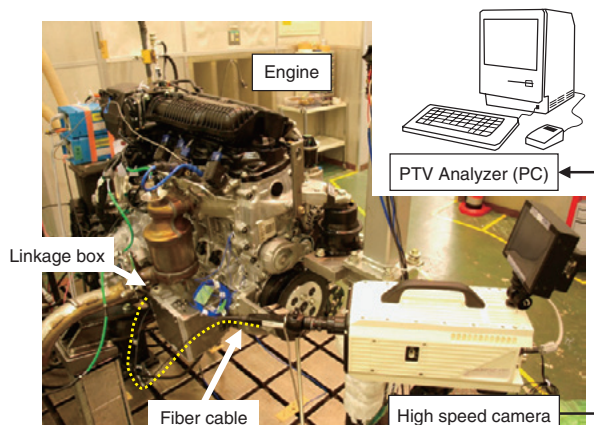


Fig. 6 Visualization and PTV system

oil behavior and the PTV system.

The interior of the engine was observed using a fiberscope mounted on the linkage mechanism. What was observed there was photographed with a high-speed camera (MEMRECAMfx K5 from nac Image Technology, Inc.) and made into particle images for use in PTV.

Table 3 presents a comparison of the measurements made by the fiberscope and linkage method applied here together with the PTV analysis and visualization methods of oil in the engine interior that have been reported to date^{(4), (5)}.

The method adapted for use here has the following characteristics:

- (1) Having the fiberscope installed on the linkage enables visualization to be maintained unchanged, always following the visualization target at the same distance, even if the target is moving.
- (2) Imagery of visualized oil droplets can be speed-vectorized by PTV processing, allowing oil behavior in the engine interior to be ascertained.
- (3) It enables visualization of the reverse side of parts and other such areas that cannot be visualized through a viewing port installed in the cylinder block or other engine exterior wall.
- (4) Since no tracer is needed, engine damage due to deterioration of the oil or admixture of foreign matter can be avoided.
- (5) Lasers, optical systems, and other such equipment generally used for PTV are not needed, so the system is simple.

Since there were no instances of reports on this measurement method to date, the suitability of the device was considered.

Table 4 Specifications of fiber scope

Consideration		Fiber specifications	Requirements
(1) Oil proof		OK	Need oil proof
(2) Heat resisting		-10 to 80°C	Up to 80°C
(3) Minimum radius of curvature		R19 mm	Less than R25 mm
(4) Imaging area		60°	Enough to visualize
(5) Size	Diameter	φ2.4 mm	Less than φ5 mm
	Length	1170 mm	More than 450 mm

Table 5 Specifications of light source

Voltage	100 V 50/60 Hz
Light	250 W metal halide
Power consumption	290 W
Cooling	Fan
Shutter	Continuously mechanical
Filter	UV, IR CUT

6.2. Examination of the Fiberscope and Light Source

For the purpose of visualization, it is necessary to install the fiberscope inside an actual operating engine by means of an intermediate linkage. Since this was the initial attempt to do this, however, consideration was given to the question of whether a fiberscope is suitable for the measurement environment.

The points requiring consideration are as shown below. The results are given in Table 4.

- (1) Oil-proof quality
- (2) Heat resistance
- (3) Flexibility
- (4) Imaging area (angular field of view)
- (5) Size (diameter, length)

As a result of this consideration, it was determined that the fiberscope satisfies every requirement and can therefore be applied to this use. The fiberscope that was used was an off-the-shelf product for industrial applications.

Consideration was next given to the light source. A 250-W metal halide light source installed coaxially with the fiberscope was tried. Imagery taken with this equipment was verified at the frame rate of the equipment as installed in the engine interior. The imagery was determined to have sufficient brightness for PTV and this equipment was therefore adopted. Table 5 shows the specifications.

6.3. Visualization of the State of Oil Flowing into and out of the Piston Pin Hole

6.3.1. The state of flow into the piston pin hole

First, the state of inward oil flow was observed. This was done by PTV (speed vectorization) of the visualization imagery from the fiberscope attached to the linkage. The oil inside the piston is also affected by oil spatter from the

crankshaft as well as by forced oil feed from the connecting rod and oil jet. This time, therefore, attention was focused on the state of lubrication resulting from the natural feed of oil by spray from the outside of the piston pin.

The visualization imagery and vector imagery acquired by this method were shown in Fig. 7 together with the diagram of the oil behavior clarified by these imageries. The results were obtained as video imagery, and the vectors of oil spatter behavior from moment to moment were clear. The following results were consequently obtained:

- (1) Oil behavior in the vicinity of the piston pin, which does not allow static visualization from outside, was made clear.
- (2) Vectorization further clarified the oil behavior.
- (3) Oil that flowed through from the bottom of the piston lands actually did not reach the piston pin hole, but instead fell off partway there.

These results clarified the state of natural oil feed by spattering from the outside and enabled consideration of methods for enhancement.

Use of this visualization method also enables determination of oil behavior on the inner side of the piston

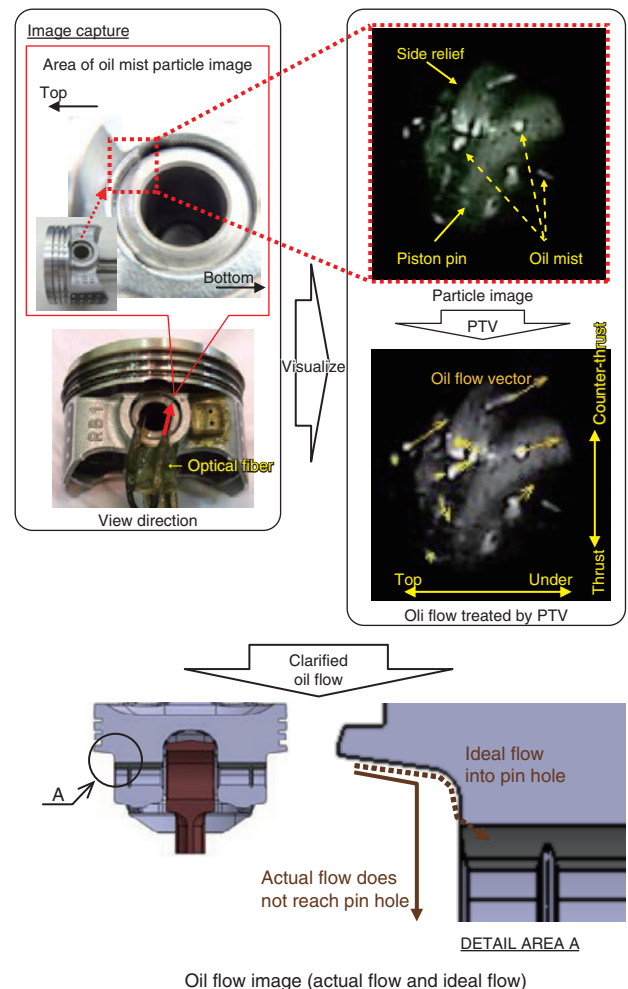


Fig. 7 Visualization of oil flow from piston to piston pin hole (Particle image: 640×560 pixel, 5000 fps)

pin. Further, it can also be used to judge flow volume quantitatively and ascertain oil behavior when forced oil feed occurs by oil jet or other such means. Also, with the use of a tracer, this method enables quantitative detection of oil flow inside the clearance spaces of each part.

This visualization technology thus offers possibilities for applications capable of ascertaining oil behavior in various locations inside the engine.

6.3.2. The state of flow out of the piston pin hole

Next, the state of oil flow out from the piston pin hole was clarified. Visualization of this phenomenon was performed with an engine that artificially recreated the circumstances in which piston pin noise occurs. Visualization was performed by direct observation using a high-speed camera. Figure 8 shows the oil behavior that occurred at that time.

As is clear from the visualization imagery, oil can be observed blowing out from the side relief following the impact of the piston and piston pin. This means that oil is leaking out from between the piston and piston pin.

Figure 9 shows the inferred course of events that lead

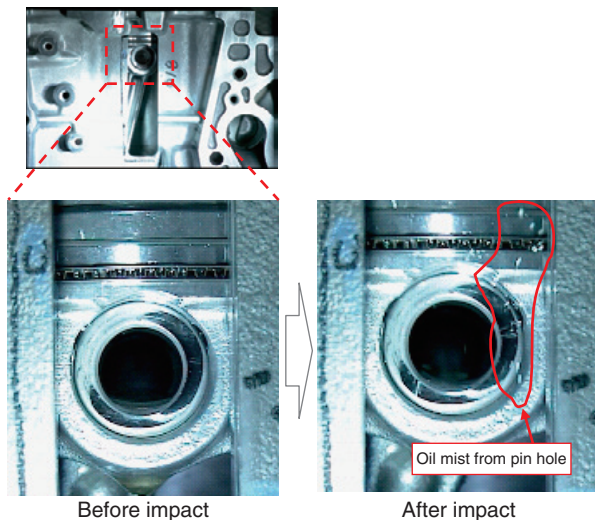


Fig. 8 Visualization of oil flow from piston pin hole to outside



Fig. 9 Oil transfer path in piston pin hole

up to oil being blown out as an end result of piston pin behavior. It is inferred that oil is pushed by the circular behavior of the piston pin and flows out through the passageway formed by the grooves around the inside circumference of the pin hole. Ultimately, it is thought to be expelled from the side relief.

6.4. Summary of Lubrication States

Visualization of the inward and outward flow states made clear that, in the state when piston pin noise is occurring, the oil at the bottom of the piston lands does not enter the piston pin hole, but instead falls off along the way and is blown out from the side relief. There is little oil inside the piston pin hole when this happens, so it can be inferred that the buffering effect when the piston pin impacts is reduced while the impact increases (Fig. 10). This is a crucial finding for the future clarification of the mechanism of piston pin noise as well as for the consideration of measures to counter it. In actuality, as well, the phenomena of being filled up and being blown out are interrelated, and their clarification will be another issue to be resolved.

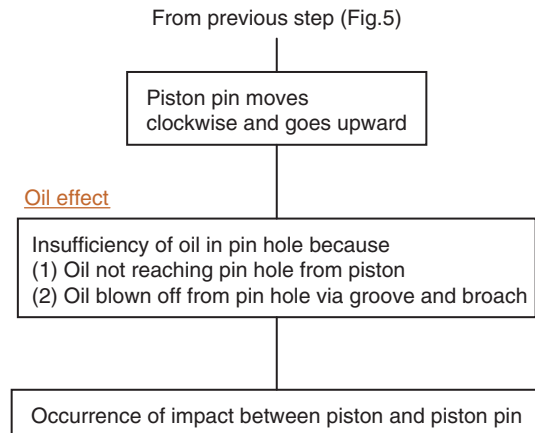


Fig. 10 Flow of piston pin noise phenomena with oil effect

7. Conclusions

- (1) Piston pin behavior when piston pin noise occurs with a semi-floating support system was clarified.
- (2) Methods of oil behavior visualization in the engine interior by means of the linkage method applying a fiberscope and of oil droplet vectorization by PTV were established.
- (3) Oil behavior around the piston pin hole when piston pin noise occurs during engine operation was clarified.

The visualization technology established by the present research is thought to be usable for ascertaining oil behavior in every part. It has future potential as a method for deciding specifications related to lubrication.

Acknowledgements

The authors would like to take this opportunity to express their profound gratitude to Hideshi Hitosugi and Fumihiro Nakada of the Nippon Piston Ring Co., Ltd., who generously cooperated in the work of fabricating test equipment for the furtherance of the present research.

References

- (1) Takiguchi, M., Aoki, Y., Anzai, S.: Relation between Lubricating Condition and Pin Slap Vibration at Pin Boss Bearing, JSAE Proceedings, No. 50-02, p. 5-8 (2002)
- (2) Kawano, K., Sue, S., Ishida, H.: Mechanism analysis of piston pin/pin boss bearing impact noise, JSAE Proceedings, No. 148-08, p. 5-10 (2008)
- (3) Kamiya, M., Kobayashi, T., Take, K., Takahashi, Y., Mihara, Y., Someya, T.: Measurement of Piston Skirt Oil-film Pressure when Piston Slap Noise Occurs, Honda R&D Technical Review, April, 2007, p. 149-155
- (4) Usui, M., Murayama, K., Sato, K., Yoshida, H.: Research in Lubricating Oil Flow and Visual Observation around Piston Ring, JSAE Proceeding, No.7 -06, p. 5-8 (2006)
- (5) http://www.nissan-global.com/JP/NEWS/2008/_STORY/081110-03-j.html

■ Author ■



Takashi KONDO



Hisayuki OHBAYASHI