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In Situ Observation of a Grease Lubricant Film on a Radial Seal by Fluorescence Induced Microscopy

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Reduction gears are installed inside the joints of industrial robots and lubricated with grease. In this study, the sealing surfaces of radial seals were observed in grease lubrication with fluorescence microscopy. The sealing performance was tested with oscillating operation. The pump rate tends to increase and sealing performance improves in proportion to the oscillation angle. Changes in oil film thickness and amount of thickener were observed on the sealing surfaces. Our results suggest pumping ability of radial shaft seals in grease lubrication is related to the viscosity of the base oil.

1 Introduction

Industrial robots are operated by servomotors and reduction gears in their joints. Grease lubrication of the reduction gears is important for the delicate movements of the robot, and radial seals prevent grease leakage. These sealing mechanisms in oil lubrication have been studied by various authors and are comparatively well understood [1]. However, many aspects of the sealing mechanism have not been understood, with grease as the sealing target in oscillating operation. Oscillating operation is defined here as an operation pattern that rotates in the forward and reverse circumferential directions, the same as the joints of an industrial robot. Grease generally contains a base oil, thickener and additives. It is a non-Newtonian fluid with frequency dependence. Because thickeners have the ability to retain the base oil and reduce friction. It is necessary to observe the base oil and thickener individually to understand the lubrication condition in grease lubrication. Y. Sato et al observed the lubrication film on the radial seal in oil using LIF (Laser Induced Fluorescence). However, the lubrication film on the radial seal in grease was not observed [2]. It is known that infrared spectroscopy and fluorescence induced microscopy are effective in observing grease behaviour in situ. These methods were used due to their special feasibility of observing film thickness and thickener individually [3,4]. Previous research suggest thickener particles are present in the sealing gap and influence the performance of the sealing system [5]. However, there are no results of individual observations of the film thickness and thickener in the grease lubrication film on the radial seals. In this study, the sealing surfaces of radial seals in grease lubrication were observed individually for film thickness and thickener using a fluorescence induced microscopy.

2 Amount of leakage and pump rate

First, the seal surfaces were observed in grease and oil lubrication to measure the amount of leakage and pump rate. To replicate the motion of an industrial robot joint, a servo motor was used. Three different operations were tested. A hollow glass shaft was used for the shaft and the sealing surface was observed in-situ using a mirror from inside the shaft.

2.1 Sample and test rig

A schematic diagram of the test rig is shown in Figure 1. A hollow glass shaft was used for the shaft. The sealing surface and amount of leakage was observed from the inside of the shaft using a mirror. An observed image is shown in Figure 2. The test conditions and operations are shown in Table 1, movement of the shaft in each operation is shown in Figure 3, and the test program under each operation is shown in Figure 4. To investigate the effects of the oscillating operation, we tested three operations: one with a small oscillation angle (A), one with a one-way rotation stop (B) to investigate the effects of the pause that occurs during the oscillating operation, and one with a large oscillation angle (C). FKM radial seals were used for the test sample. The lubricants used were lithium soap grease, often used to lubricate reduction gears for industrial robots, and PAO (Poly-Alpha-Olefin), which is a base oil component of lithium soap grease. Sample details are shown in Table 2.

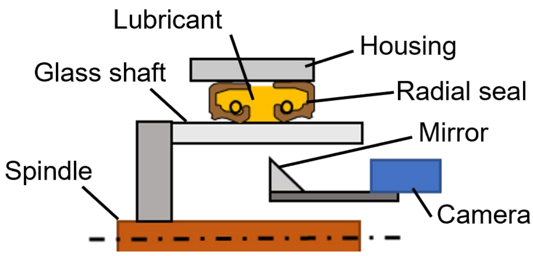

Figure 1 : Schematic diagram of test rig

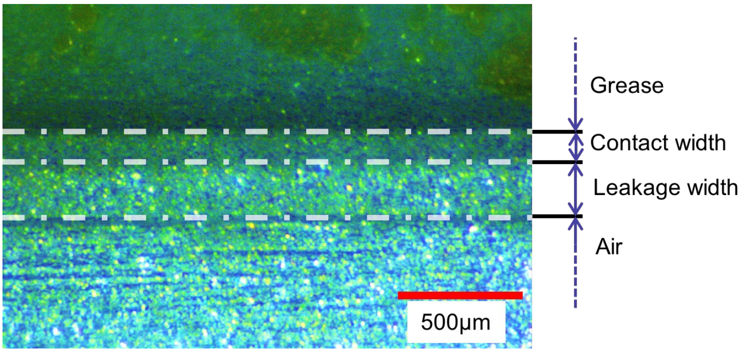

Figure 2 : Observation imager

Table 1 : Test condition

	(A)	(B)	(C)
Shaft eccentricity	T.I.R. aiming for 0mm		
Rotation speed	Max 42mm/s		
Operation	Oscillation	One-way rotary stop	Oscillation
Oscillation angle	17°	45°	90°
Test time	24~48h		

Table 2 : Sample details

Test radial seal			
Material	FKM		
Remarks	Dust lip cut out		
Lubricant			
	Li soap grease1	Li soap grease2	oil
Base oil	PAO		
Base oil viscosity, cSt@40℃	30,191		30,191,400
Thickener	12-Hydroxystearic acid lithium salt		-
Thickener shape	Long fiber	Short fiber	-
Penetration	285		-

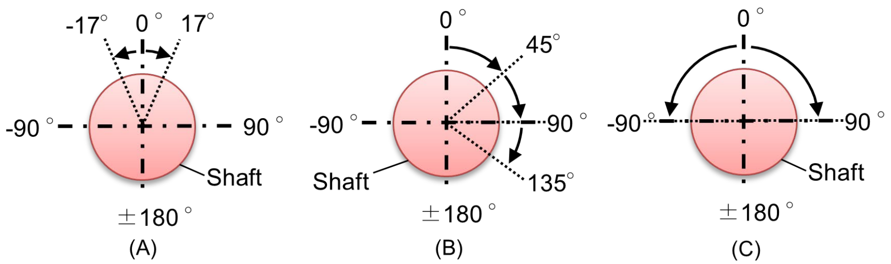

Figure 3: Movement of the axis in each operation

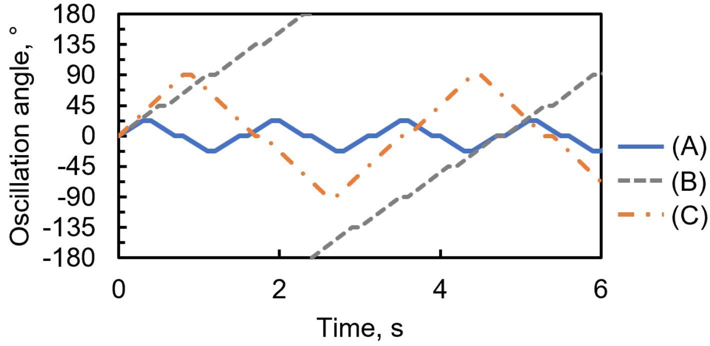

Figure 4: Program of each operation

2.2 Results and discussion

The results of leakage measurements using oil with a viscosity of 30 cSt under (A) operating conditions are shown in Figure 5. These tests were conducted four times with new radial seals under the same conditions and changes in leakage were observed. The amount of leakage increased linearly with the sliding distance. Also, the amount of leakage was different in all four cases despite the same test operations. This is probably due to some other factor than insufficient pump rate during oscillating operation. The results of the seal test for each lubricant under operations (A) and (B) are shown in Table 3. Test results are indicated only as leak or seal. This was because the amount of leakage was different for each test. From those results, the higher the viscosity of the base oil, the less tendency to leak during oscillating operation. In test operation (B), any lubricant would seal. Pump rates were also measured in each operation. Pump rate was calculated from the amount of leakage caused by installing the seals backwards. When measuring with this method, it was necessary to determine whether the leakage volume is due to gap leakage or leakage due to pump effect. Therefore, only the sealed condition of PAO and 400cSt was considered. The results are shown in Table 4. It was found that the pump rate tends to increase in proportion to the oscillation angle. This seemed to show that the pump rate is related to the sliding distance, even during oscillating operation. When the sealing target is oil, the pump rate related to the viscosity, the lubricant with higher viscosity seemed to seal better. When the sealing target is grease, the pump rate is also related to the base oil viscosity and showed a tendency to increase the sealing performance.

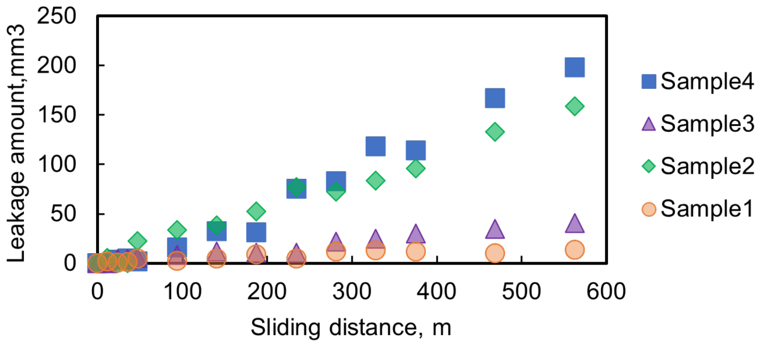

Figure 5: Visualization test result (about leakage amount)

Table 3: Seal test result

<table>
<tr><td>Operation</td><td colspan="7">Oscillating</td><td colspan="3">One-way rotary</td></tr>
<tr><td>Lubricant</td><td colspan="3">PAO</td><td colspan="4">Li soap grease</td><td>PAO</td><td colspan="2">Li soap grease</td></tr>
<tr><td>Thickener shape</td><td colspan="3">-</td><td colspan="2">Long fiber</td><td colspan="2">Short fiber</td><td>-</td><td>Long fiber</td><td>Short fiber</td></tr>
<tr><td>Base oil Viscos-ity(cSt)</td><td>30</td><td>191</td><td>400</td><td>30</td><td>191</td><td>30</td><td>191</td><td>30</td><td>30</td><td>30</td></tr>
<tr><td>Condition</td><td>Leak</td><td>Leak</td><td>Seal</td><td>Leak</td><td>Seal</td><td>Leak</td><td>Seal</td><td>Seal</td><td>Seal</td><td>Seal</td></tr>
</table>

Table 4: Pump rate at each oscillation angle

Operating conditions	Pump rate $(\mathrm{mm}^3/\mathrm{min})$
Oscillating operation at 17°	0.25
One-way rotary stop operation at 45°	1.07
Oscillating operation at 90°	1.29

3 Fluorescence observation

From the measured leakage and pump rate, it was found that the base oil viscosity of the grease is related to the sealing property. To find out how the thickener affects pump rates and leakage, the sealing surfaces of the radial seal were observed individually for film thickness and amount of thickener using the fluorescent method.

3.1 Sample and test rig

A schematic diagram of the test apparatus is shown in Figure 6. A mercury xenon lamp and a line laser were used as light sources. An excitation filter was used to extract light of the wavelength that excites the fluorescent agent from the light source, and an emission filter was used so that only the light that fluoresces can be observed. For the test sample, a FKM radial seal was used, and for the lubricant, fluorescent agents were dissolved in the Li soap grease1 in Table 2. Pyrene was used as the fluorescent agent to observe the film thickness, and Coumarin 6 to observe the amount of thickener. 1 wt.% of Pyrene and 500 ppm of Coumarin6 was dissolved in Li soap grease1. To observe the behaviour of thickener and film thickness of grease during pumping, the lip was pushed with a spatula to make it leak to the air side.

3.2 Results and discussion

Figures 7 and 8 show the distribution of luminance on the sliding surface. Because the luminance is proportional to the film thickness and thickener amount, Figures 7 and 8 represent their respective distribution [4]. The film thickness distribution of the radial seal for grease lubrication was found to be thinner toward the air side. This result is similar to the film thickness distribution during oil lubrication of radial seals [2]. The distribution of thickener was different from that of the film thickness distribution, and the amount of thickener seemed to be almost constant in the contact area. From the results, the base oil in the grease appeared to flow along the contact pressure distribution in the contact area. The thickener remained trapped in the contact area as in the start of the test. It was observed that occasionally agglomerates of the thickener would enter the contact area. However, the base oil basically flowed within the contact area while most of the thickener did not.

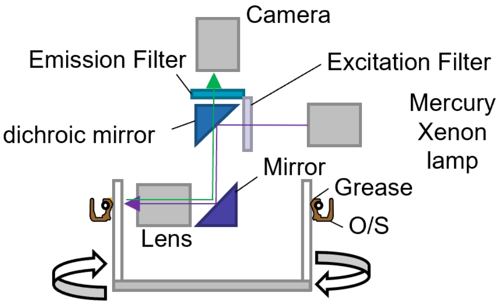

Figure 6: Schematic of Fluorescence observation

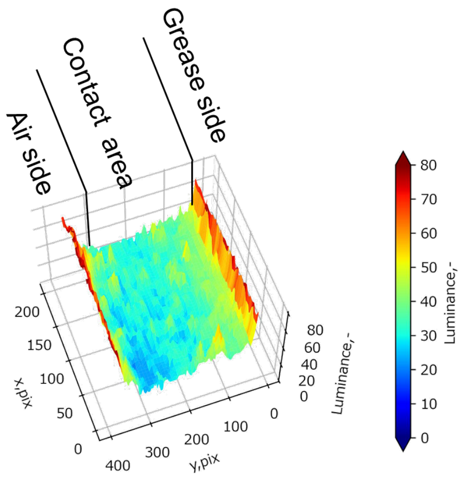

Figure 7: Distribution of film thickness on sealing surface

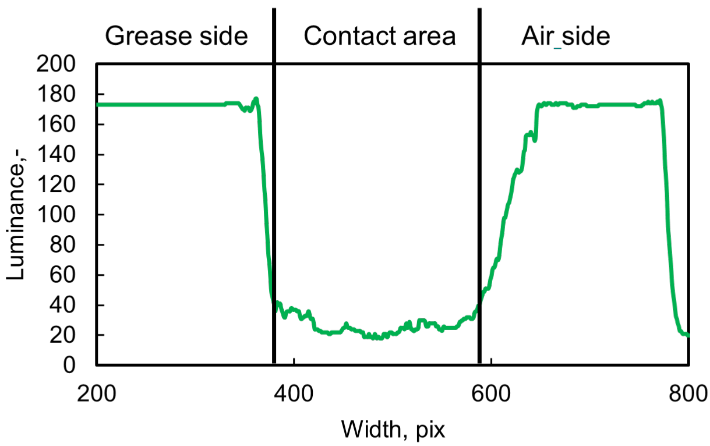

Figure 8: Distribution of thickener amount on sealing surface

4 Summary

To investigate the lubrication and sealing mechanism of radial seals in industrial robots, seal performance tests and sealing surface observation using a fluorescence method in grease lubrication were conducted. The pump rate in grease lubrication seemed to be related to the viscosity of the base oil. The pump rate tends to increase and sealing performance improves in proportion to the oscillation angle. This suggests pump rate required for sealing could differ depending on the oscillation operating conditions. Fluorescence observation might be useful to investigate the state of the lubricant seal in more detail.

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