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# Control of contact resistance and frictional condition between cylindrical models for hydraulic half-floating sliding leadscrew

Shigeo Fukada [1], Yukihiro Nakajo [1]

[1]Shinshu University, Japan

sfukada@shinshu-u.ac.jp

**Abstract**
A method of improving the frictional property of a sliding leadscrew is here proposed: applying hydraulic half-floating sliding surfaces where the axial load is supported by both solid contact and hydraulic pressure. To maintain and control the half-floating condition, appropriate measure of the contact condition is necessary. This study introduces electric contact resistance as a measure of contact condition. In this report, using cylindrical models to simplify an actual sliding leadscrew, some experiments are performed to examine the property of contact resistance under hydraulic pressure. It is shown that the feedback control system with real-time sensing of electric contact resistance makes it possible to keep the rate of separation at reference values.

Keywords: Sliding leadscrew, Half-floating condition, Cylindrical model, Hydraulic pressure, Contact resistance, Rate of separation

## 1. Introduction

Sliding leadscrews have superior advantages compared with ball screws or hydrostatic leadscrews: higher static stiffness and damping effects for low frequency vibration [1]. However, they have the disadvantages of large friction loss and nonlinear frictional property around reversal motion [2]. The author has proposed a novel leadscrew mechanism applying half-floating sliding surfaces where the axial load is supported by both the hydraulic pressure and the solid contact [3]. The half-floating condition results in an ideal sliding contact featuring both low friction and high stiffness. Though dynamic control is necessary to maintain the optimum half-floating condition under external load, practical reference parameters corresponding to the half-floating condition have not yet been established. This study introduces electric resistance as a measure of contact. In this report, using cylindrical models to simplify an actual sliding leadscrew, some experiments are performed to examine the property of contact resistance under hydraulic pressure. In addition, a control system is constructed to maintain the half-floating condition by manipulating hydraulic pressure.

## 2. Principle and simplified model

Frictional surfaces of a full-floating hydraulic bearing are separated perfectly by an oil film, and the whole axial load is supported by hydraulic pressure. If the pressure is reduced, the thickness of the oil film is also reduced, so that the frictional surfaces have partial contact areas, and the hydraulic oil leaks through a slight gap $h$ formed by surface roughness or form deviations, as shown in Figure 1. This condition, where the axial load is supported by both the hydraulic pressure and the solid contact, is called hydraulic half-floating condition [4]. To keep the half-floating condition steady, it is necessary to manipulate the pressure, compensating for the increase of the axial load. It is desirable to control the pressure with appropriate measured reference of the contact condition. Electric resistance between contact surfaces representing the area of real contact is a typical measure of contact [5][6]. If electric voltage $V_s$ is applied between the contact surfaces through a buffer resistance $R$, as shown in Figure 1, the electric potential $V_x$ between the surfaces is determined by the contact resistance $R_x$ and $R$. Here, the ratio of $V_x$ to $V_s$ is called the rate of separation $\tau$, which is explained by $R_x$ and $R$ as follows.

$$\tau = \frac{V_x}{V_s} = \frac{R_x}{R + R_x} \tag{1}$$

The rate of separation $\tau$ is 0 under perfect conductive contact, while it approaches 1 under full-floating separation.

This study applies the half-floating condition to the sliding leadscrew to make possible the hydraulic half-floating leadscrew. For the simplified experiments, the contacts between screw threads are modelled to the contact between the end surfaces of a pair of cylinders, as shown in Figure 2. The outer diameter of the screw model is 30 mm, and inner diameter of the nut model is 22 mm for target screw thread of Tr30×8. The hydraulic pressure is supplied to the sliding surfaces by plain machine oil of VG10 through three capillary-

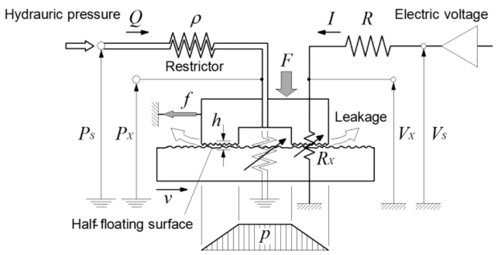



**Figure 1.** Half-floating bearing

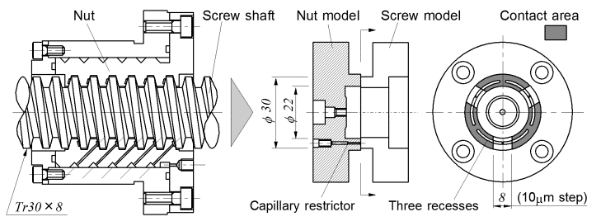



**Figure 2.** Experimental cylindrical model for sliding leadscrew

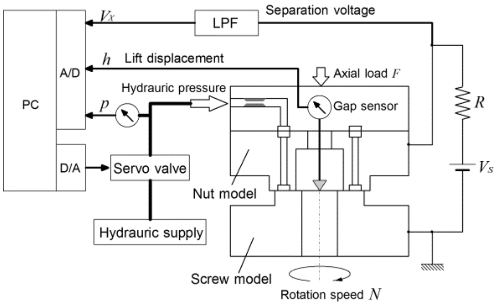
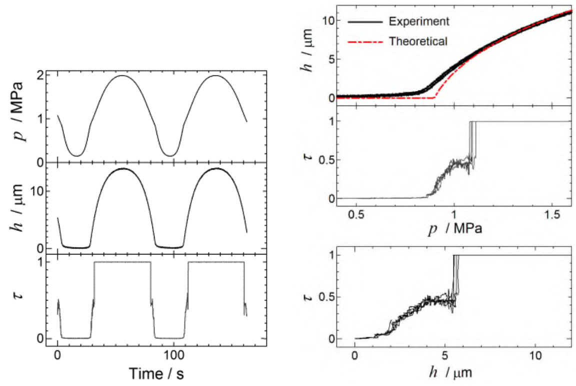



**Figure 3.** Experimental setup




(a) Time response (b) Relation between variables

**Figure 4.** Experimental results ($F$=100 N, $N$=0 rpm, R=10 Ω)

type restrictors and recesses.

Figure 3 shows the experimental setup schematically. The cylindrical models are driven under a fixed axial load and rotational speed on a universal friction tester. The pressure is manipulated using a linear hydraulic servo valve, and an electronic circuit is connected between the models to measure contact resistance. The lifting displacement $h$ is measured using an eddy-current gap sensor on centre axis, and the measured displacement is identified with the gap $h$ between the surfaces.

## 3. Transitional property from contact to separation

First, the hydrostatic properties were measured under conditions ranging from perfect contact to full-floating. Figure 4 shows the experimental results: (a) shows the response to sinusoidal change of voltage input into the servo valve, and (b) shows the relations between the variables. It is confirmed that the relation between the hydraulic pressure and the lifting displacement agrees with the theoretical property. The rate of separation begins to rise at the start of floating where pressure $p$ is about 0.8 MPa, and it increases gradually to 0.5, where the gap $h$ is about 5 µm. Finally, $\tau$ reaches maximum value after significant fluctuation. Because the rate of separation tends to fluctuate significantly, a low-pass filter is necessary to use the rate of separation to indicate the half-floating condition.

## 4. Control of rate of separation

Next, a feedback control system was constructed using PI controller to regulate the rate of separation as a reference value. Figure 5 is a block diagram of the control system. It consists of cascade controllers with a minor loop for pressure control and a major loop for $\tau$ control. The wide band-width of the pressure control system was realized at 165 Hz. The cut-off frequency of the low-pass filter for the rate of separation was set at 100 Hz. The author's previous study on the hydrodynamic sliding leadscrew showed that the frictional torque took its minimum value around the condition where $\tau$ was 0.5, so the primary target of the control is to keep $\tau$ at 0.5 [7]. Figure 6 shows the controlled results for reference value of $\tau$ =0.5. The control was stable under stationary conditions without rotation, while the controlled $\tau$ showed fluctuations under $N$ =36 rpm. Here the graphs of $\tau$ are shown after processing with moving averaging over 50 ms. Though the rate of separation generally shows significant fluctuation, the average level of control is satisfactory at reference value. Figure 7 shows the controlled results for sinusoidal reference. The average curve of the controlled $\tau$ follows quasi-static change of the reference successfully, and the availability of the control system is thus verified. Dynamic performance of the controlled system under various contact conditions will be investigated in future works.

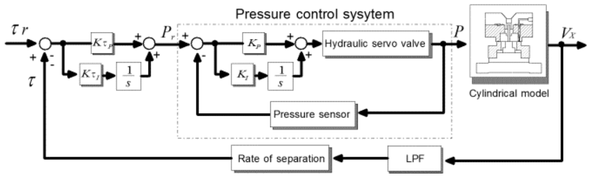
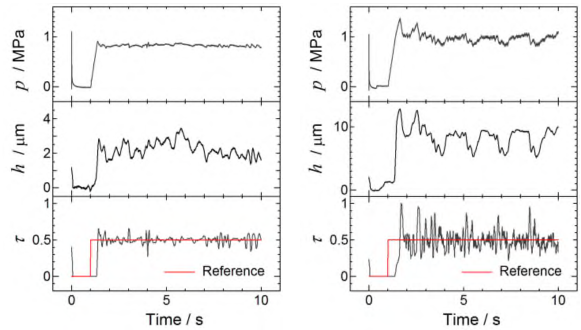
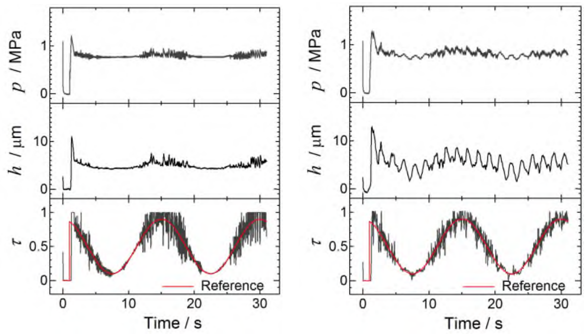



**Figure 5.** Control system




(a) $N$=0 rpm (b) $N$=36 rpm

**Figure 6.** Controlled results (constant reference $\tau_r$=0.5)




(a) $N$=0 rpm (b) $N$=36 rpm

**Figure 7.** Controlled results (Sinusoidal reference)

## 5. Conclusion

The electric resistance and the rate of separation between contact surfaces were introduced as a measure of contact condition for the hydraulic half-floating sliding leadscrew. Using a simplified cylindrical model, a control system for the rate of separation was constructed. It was possible to maintain the rate of separation at the desired value, so the availability of the control system using the rate of separation was thus verified.

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