# Causes of and Countermeasures for Allophone Trouble in a Piston Seal System for Cylinders

## 1. Introduction

In recent years, to accommodate requests regarding hydraulic machinery, hydraulic systems have been streamlined by increasing the operating pressure and temperature and reducing the size and weight of hydraulic systems. Accordingly, the performance requirements of hydraulic cylinders including packings for hydraulic cylinders have changed, and so the performance of various packings has been improved.

We have developed a seal system for high-pressure cylinders as a maintenance kit for cylinders for hydraulic shovels in the construction machinery industry. When evaluating actual equipment during the development stage, we found that allophone (stick-slip phenomenon) occurs in cylinders under certain conditions. During allophone of the cylinder, a stick-slip phenomenon occurs at the contact zone of a reciprocating packing, causing abnormal noise and oscillation while the cylinder is moving. Such allophone is a problem of hydraulic cylinders.

This report describes an allophone trouble and its solution. In this particular case, we considered that the allophone trouble was caused by the defective formation of an oil film at the contact zone between the packing and its opposing face, so we designed the packing to improve its ability to absorb the oil film.

## 2. Example of Packing Structure for Hydraulic Cylinders

Generally, several packing and parts are used in high-pressure cylinders including cylinders for hydraulic shovels. Figure1 illustrated the structure of a high-pressure cylinder.

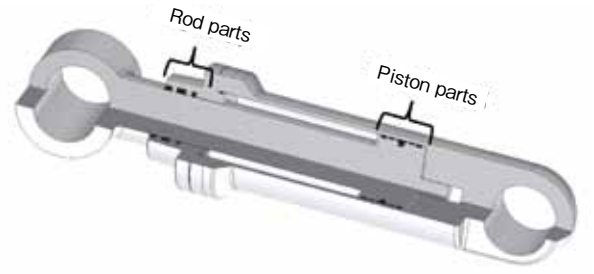



Figure1 Structure of a hydraulic cylinder

### 2-1) Structure of Seal System in the Rod Segment

The packing used in the rod segment plays an important role in preventing external leakage, and is an important function of cylinders. Figure 2 illustrated the structure of the seal system in the rod segment. Table1 showed the component parts.

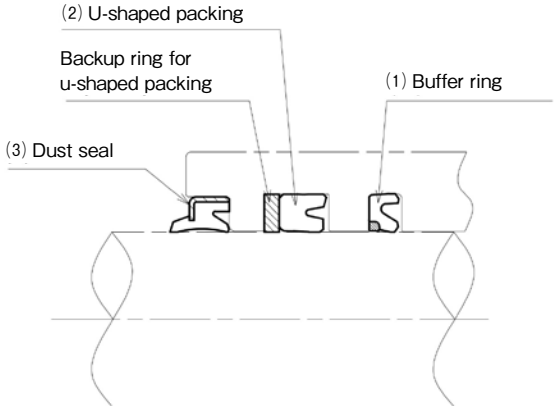



Figure2 Structure of seal system in the rod segment

Table1 List of component parts of the seal system in the rod segment

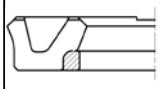
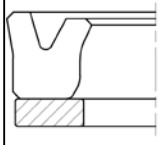
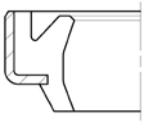
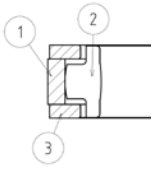
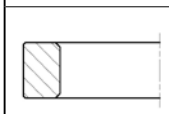
| | |
|---|---|
| (1) Buffer ring | |
|  | Absorbs the initial high pressure to reduce the strain on the u-shaped packing. The pressure resistance is enhanced by the use of the backup ring in reinforced plastic. |
| (2) U-shaped packing | |
|  | The main sealing component to prevent fluid leakage. The pressure resistance is enhanced by the use of the backup ring in reinforced plastic. |
| (3) Dust seal | |
|  | This packing prevents the infiltration of external contaminants such as sand and gravel. It also helps to ensure the prevention of minor leakage from the u-shaped packing. |

Table2 List of component parts of the seal system in the piston segment

| | |
|---|---|
| (4) Piston seal | |
|   | The main component that maintains the oil pressure inside the cylinder for operation. Its components are as follows:<br>① : Sliding ring to enhance the tribological properties<br>② : Rubber back ring to ensure tight sealing<br>③ : Backup ring to support the pressure resistance |
| (5) Wear ring | |
|  | Functions as a bearing when the piston is in motion. Typically made of cloth-reinforced phenolic plastics. |
| (6) Sliding ring | |
|  | Prevents the contaminants in the oil from infiltrating the piston seal. Typically made of Polytetrafluoroethylene (PTFE). |

### 2-2) Structure of Seal System in the Piston Segment

The packing used in the piston segment retains hydraulic pressure and provides appropriate thrust and load-retention ability to move the cylinder.[2] Figure 3 illustrated the structure of the seal system in the piston segment. Table 2 showed the component parts.

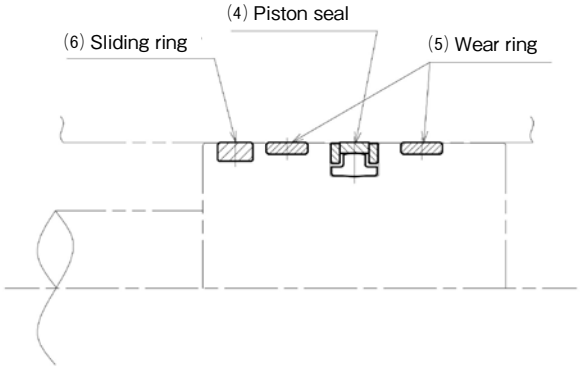



Figure3 Structure of seal system in the piston segment

## 3. Allophone (Stick-slip Phenomenon)

Static and kinetic frictional forces act on the contact surface between the packing and the opposing face; the two forces are closely interrelated. Sticking is the condition in which static frictional force (starting resistance) acts on the contact surface, and slipping is the condition in which kinetic frictional force (sliding resistance) acts on the contact surface. The stick-slip phenomenon is when both stick and slip conditions occur instantaneously and cyclically on the contact surface.[2,3]

This phenomenon occurs in hydraulic cylinders mainly at low speed, and sometimes causes troubles such as noise and oscillation. This noise is called allophone.[2,4]

## 4. Evaluation of Allophone

We have developed a seal system for high-pressure cylinders. We mounted actual equipment in a cylinder of a hydraulic shovel to conduct an operation test of the cylinder. As a result, allophone (stick-slip phenomenon) occurred in the cylinder when the shovel was operated at low speed and when the oil temperature was high. However, we did not confirm allophone at the lab evaluation during development. This meant that the operating conditions of the actual equipment had not been recreated, and revealed the difficulty of evaluating allophone.

### 4-1) Lab Evaluation

We conducted lab evaluation (stick-slip test) of a seal system for high-pressure cylinders during the development stage under the conditions shown in Table 3. The test results showed no allophone or stick-

slip phenomena.

It is difficult to conduct a quantitative assessment of the stick-slip phenomenon; we need to precisely replicate the usage conditions and environment in order to fully understand the characteristics of the packing, and then to plan and conduct a test.[4] However, in the lab evaluation, the operating conditions including the cylinder's transverse load and high oil temperature had not been replicated.

Table3 Conditions for stick-slip test

| Parameter | Testing conditions |
|---|---|
| Oil temperature | Ambient temperature (temperature without artificial control: approximately 40° C) |
| Velocity | 0.01 m/sec |
| Weight | 25 kg |
| Lubricant | Hydraulic lubricant (kinetic viscosity at 40° C: 46.0 $mm^2$/sec) |
| Verification method | Verification is based on the wave form depicted in the accelerometer measuring the up/down movements of the cylinder. |

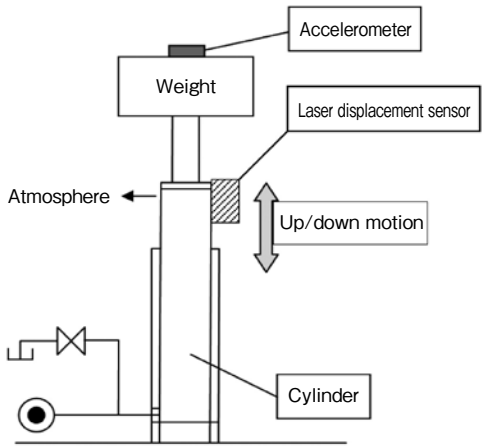



Figure 4 Equipment for stick-slip test

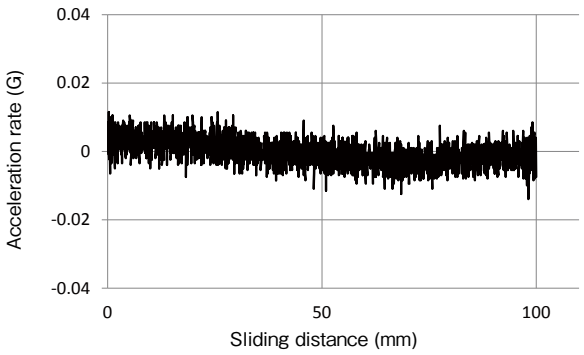



Figure5 Results of stick-slip test

## 5. Relationship between Stick Slip and Oil Film on Packing

Poor lubrication and frictional resistance at the contact surface affect the stick-slip phenomenon on packing. That is, periodical and recurring cycles of sticking and slipping at a contact surface cause the phenomenon. In the sticking condition of the cycle, the packing deforms itself to remain in the original position, and tries to return to its original shape when it is forcefully slipped by an external force, etc. The stick-slip phenomenon of the packing is affected by various factors including temperature, speed, pressure, surface roughness, viscosity of hydraulic oil, and oiliness. Although these factors have not been quantitatively investigated, qualitatively, the low viscosity of hydraulic oil often causes rupture of the lubricating film when equipment is operated at low speed under high pressure and when insufficient lubricant is applied.[5]

To alleviate the stick-slip phenomenon of a packing, the overall frictional resistance is sometimes lowered. One way to do this is to improve the retention of oil film between the opposing face and sliding surface.[2]

### 5-1) Formation of Oil Film on Packing

Regarding retention of an appropriate oil film on the sliding surface of a common reciprocating packing, the pressure gradient of the pressure pattern on the side of the fluid inlet and the same pressure gradient on the side of atmosphere are closely interrelated.[6] Absorption or scraping of the oil film may occur depending on the angle of the pressure gradient; this absorption and scraping affects the thickness of the oil film and sealing properties.

In the process of developing a high-pressure rod seal (U-packing), we focused on the shape of the packing on the heel side and the pressure gradient of pressure patterns in the heel segment. We verified that a seal with excellent absorbability could be developed by setting both the shape and the pressure gradient to optimal values.[1]

### 5-2) Application of Forming Method of Oil Film to a Piston Seal System

In the cylinder in which allophone occurred, the rod seal system of the cylinder used a U-packing developed by Valqua, and an appropriate oil film was retained between the opposing face and sliding surface. Taking these conditions into consideration, we assumed that allophone occurred in the piston seal system.

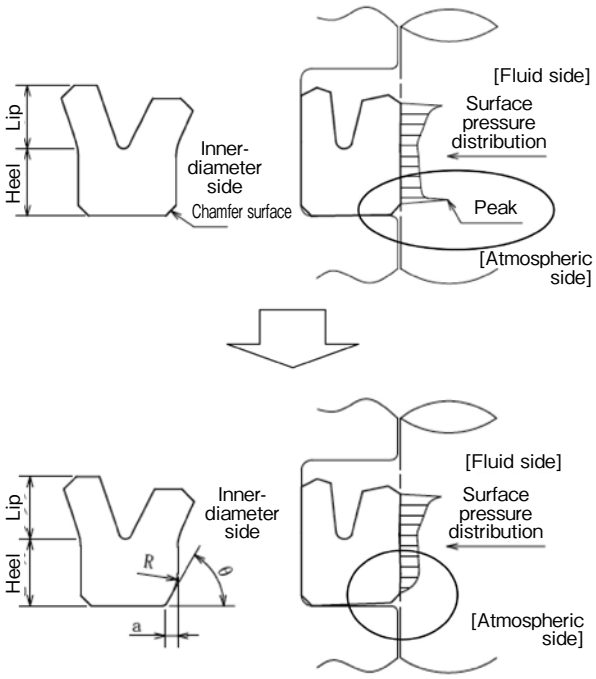



Figure6 Technique to absorb oil film used in the developed product

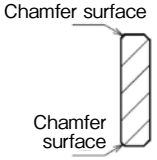
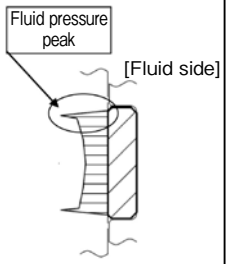
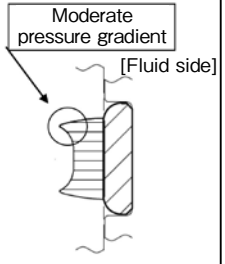
The results of allophone evaluation of actual equipment suggested that allophone occurred both when the viscosity of the oil was low due to high oil temperature and when transverse load was applied to the piston seal system. When transverse load was applied to a shaft bearing, wear ring of the shaft bearing was strongly pushed to the opposing face, and then the contact pressure reached its maximum value. As a result, the pressure gradient of pressure patterns is presumed to have become sharper, too. Therefore, we consider that allophone was caused by higher frictional resistance due to scraping of the oil film by the wear ring.

To verify this hypothesis, the pressure pattern of the wear ring was confirmed by finite element analysis (FEA). As a result, greater peak contact pressure and a sharper pressure gradient were confirmed in the C-chamfer at both ends.

It was found that the developed U-packing had functions of both scraping and absorbing the oil film. As a countermeasure against problems associated with the C-chamfer, the U-packing was applied to the system to make use of the two functions. Table4 shows the results of the analysis and investigation of the countermeasure.

The absorbability of the U-packing was used in shaping both ends of the wear ring into an R-shape to form an appropriate oil film on the sliding surface. No allophone was confirmed in an allophone evaluation of actual equipment in which this wear ring was provided. Based on this result, we consider that an appropriate oil film was formed.

Table4 Results of analysis of wear ring and investigation on countermeasure

| Parameter | Analysis outcomes | Alternative product evaluation results |
|---|---|---|
| Edge form | Chamfering (edge)<br>Chamfer surface<br>  <br>Chamfer surface | Round<br>  <br>R<br>R |
| Surface pressure distribution of sliding surface | Localized surface pressure peaks appear in the chamfer surface of the edges.<br>  <br>Fluid pressure peak<br>[Fluid side]<br>[Piston seal side] | Reduces the pressure gradient by applying rounded chamfering on the edges.<br>  <br>Moderate pressure gradient<br>[Fluid side]<br>[Piston seal side] |
| Material properties | Glass-fiber reinforced nylon. It is stronger and more cost effective than conventional materials such as PTFE and cloth-reinforced phenolic plastics. It is inferior to PTFE in its frictional characteristics. Thus, some products have the sliding surface treated with knurling.[2] | Based on the cost factor, the raw material will not be replaced. |

## 6. Allophone Evaluation of Cylinders of Actual Equipment

An allophone evaluation was conducted with an actual hydraulic shovel before and after taking the countermeasure described above. Figure7 showed the frequency of the allophone sound. No allophone wave shape was confirmed in the evaluation after taking the countermeasure.

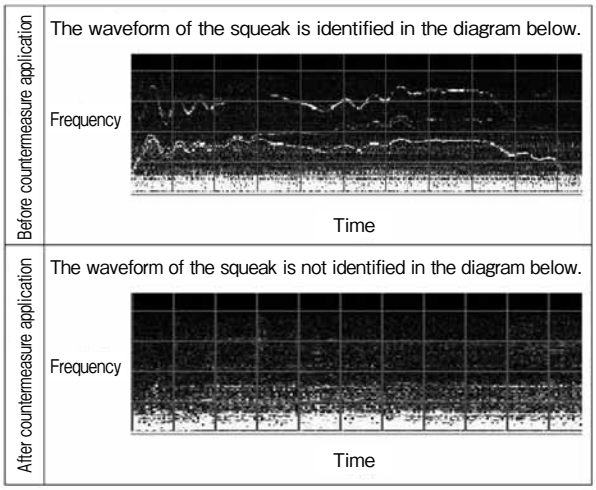



Figure7 Allophone evaluation of cylinders

## 7. Conclusion

This study verified that retention of an appropriate oil film alleviated allophone in packings for hydraulic cylinders.

To retain an appropriate oil film, the functions of scraping and absorbing the oil film are essential. By understanding these functions, this technique can be applied to other products to reduce allophone and frictional resistance. However, we still do not have a quantitative understanding of usage conditions, appropriate thickness of oil film for each product, and other factors, and many challenges remain. Therefore, further product development is needed for verification.

## 8. References

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2) Ando, T., *Hydraulics & Pneumatics*, May 2003, pp. 28–33
3) Nakano, K., *Journal of the Society of Rubber Science and Technology*, Vol. 80, 4th issue, 2007, pp. 134–139
4) Takamure, T., Tsuji, K., Muramatsu, A., and Yoshida, T., *Hydraulics & Pneumatics*, May 2003, pp. 34–37
5) Akai, *H., Hydraulics & Pneumatics*, May 2003, pp. 13–20
6) Kaneda, S., *Journal of the Society of Rubber Science and Technology*, Vol. 72, 4th issue, 1999, pp. 194–201

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