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Expansion of Application Range of Component Restricting Pressure Change Caused by Oil Temperature Change

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Abstract: One of the advantages of an oil-hydraulic system is that the system keeps the value of oil pressure when the pressurized oil is enclosed in a container. However, when the pressurized oil is enclosed in a head or a rod end chamber of an actuator by a check valve or a shut-off valve, the value of the oil pressure deceases gradually by the leakage from the check valve or the shut-off valve. Then, it is necessary to employ non-leakage valve which is expensive or to control the pressure by using a valve or a pump control. In pressure control, energy to compensate pressure is required. From the view point of cost reducing or especially energy saving, it seems to be desirable to develop a component which prevents this pressure drop without energy consumption. Authors had developed a component restricting pressure change caused by oil temperature change. This component has simple mechanism and hardly needs energy. In this study, the possibility of the component to prevent pressure drop due to leakage is investigated experimentally. Consequently, it makes clear that the component is effective to prevent pressure drop by leakage and the enclosed pressure decreases only about 3% in 3 min and about 7% in 60 min when the target enclosed pressure is 3.5 MPa.

Key words: Oil-hydraulic, component, leakage, pressure drop, energy-saving.

1. Introduction

The significant merit of oil-hydraulics systems is to keep a constant pressure when the pressurized oil is enclosed in a container, for example a rod or head end chamber of oil-hydraulic cylinder. By the use of this merit, the position of an inertial mass can be maintained against gravitational force without an energy supply. This is a considerable point compared with electric systems [1] and an important point when energy saving is realized in oil-hydraulic systems. In addition to it, when a hydraulic chuck [2] of a machine tool fixes a workpiece at once, it is necessary to supply energy from outside to cope with the pressure drop by the leakage from a valve.

When a valve is used to enclose the pressurized oil in a container, there is a case where the pressure of oil in it decreases due to the leakage from the valve. To overcome this, a kind of pressure control technique, a non-leak type valve or an accumulator is introduced usually. When a pressure control is employed, a pump must be kept in operation at all time and this results in energy loss. When non-leak valve is selected, the cost is increased. In an accumulator, since it contains gas, regular maintenance is required in order to prevent its performance deterioration due to gas leakage [3].

From the above-mentioned viewpoints, it seems desirable to develop an oil-hydraulic component restricting pressure drop caused by leakage. It is significant that the energy used by the component should be as low as possible and its structure and working principal should be simple to achieve maintenance-free. There are few reports about the oil-hydraulic component with this function as authors know.

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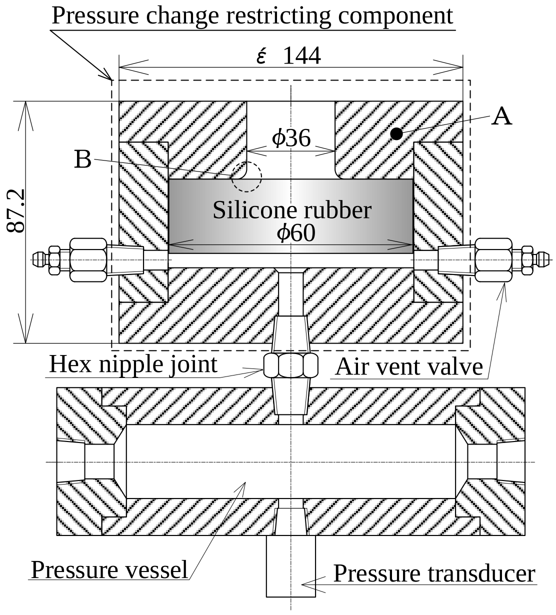
On the other hand, authors had developed a component restricting pressure change caused by oil temperature change [4]. This component has simple mechanism, hardly needs energy, and is maintenance-free. Therefore, it is meaningful to investigate its characteristics when there is leakage from a vessel.

In this paper, to expand the application range of the above-mentioned component, its characteristics about restricting the pressure drop are made clear in the case where oil leaks from a vessel. To realize this, some experiments are carried out varying the value of the enclosed pressure.

2. Outline of the Oil-Hydraulic Component to Restrict Pressure Change Owing to Oil Temperature Change

Fig. 1 describes the structure of the oil-hydraulic component to restrict pressure change owing to oil temperature change [4]. In this figure, the component is connected to a pressure vessel. The oil in the pressure vessel and the component may be contaminated with air bubbles. In order to vent the air bubbles in oil, air vent valves were set on the left and right sides of the component. In the component, silicone rubber was installed, which has stable characteristics over a wide range of temperatures and has excellent resistance to chemicals. When the temperature of the oil in the vessel changes, the rubber expands and contracts to keep the pressure constant. The upper section of the metallic container (Fig. 1a) is exposed to the atmosphere. The silicone rubber deforms into this space.

Fig. 2 shows the experimental results with and without component when the diameter, thickness, and hardness of the silicone rubber were 60 mm, 30 mm, and A30, respectively [4]. In Fig. 2, in the experiment without the component, pressure P in the vessel is raised by about 1.8 MPa when the temperature of oil is raised by 2 °C. On the other hand, in the experiment with the component, pressure P in the vessel is raised by about 0.04 MPa when the temperature of oil is raised by 8 °C. Therefore, it is known that the effectiveness of the component is verified.



(a) Schematic

(b) Photo from outside

Fig. 1 Oil-hydraulic component to restrict pressure change owing to oil temperature change.

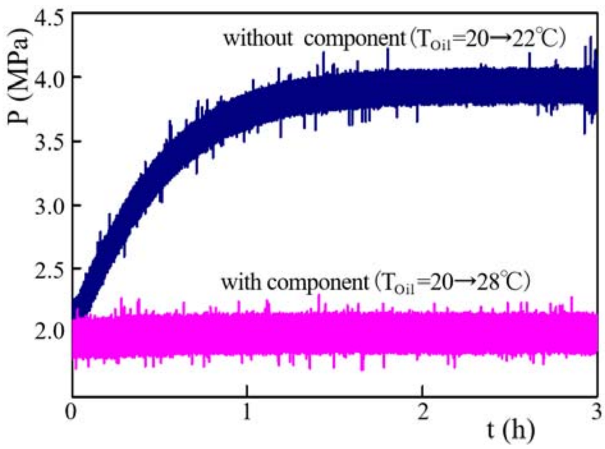


Fig. 2 An example of experimental results.

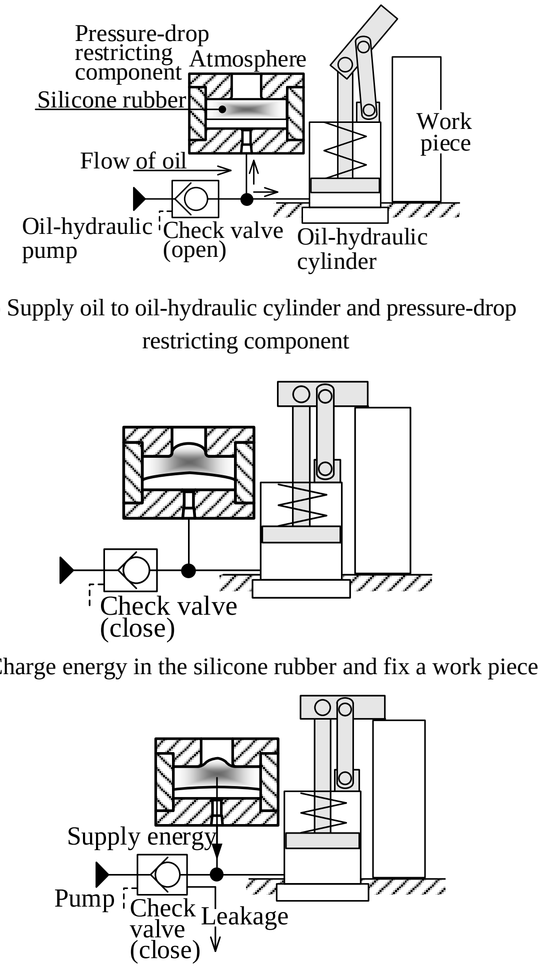
3. Prevention of Pressure Drop by Leakage

In this section, the characteristics of the oil-hydraulic component to restrict pressure change owing to oil temperature change (hereafter pressure-drop restricting component) are described in the case where oil leaks from a vessel through a valve.

3.1 Mechanism to Prevent Pressure Drop by Leakage

Fig. 3 shows the mechanism to prevent pressure drop by leakage through a valve. In this case, the pressure-drop restricting component is applied to an oil-hydraulic system to fix a workpiece in a machine tool. The system shown in Fig. 3 describes only the oil-hydraulic components which are necessary to latch a workpiece.

As shown in Fig. 3a, the oil-hydraulic pump supplies pressurized oil into both the head-end chamber of the oil-hydraulic cylinder and the pressure-drop restricting component. Then, as seen from Fig. 3b, the silicone rubber installed in the component extends to the atmosphere-opened hole and the energy provided by the pressurized oil from the pump is stored. The pressure in the head end camber of the oil-hydraulic cylinder becomes to be a constant value and the workpiece is fixed. And then, the pump stops. In the state shown in Fig. 3c, the pressure in the head end chamber of the oil-hydraulic cylinder begins to decrease owing to the leakage from the check valve. However, the energy stored in the silicon rubber in the component is supplied to the oil and pressure drop is restricted.



(a) Supply oil to oil-hydraulic cylinder and pressure-drop restricting component

(b) Charge energy in the silicone rubber and fix a work piece

(c) Prevention of pressure drop owing to leakage

Fig. 3 Mechanism to prevent pressure drop by leakage.

3.2 Basic Experiments

In order to verify the effectiveness of the mechanism to prevent pressure drop by leakage, some experiments were performed varying the value of the enclosed pressure.

The experimental apparatus to verify the usefulness of the component is shown in Fig. 4. This experimental apparatus is composed of an oil-hydraulic pump, a relief valve, a check valve, a pressure vessel with the pressure-drop restricting component, a stop valve and a bubble eliminator to reduce the effects of air bubbles in the oil. The pressurized oil delivered by the pump flows into the pressure vessel through the check valve. The oil flown out the pressure vessel flows back to the tank through the stop valve and the bubble eliminator. After circulating the oil for a while, the pressure at the pump discharge port was determined by using the relief valve. Then, the experiment was carried out by closing the stop valve and stopping the operation of the pump. And then, the pressure in the vessel was measured by using the semiconductor-type pressure transducer and the data logger.

To confirm the effectiveness of the mechanism to prevent pressure drop by leakage, target initial pressure P_{ti} of the oil enclosed in the pressure vessel

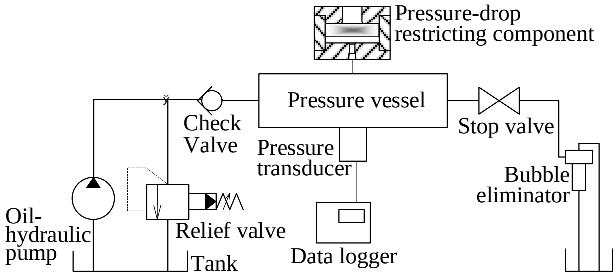
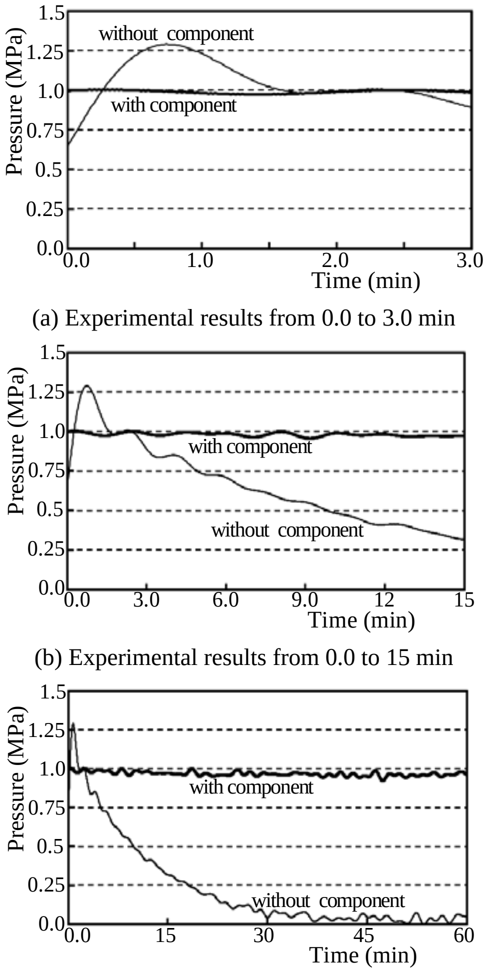


Fig. 4 Experimental apparatus.



(a) Experimental results from 0.0 to 3.0 min

(b) Experimental results from 0.0 to 15 min

(c) Experimental results from 0.0 to 60 min

Fig. 5 Experimental results (P_{ti} = 1.0 MPa).

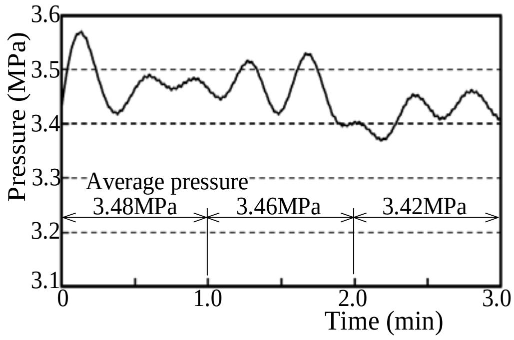
was set at about 1.0 MPa and experiments were conducted with and without the component. Then, the hardness of the silicon rubber was A50 and the oil temperature was about 25 °C.

The experimental results are shown in Fig. 5 where the stop valve is started to be closed and the pump is stopped at 0.0 s. As seen from Fig. 5a, in the case where the component is not installed, the pressure of the enclosed oil in the pressure vessel increases at the onset of the experiment that is at the time when the stop valve is started to be closed. This phenomenon seems to be influenced by the inertia of the oil. After this pressure rise, the pressure starts to decrease and it becomes 1.0 MPa. After the pressure becomes 1.0 MPa, it starts to decease by the leakage of the check valve and the stop valve. The pressure becomes 0.0 MPa in about 30 min. On the other hand, when the component is installed, the pressure decreases slightly. The pressure after 3.0 min becomes about 0.990 MPa which is about 1.0% lower than target initial pressure P_{ti} of the oil enclosed in the pressure vessel, the pressure after 15 min is about 0.981 MPa which is about 1.9% lower than P_{ti} and the pressure after 60 min is about 0.967 MPa which is about 3.3% lower than P_{ti}. Therefore, it is known that the mechanism effectively works to prevent the pressure drop by leakage. In addition to it, when the component is employed, the pressure rise at the onset of the experiment is not appeared. Therefore, it can be deduced that the component can absorb the pressure rise due to the inertia of oil and it works as a kind of water hammer phenomenon [5] preventing device.

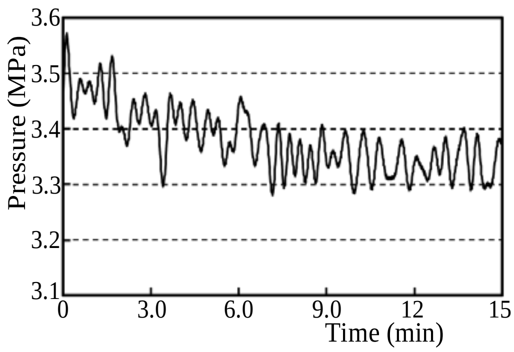
3.3 Experiments at Practical Pressure

In a machine tool such as a numerical controlled lathe, an oil-hydraulic system is often used [6-8] to drive clamp a workpiece, a tool and a table for machine tool. When a workpiece is clamped by an oil-hydraulic chuck, the maximum operation pressure of the chuck cylinder is 3.0 MPa-4.0 MPa [9, 10]. Therefore, it is necessary to carry out the experiments on the component when the pressure is increased.

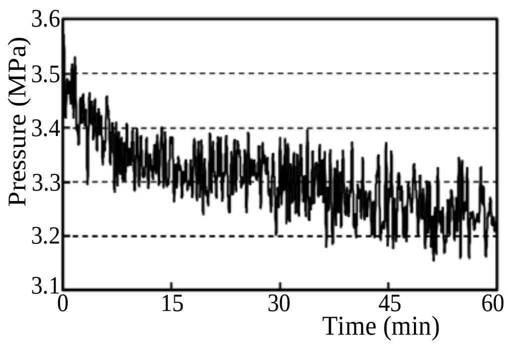
Experiment was conducted as target initial pressure P_{ti} of the oil enclosed in the pressure vessel was 3.5 MPa. The experimental results are shown in Fig. 6, where the stop valve is started to be closed and the pump is stopped at 0.0 s. As can be seen from Fig. 6, the pressure decreases with oscillation. This oscillation seems to be due to the interaction with the



(a) Experimental results from 0.0 to 3.0 min



(b) Experimental results from 0.0 to 15 min



(c) Experimental results from 0.0 to 60 min

Fig. 6 Experimental results (P_{ti} = 3.5 MPa).

silicon rubber and the leakage from the valve. From Fig. 6a, when the stop valve is started to be closed, the pressure is increased slightly by the inertia of the oil. After this pressure rise, the pressure starts to decrease gradually and the average pressure in each section which is shown in this figure also decreases gradually. However, until 3 min the pressure is almost 3.5 MPa, which is the target pressure. As seen from Figs. 6b and 6c, the pressure decreases with the lapse of time and it becomes about 3.2 MPa in 60 min by the interaction between the leakage of the valves and the energy supply from the silicon rubber.

Table 1 Pressure at time *n* and the ratio to P_1.

Time (s)	P_n	P_n/P_1
1	3.480	1.000
2	3.464	0.996
3	3.420	0.984
6	3.383	0.973
9	3.351	0.964
12	3.327	0.957
15	3.337	0.960
30	3.281	0.944
45	3.248	0.934
60	3.233	0.930

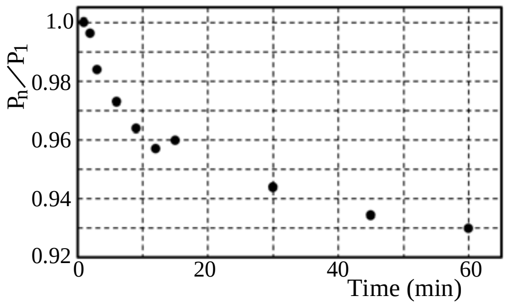


Fig. 7 Ratio P_n/P_1 vs. time.

The pressures at time *n* and ratios P_n/P_1 are shown in Table 1, where P_1 means the pressure at 1.0 second and P_n the pressure at *n* seconds. Ratio P_n/P_1 vs. time is illustrated in Fig. 7. As mentioned before, the pressure is oscillating because of the interaction between the leakage of the valves and the energy supply from the silicon rubber. Therefore, pressure P_n is the average pressure for one minute before time *n*. As can be seen from Table 1 and Fig. 7, ratio P_n/P_1 is 0.944 in 30 min, which is about 5.0% lower than initial average value P_1 and ratio P_n/P_1 is 0.93 in 60 min, which is about 7.0% lower than initial average value P_1. Hence, it is known that this component prevents pressure drop by leakage and then the enclosed pressure reduces about 7.0% of the initial pressure in 60 min. Consequently, it is deduced that the component can be used as the oil hydraulic system to clamp a workpiece of a machine tool.

4. Conclusions

In this paper, to expand the application range of a component restricting pressure change caused by oil temperature change that authors had developed, its characteristics about restricting the pressure drop were made clear in the case where oil leaks from a pressure vessel through some experiments. As a result, it can be made clear that the component is effective to prevent the pressure drop in a pressure vessel due to leakage from valves. By using this component, when the target enclosed pressure is 3.5 MPa, the enclosed pressure decreases only about 3% in 3 min, about 5% in 30 min and about 7% in 60 min. Next step is to clarify the relation between the performance of the component and its design parameters such as the diameter of silicon rubber and its hardness to improve the performance of the component.

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References

[1] Wang, T., and Wang, Q. F. 2014. "An Energy-Saving Pressure-Compensated Hydraulic System with Electrical Approach." *IEEE/ASME Transactions on Mechatronics* 19-2: 570-8.

[2] Manhajm, J., and Sweeney, D. C. 1955. "An Investigation of Hydraulic Lock." *Proceedings of the Institution of Mechanical Engineers*, 865-79.

[3] Cheng, F. Y., and Ma, Y. 2012. "A Review of the Present Status of Hydraulic Accumulator." *Applied Mechanics and Materials* 246-247: 629-34.

[4] Sakurai, Y., et al. 2012. "Proposal of a Mechanism to Restrict Pressure Change by Oil Temperature Change." *Intentional Journal of Automation Technology* 6 (4): 1-7.

[5] Berganta, A., Simpsonb, A. R., and Tijsseling, A. S. 2006. "Water Hammer with Column Separation: A Historical Review." *Journal of Fluids and Structures* 22-2: 135-71.

[6] Firth, D., and Hancock, R. H. Y. 1961. "The Advantages of Hydrostatic Drives for Machine Tools." *International Journal of Machine Tool Design and Research* 1-4: 275-82.

[7] Brecher, C., Jasper, D., and Fey, M. 2017. "Analysis of New, Energy-Efficient Hydraulic Unit for Machine Tools." *International Journal of Precision Engineering and Manufacturing-Green Technology* 4: 5-11.

[8] Brecher, C., Triebs, J., and Jasper, D. 2015. "Energy Efficient Solutions for Hydraulic Units of Machine Tools." *Re-engineering Manufacturing for Sustainability*, 191-6.

[9] Kitagawa. "High-Speed Closed Centre Double Piston Hydraulic Cylinder YW-R Series." https://www.kitagawa.com/en/mtools/cyl/yw-r.html.

[10] Kitagawa. "High-Speed Hydraulic Cylinder with Through-Hole F Series." https://www.kitagawa.com/en/mtools/cyl/f.html.