Technical Paper

# Development of Oil Passage Integrated Cylinder

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*An oil passage integrated cylinder was developed as a bucket cylinder for medium-size hydraulic excavators.*

*A bucket cylinder for a hydraulic excavator is mounted on a vehicle with the rod facing the ground surface, placing the bucket cylinder close to the ground surface and work target objects, which puts it in an environment that is in the immediate vicinity of potential failures arising from scratches on rod plating, damages to piping, oil leaks caused by deteriorated dust environment and the like.*

*An oil passage was installed inside the rod to eliminate exposure of piping and an oil passage integrated cylinder that can be mounted in a reversed orientation on the vehicle was developed, to solve this problem. This paper reports on the development in detail.*

***Key Words:*** *Hydraulic cylinder, Improvement of robustness, Oil passage integrated cylinder*

## 1. Introduction

A hydraulic cylinder delivers motive power for moving work equipment according to the operation of an operator, who controls a construction machinery, such as a hydraulic excavator. Hydraulic cylinder is therefore an essential component that comprises a construction machinery.

Such hydraulic cylinders are available in a variety of versions, in order to satisfy required specifications of the vehicle on which it is installed. We are one of very few construction machinery manufacturers that develops hydraulic cylinders in house. This provides us an opportunity to hear and perceive opinions of our customers, which are reflected on our development of components as we develop our machine bodies, which can be considered one of our strengths.

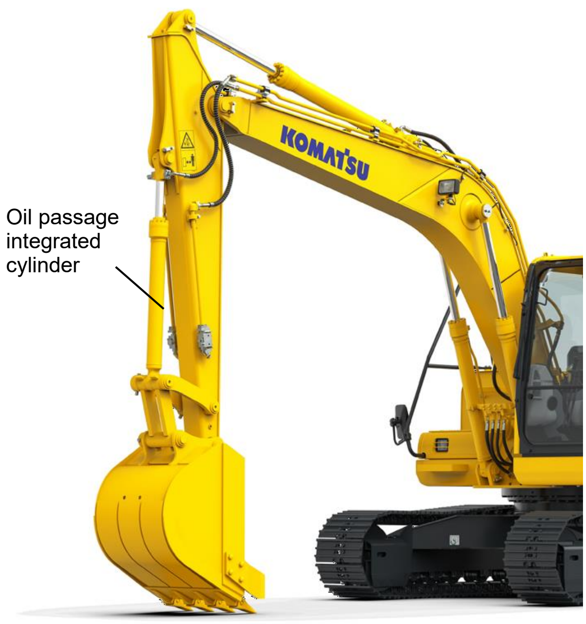



**Fig. 1** PC130-10M0 oil passage integrated cylinder installed vehicle

## 2. Information about hydraulic cylinders

A hydraulic cylinder is a component that can generate great strength, by utilizing expanding and contracting movements delivered by hydraulic pressure. A brief explanation on the standard cylinder configuration is explained, using a medium-size hydraulic excavator as an example.

### 2.1 Cylinder tube

Cylindrical part that forms the body.

There is a port for delivering hydraulic oil to the cylinder, and a part, which facilitates pin connection to the machine body, is bonded.

### 2.2 Piston rod

A part of a rod shape for transmitting hydraulic force.

The surface is treated with hard chromium plating and the base material is treated with high-frequency hardening, and these are means devised to prevent scratching from impacting rocks and wood.

A part for facilitating pin connection to the machine body is bonded on the one side, while on the other side the piston is bonded with a thread fastening.

### 2.3 Piston

A part inserted with a seal for partitioning the head-side and the bottom-side.

Both chambers are partitioned by a piston seal.

### 2.4 Cylinder head

A part inserted with a seal for holding back hydraulic pressure on the head side.

A dust seal to prevent intrusion of dust from exteriors, as well as a packing for holding back the hydraulic pressure are installed.

### 2.5 Piping

A part for delivering hydraulic oil to the cylinder.

A part for supplying hydraulic pressure from the pump to the cylinder.

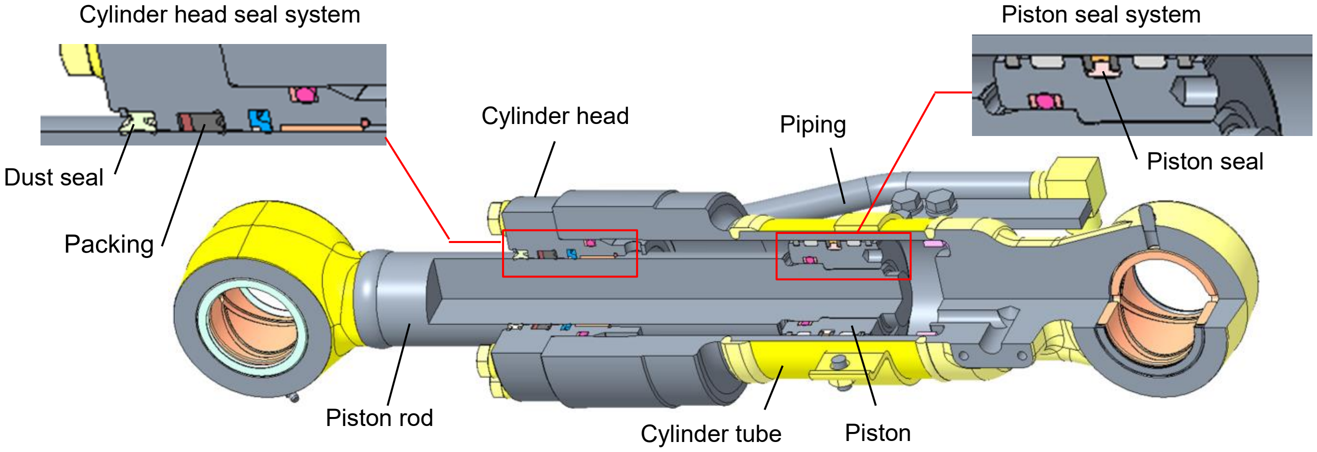



**Fig. 2** Basic configuration of hydraulic cylinder for medium-size hydraulic excavators

### 2.6 Movement of hydraulic cylinder

Oil is introduced from the bottom-side to extend the rod.

In case of a bucket cylinder on a hydraulic excavator, the bucket moves to the excavating-side, with the force relayed via a link (refer to **Fig. 3a**).

Oil is introduced from the head-side to contract the rod.

In case of a bucket cylinder on a hydraulic excavator, the bucket moves to the dumping-side, with the force relayed via a link (refer to **Fig. 3b**).

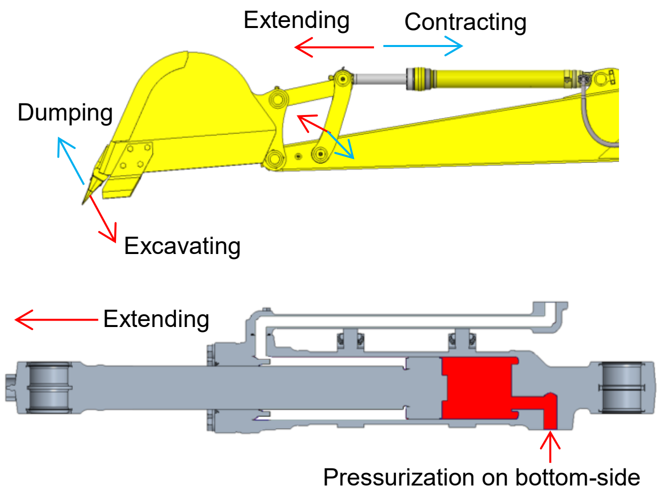



**Fig. 3a** Rod extended

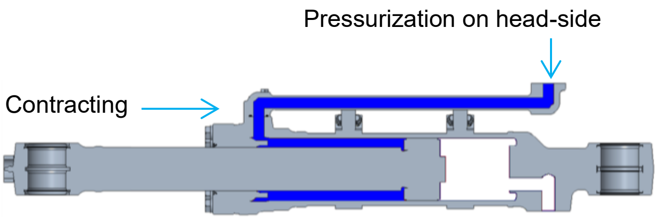



**Fig. 3b** Rod contracted

## 3. Malfunctions of hydraulic cylinder

### 3.1 Classification of malfunctions with hydraulic cylinders for medium-size hydraulic excavators

A boom cylinder, arm cylinder and bucket cylinder are installed on medium-size hydraulic excavators, to move the work equipment (refer to **Fig. 4**).

Malfunctions with cylinders for 20-ton hydraulic excavators are most often caused by oil leaks, and according to classifications, this occurs most often with bucket cylinders in particular (refer to **Fig. 5**).

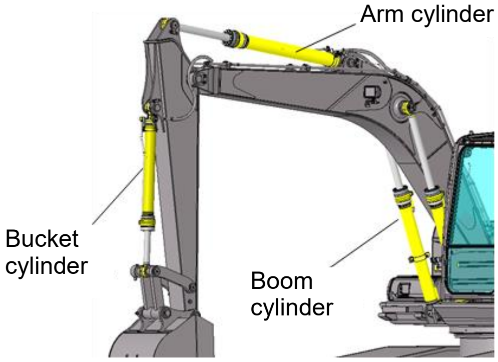
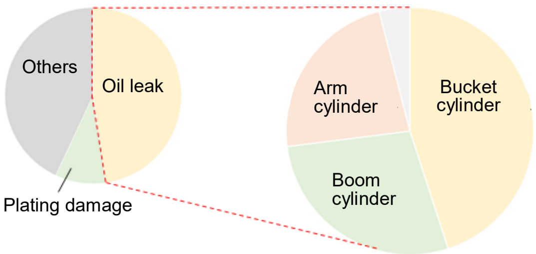



**Fig. 4** Cylinder arrangement of medium-size hydraulic excavator




a) Malfunction classifications of cylinders for 20-ton hydraulic excavators
b) Breakdown of oil leak

**Fig. 5** Malfunction classifications of cylinders for 20-ton hydraulic excavators

### 3.2 Oil leaking mechanism

An oil leak is a phenomenon that involves leaking of oil to the exterior of a component, which occurs when a damaged packing inside the cylinder head fails to keep the oil inside. Causes for packing damages can be largely categorized into two types.

One type consists of an external factor causing a scratch on the rod, which in turn scratches the packing (refer to **Fig. 6**).

The other type consists of packing damaged by dust, when a dust seal, which is intended to prevent intrusion of dust from the outside, fails to prevent dust intrusion under deteriorated dusty environment (refer to **Fig. 7**).

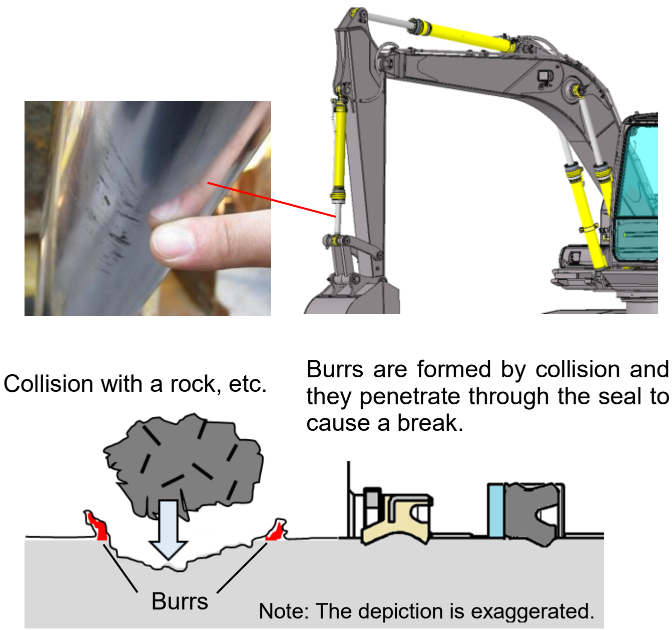



**Fig. 6** Oil leak due to rod damage

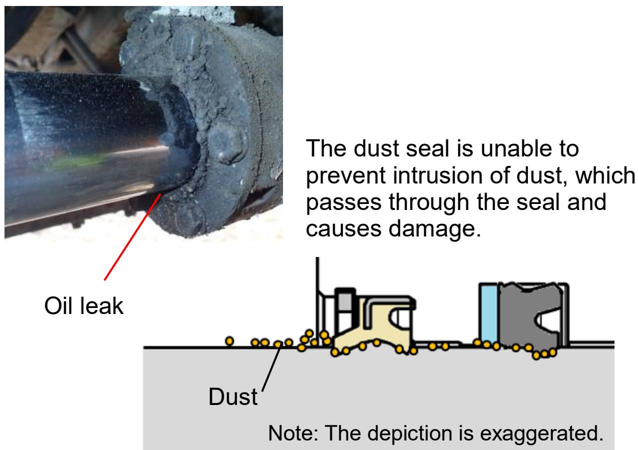



**Fig. 7** Oil leak due to dust intrusion

We have implemented countermeasures for the first type that consists of rod damage, with heat treatment of rod base material and applying hard chromium plating on the rod surface.

We have enhanced the dust seal system as a response for dust intrusion of the second type. Suitable seal systems are utilized for ordinary environments and deteriorated dusty environments, respectively.

Such actions have put the oil leak to a declining trend, but since the bucket cylinders on hydraulic excavators are installed so that the rods face the ground, they have greater probability of encountering rocks and other matters, and they are also more likely to have the seal breaking due to such external factors as dust, when compared with other types of cylinders and unless this environment is improved, the risk of oil leak cannot be reduced.

Changing the installation direction of the bucket cylinder and facing the rod upward to move away from external factors can be considered as an improvement idea, but since cylinders are ordinarily fitted with a cylinder tube on the hydraulic port, and installing a cylinder tube on the side of the bucket line causes the cylinder tube to move, which then requires longer hydraulic hose and that can lead to the risk of hose bursting when something gets caught by the hydraulic hose during work (refer to **Fig. 8** and **Fig. 9**).

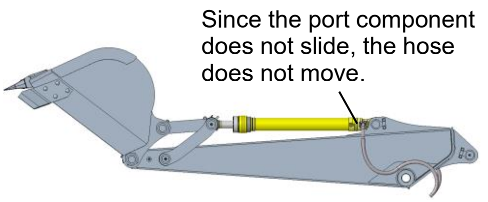



**Fig. 8** Ordinary cylinder-cylinder contraction

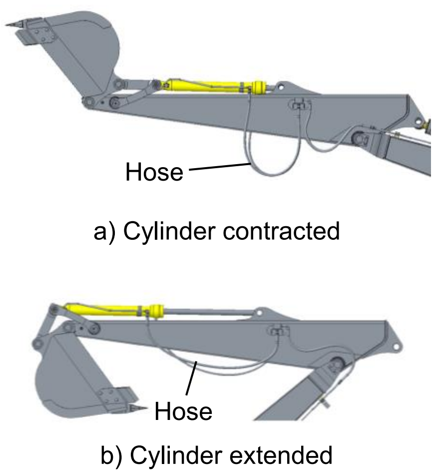



**Fig. 9** Ordinary cylinder installed in reverse

## 4. Oil passage integrated cylinder

### 4.1 Development of cylinder that can be installed in reverse

The bucket cylinder on a hydraulic excavator cannot be installed in reverse if the structure of the cylinder tube includes a hydraulic port. A hydraulic cylinder that can have the rod installed facing up was developed, by designing a structure with the port installed on side of the rod.

The hydraulic cylinder was prototyped and an evaluation was performed on an actual machine in early 2000, which established the structure of the hydraulic cylinder, but since there were numerous issues with productivity at the time, the matter did not move onto mass production.

This paper describes the cylinder after such issues have been cleared away. Issues of the time and their solutions are described in **Section 6.5** later on.

### 4.2 Movement of oil passage integrated cylinder

**Figure 10** shows a chamber with the red on the head-side and blue on the bottom-side. The movement is achieved by supplying oil from the head-side to contract, and from the bottom-side to extend.

This structure is referred to as the “oil passage integrated cylinder”.

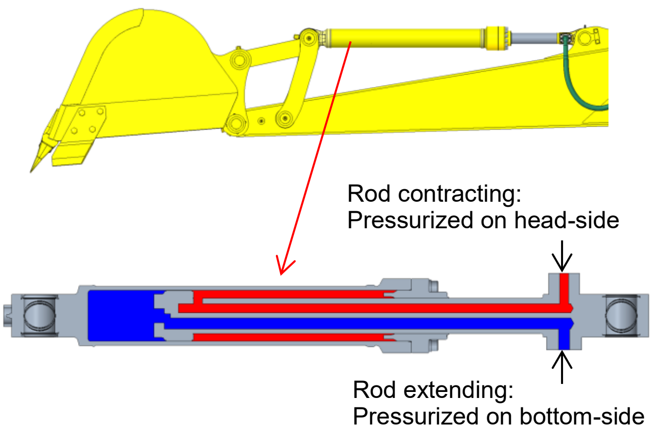



**Fig. 10** Schematic diagram of oil passage integrated cylinder

## 5. Effectiveness of installing an oil passage integrated cylinder on the vehicle

Expected effectiveness of adopting an oil passage integrated cylinder for the bucket cylinder of a hydraulic excavator is described, citing examples for general work as well as for underwater work.

### 5.1 Implementation for general work

The rod is moved away from earth and sand, reducing risk of rod damage and oil leak (refer to **Fig. 11**).

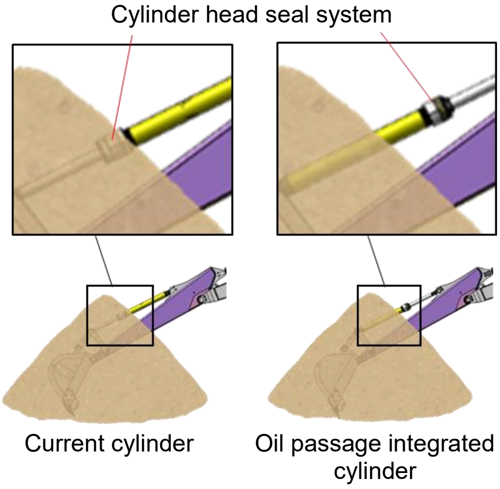



**Fig. 11** Effectiveness of reversing cylinder (general work)

### 5.2 Implementation for underwater work

The duration of the cylinder head seal system being immersed underwater becomes shorter and the risk of mud entering into the cylinder is reduced (refer to **Fig. 12**).

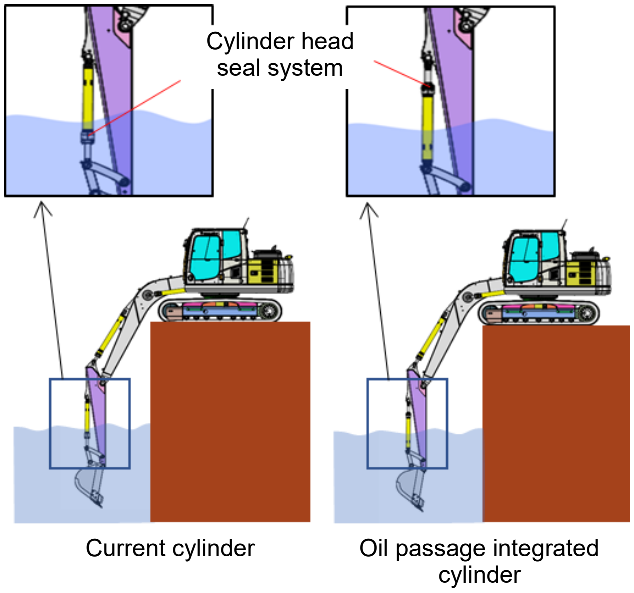



**Fig. 12** Effectiveness of reversing cylinder (underwater work)

## 6. Technical issues of oil passage integrated cylinder and responsive actions taken

An oil passage integrated cylinder must satisfy specifications and requirements of a machine body on which it is used. The development was conducted to establish a structure that fulfills such major premise.

This paper briefly references rod strength, pressure loss, as well as bonding of rod head, which had been an issue of productivity in the past.

### 6.1 Rod strength

The first concern that comes to mind is that establishing two oil passages inside a rod reduces the section modulus of the rod and specification values may not be satisfied, since rods in the past had been made of solid materials.

Buckling strength of the stationary component, as well as the piston fastening component are explained.

### 6.2 Buckling strength of stationary component

A destruction mode that may be encountered during an operation is rod buckling. The most severe condition arises, when the cylinder is extended and positioned near the end, while oil is filled at the bottom-side and the external force for contracting the rod is applied, which raises the pressure on the bottom-side and the peak pressure is reached. There is a concern that the rod may buckle in such an instance (refer to **Fig. 13**).

Oil passages are established at positions that enable retaining of rigidity in the buckling direction and minimize the reduction of the section modulus (detailed calculation shall be abbreviated here). Buckling test has indeed been conducted to verify pressure that causes buckling and confirm that specifications are satisfied.

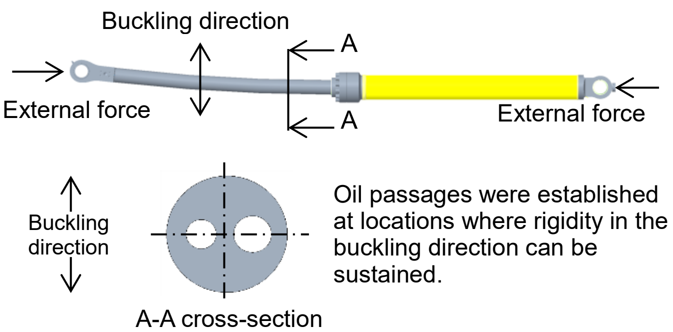



**Fig. 13** Failure mode for rod buckling

### 6.3 Thread strength in piston fastening component

Threading is machined on the rod to fasten the piston. Since two oil passages are machined in the oil passage integrated cylinder, the thread diameter needs to be greater than that of rods made of solid materials, in order to secure sufficient strength of the thread cross-section. The conventional fastening method positions the piston and rod contacting surfaces at a level that is indented from the stationary component. Thus, when the thread diameter is increased, the area of the contacting surface becomes smaller, and hence sufficient strength cannot be secured. For that reason, increasing the thread diameter had not been possible.

The contacting surface is located at the rod end surface with oil passage integrated cylinder, which makes it possible to increase the thread diameter to 1.2 times the conventional dimension.

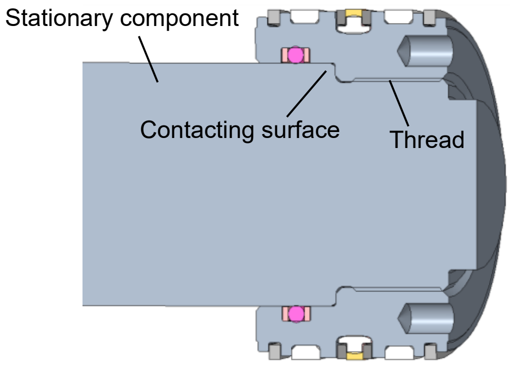



**Fig. 14a** Piston fastening of current cylinder

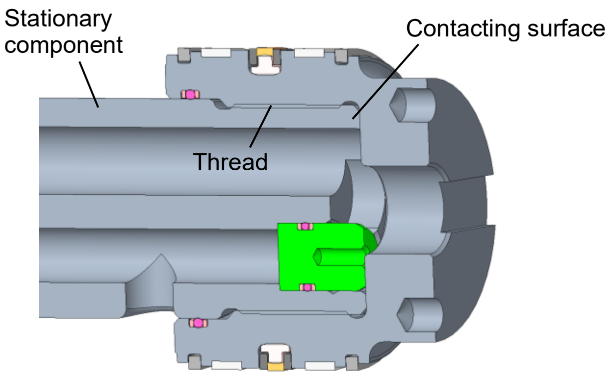



**Fig. 14b** Piston fastening of oil passage integrated cylinder

### 6.4 Information on pressure loss

There is a concern about pressure loss arising from the change in the flow of hydraulic oil, when the oil passage and diameter of a hydraulic cylinder are changed. The issue was about securing the same oil passage diameter as the current oil passage diameter and secure the cross-sectional area for the thread portion. However, due to the piston shape described above, the same oil passage diameter that is same as the current cylinder piping diameter can be secured, and confirmed that the pressure loss is not different from the current pressure loss.

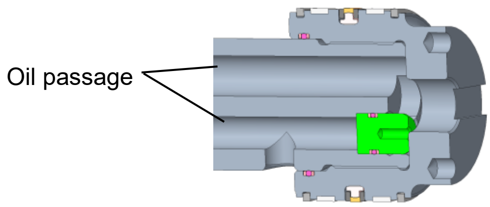



**Fig. 15** Oil passage of piston component

### 6.5 Information on rod head bonding method

Since groove for welding was required and defects of weld portions had to be taken into consideration with the bonding method of the conventional construction method, it had been difficult to establish oil passages that pass through bonded junctions.

Briefly explaining a case example involving the use of the conventional construction method, the bonded junction consists of deposited metal and spigot pin, making it impossible to put oil passages through. For this reason, the bonded junction diameter had to be made greater than the rod external diameter to secure bonded junction strength, then piping had to be inserted inside the base material to establish an oil passage for the head-side and the bottom-side. This led to poor yield of the material and because of internal piping, the structure had issues with productivity (refer to **Fig. 17**).

The friction welding method was adopted as the bonding method that resolves such issues. Since weld metal component like the conventional structures does not exist with the bonded junction of the friction welding method, it became possible to establish oil passages at the bonded junction and productivity issues were resolved.

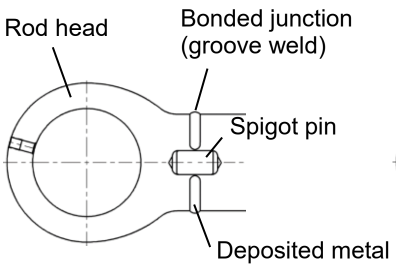



**Fig. 16a** Conventional bonding method

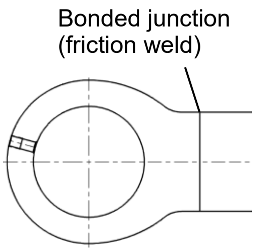



**Fig. 16b** Friction welding

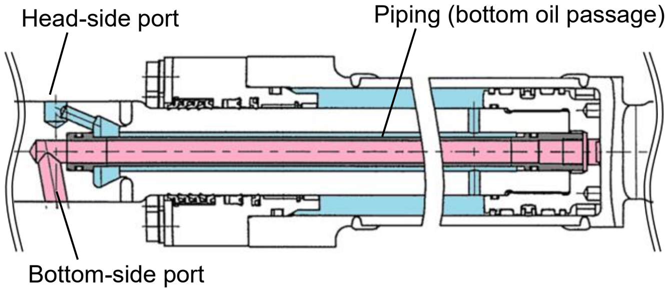



**Fig. 17** Shape from past prototyping

## 7. Information on oil passage sealing structure

The oil passage machining of the rod of the piping integrated cylinder is machined from the end surface of the rod and it is necessary to seal the oil passage on the head-side. An explanation about the sealing structure is provided, as it has a characteristic structure.

Performing threading work on the oil passage to seal off the passage with a plug may ordinarily be considered for the structure of sealing, but performing threading work causes the area to become even greater than the oil passage and that brings up an issue concerning the cross-sectional area of the piston thread portion. Furthermore, if by chance the plug becomes loose, cylinder interior may be damaged and the plug may get loose and flow into the circuit, which can potentially lead to damage of a valve, a means to prevent loosening of the plug is necessary to avoid such risks.

A structure with no threading work performed for oil passages, with a plug inserted and restrained by piston, was adopted for this reason. The deterioration of strength for the piston thread cross-section can be reduced in this manner. The risk of the plug becoming dislodged and flowing into the hydraulic circuit can be eliminated, by using the piston for restraining.

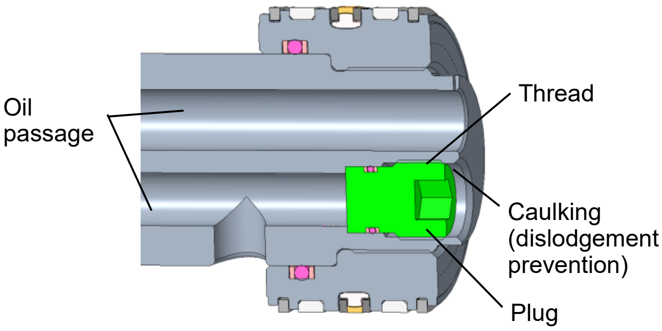



**Fig. 18a** Ordinary structure

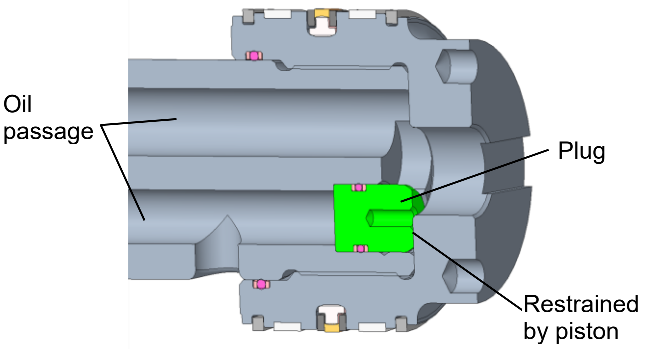



**Fig. 18b** Adopted method

## 8. Market operation survey

An operation survey was conducted in markets of Japan, Indonesia and Thailand, for a total of 10 units. All of these vehicles were used in an environment where oil leaks and damages to piping had occurred with the conventional installation, but installing the cylinder in reversed orientation is confirmed to have eliminated malfunctions.

**Fig. 19a** Scene of actual operation (water channel maintenance)

**Fig. 19b** Scene of actual operation (waste management)

## 9. Conclusion

We advanced our development of the cylinder for use as bucket cylinder on 13-ton series hydraulic excavators. The cylinder was adopted in the Southeast Asian markets, as well as for domestic demolishing specifications.

The fact that we were able to fundamentally change the environment that surrounds the cylinder head seal system in such a rapid manner, can be attributed to our great strength in conducting developments in-house, which enables us to consider opinions of people working on components and provide advice to those working on the machine body.

**Acknowledgments**

We would like to express our utmost gratitude to all those who cooperated with us in conducting actual operation survey in the market.

**Introduction of the author**

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**[A comment from the author]**

It is from this point on that we expect to be assessed by a large number of customers and we look to finding out what kind of evaluations we receive. We are hopeful that in the future, the orientation of the rod on bucket cylinder of hydraulic excavators become upward facing, with this development as the trigger.