The Influence of Contact Area on Oil Film Thickness

Shao-Hsien Chen, Zih-Jing Huang, Jia-Xin Tsao, and Rui-Ke Jian

***Abstract*—With the development of the tool machine industry, the precision and quality demand for processing is more exquis-ite, from the traditional industrial manufacturing equipment in the past, to the current development of high-speed, high-pre-cision, high-efficiency intelligent automation tool machine equi-pment, in the face of today's globalization,customerization andenvironmental awareness trend.**

Taking the vertical milling machine as an example, the feed system drives the machining in the direction of the tool machining to complete the cutting process.The rail c-ontact surfac-e of the feed system is grinding. It produces noise, bad vibration, processing rigidity is reduced, processing accuracy is reduced, friction almost thermal energy is generated, etc. Finally it reduces the service life of the servo motor. In this study, the contact between the slide rail and the slide seat was obtained by using the homemade device to obtain the influence of the contact area of the rail on the thickness of the lubricant. When the same contact area, the oil film thickness of the lower oil injection amount is small. The thickness of the oil film with higher oil injection amount is thicker. When the same oil injection volume, the thickness of the oil film of the larger contact area is small.

***Index Terms*—Lubrication, oil film, voltage measurement method.**

I. INTRODUCTION

When machinery produces high-precision components, it needs its conditions for high precision, high speed, high effi-ciency, and the feed system is one of the important key systems of the tool machine. Among them, the ball screw and sliding guide as the main source of heat due to friction of the original. The effects of component heat include structural deformation and mechanism wear. In the end, the overall machining accuracy is greatly reduced.

Combined with the above factors, the advantages and disadvantages of the feed system will directly affect the ove-rall accuracy and reliability of the tool machine, and the er-ror factors affecting the feed system are shown in Fig. 1.

A. Oil Film Measurement Method

Mechanical component lubrication mechanism plays an i-mportant role in the joint mechanism system In addition to the most basic lubrication supply, mechanical component cooling, but also affect the processing accuracy. Therefore, the determination of oil film thickness is very important.

Xie Qikai [1]. Used optical multi-beam interference theory to measure the thickness of the oil film, explore the relationship between the thickness of the oil film and the resistance value, understand the relationship between the resistance value and the thickness of the oil film in dynamic situations, the faster the speed of the oil film thickness, the greater the resistance value, the larger the load, the smaller the thickness of the oil film, the smaller the resistance value. This experimental phenomenon is consistent with the Renault procedure, summarizing the above, the most affected factor is the thickness of the oil film, the oil film thickness increases its resistance value.

B. Feed System Lubrication Analysis

Lubricants provide reduced friction, resistance, cooling, cleaning, rust protection, sealing and earthquake resistance. There are many factors affecting lubricants, as illustrated in Fig. 2.

Joshia *et al*. [2], foreign scholars. Used rheometers and lubricants of different viscosity to do experiments, in which the steel ball sliding on the surface of the object to be mea-sured. A smoother interface can be created, which reduces friction.

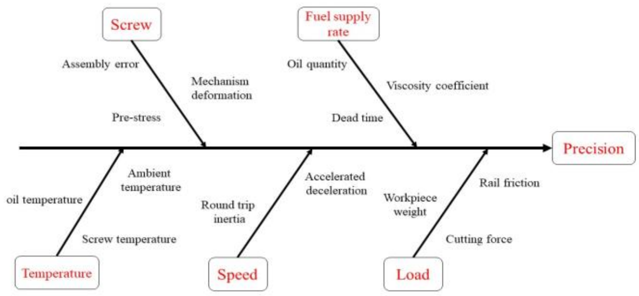

Fig. 1. Factors affecting the positioning accuracy of the feed system.

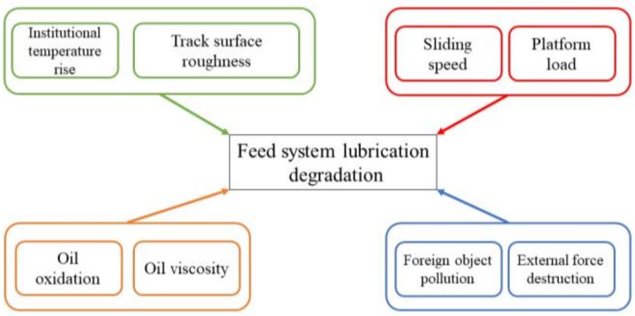

Fig. 2. Lubrication degradation factors of feeding system.

C. Feed System Friction Analysis

The motion mode of feed system drives the ball screw to transmit power to sliding track and sliding seat by servo motor, which forms reciprocating friction action. Therefore, lubricants play an important role in this area, providing benefits such as cooling, corrosion prevention and good sliding, as shown in Fig. 3.

Manuscript received October 12, 2019; revised February 7, 2020.
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Abdullah Azam *et al.* [3], a foreign scholar. Has obtained contact pressure and oil film distribution by using a rough ball and a rough disk. In this method, the contact pressure can be predicted by solving the equation by using the Leiruo equation. The results show that the average friction film thickness increases with the increase of SRR (sliding/rolling ratio), the lower the entrainment velocity and the lower the ratio of λ, the thick of the friction film increases.

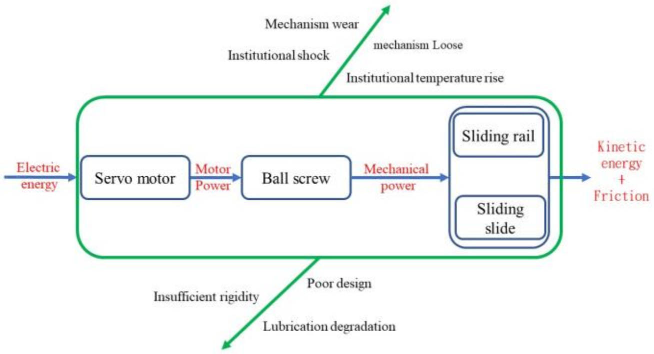


Fig. 3. Friction factors of feed system.

D. *The Composition of the Feed System*

The composition of the feed system is shown in Fig. 4. The main function is to make the platform move along the direction of ball screw and sliding rail. ts main components are driver, rotary encoder, servo motor, coupling, ball screw, fixed bearing seat, support bearing seat, slide rail and slide seat, and motion platform.

For example by a three-axis machine tool support hard track. The drive of the feed system is from NC controller to servo driver. The servo driver transmits the pulse signal to servo motor. The servo motor drives the ball screw through the coupling and installs bearing support at both ends of the screw. The restriction of axial force and radial force is generated, and then the rotational motion is transformed into linear motion by ball screw, which drives the ball screw nut and nut to make the working platform move in X and Y axis direction. The action is shown in Fig. 5.

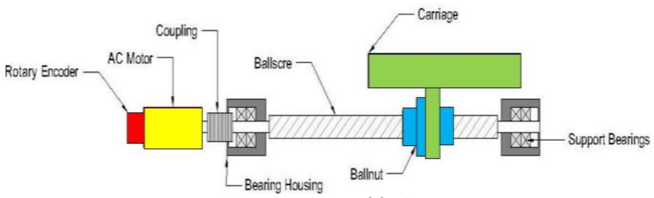


Fig. 4. Composition of feed system.

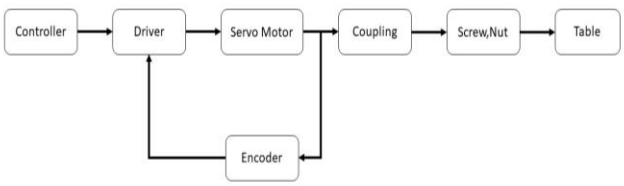


Fig. 5. Action program diagram of feed system.

E. *Voltage Measurement Method*

The voltmeter for measuring the voltage in the circuit must be connected in parallel with the object to be measured, as shown in Fig. 6. Fig. 6(a) is a DC voltage measurement circuit. When wiring, attention should be paid to the voltage input polarity of the voltmeter and the voltage output polarity of the object to be measured. Fig. 6(b) illustrates the AC voltage measurement circuit. There is no polarity requirement for input and output when measuring load voltage.

If the measurement of AC high voltage is more than 500 V (volt), the voltage transformer should be used to expand the range of the voltmeter. Voltage transformer is a step-down transformer whose turn number of secondary winding is far less than that of primary winding. The rated voltage of primary winding is different from that of secondary winding. The rated voltage of secondary winding is 100 V (volt). This method brings greater convenience in measurement.

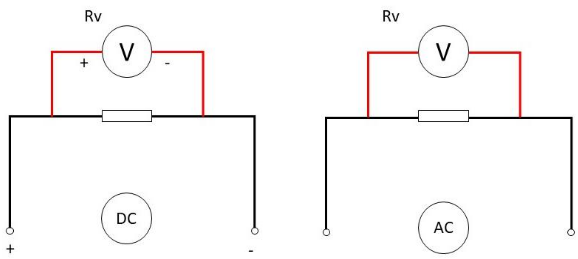
The circuit description of the voltage transformer is shown in Fig. 7. The primary winding A-X is connected in parallel with the load to be measured, and the secondary winding A-z is connected in series with the voltmeter. If the turn number of primary winding is $N1$ and the turn number of secondary winding is $N2$, then the voltage ratio is:

$$K = N1 \,/\, N2 = U1 \,/\, U2 \quad \text{voltage}(V) \tag{1}$$

If the voltmeter reading is $U2$, the load voltage to be measured is:

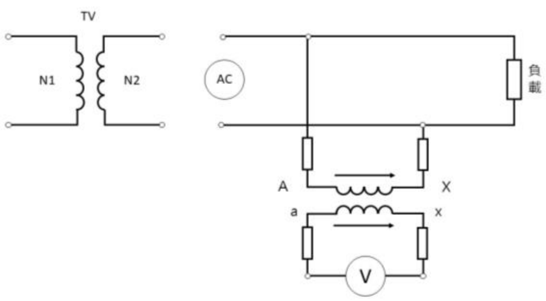
This voltage range can be expanded to the original table K times.

$$U1 = K \times U2 \;\; \text{voltage}(V) \tag{2}$$



(a) (b)

Fig. 6. Voltage measurement circuit [4] (a) DC voltage measurement method (b) AC voltage measurement method.



(a) (b)

Fig. 7. Voltage transformer circuit wiring diagram [4] (a) Voltage transformer symbol (b) Voltage transformer circuit.

II. Experimental

A. *Experimental Equipment*

This experiment is to simulate the lubricating film characteristics of the rail and slide of the hard rail feed system. Make three sets of closed simulated slide rail contact fixtures with different contact areas, as shown in Fig. 8. Its dimensions are surface area 30 × 30 mm^2, 40 × 40 mm^2, 50 × 50 mm^2, and the material is medium carbon steel. Table I is a detailed specification table of the closed simulated slide rail contact fixture.

TABLE I: SPECIFICATIONS OF THE CLOSED-CIRCUIT SIMULATION SLIDE CONTACT JIG

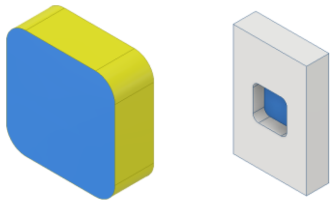
Jig size	100 mm×65 mm×20 mm		
Oil film contact area (mm2)	30×30	40×40	50×50
Jig depth (mm)	10		

TABLE II: VOLTAGE SENSOR SPECIFICATION SHEET

Input voltage (V)	DC 0 ~ 25
Voltage detection (V)	DC 0.02445 ~ 25
Voltage analogy resolution (V)	0.0489

The voltage Sensor DC voltage sensor measures the voltage between the contact surface of the analog jig and the base contact surface, specification as Table II. We use KEITHLEY DMM6500/6-digit half-touch screen digital multimeter to calibrate the sensor to measure the relative voltage value of the simulated jig film, Specification as Table III. MEAN WELL/HLG-80H-12-A constant voltage constant current power supply supplies the circuit power of the analog jig, Specification as Table IV.

The experiment carried out the measurement of relative oil quantity and relative oil film thickness by self-made oil tank fixture and voltage measurement circuit. Experiments were carried out with three different cross-sectional areas and three different oil amounts. Data are retrieved and recorded on PC through toughness instruments and sensors. After the analysis was organized by OriginPro software, the experimental measurements were presented.



(a) Contact surface (b) contact base

Fig. 8. Closed simulation slide rail sliding contact fixture.

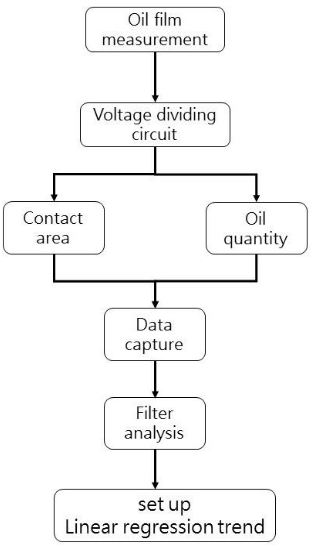


Fig. 9. Experimental flow chart.

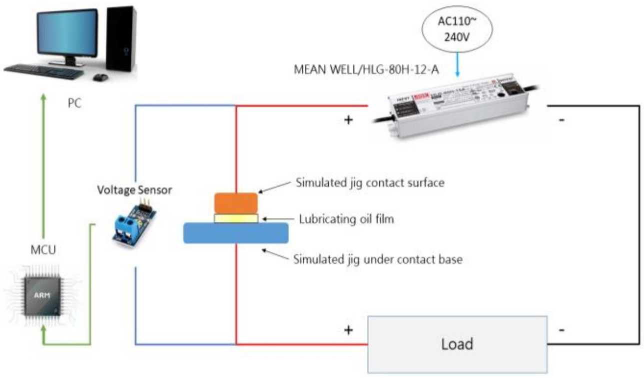


Fig. 10. Oil film voltage measurement.

B. *Experimental Procedure*

Experiments were performed according to Fig. 9 using the Table V parameter table. The circuit architecture diagram is shown in Fig. 10.

TABLE III: KEITHLEY DMM6500 DIGITAL MULTIMETER SPECIFICATION [5]

DC voltage (V)	100 n ~ 1010
AC voltage (Vrms)	100 n ~ 750
DC current (A)	10 p ~10.1
AC current (A)	100 p ~10.1

TABLE IV: MEAN WELL/HLG-80H-12-A POWER SUPPLY [6]

OUTPUT	
DC VOLTAGE (V)	12
CONSTANT CURRENT REGION(V)	7.2 ~ 12

III. RESULTS AND DISCUSSION

This experiment is mainly for the simulation analysis and discussion of the lubrication characteristics of the machine tool feed system. It is possible to directly know the relative thickness of the oil in the middle of the two metal parts. A record of one pen per second, measured for 15 minutes, a total of 900 data. Further, the lubrication characteristics and trends between the two metal members are known from the measured voltage value changes. It can be seen from Fig. 12 that the contact area is proportional to the amount of oil.

A. *Analysis of Different Oil Quantities with the Same Contact Area*

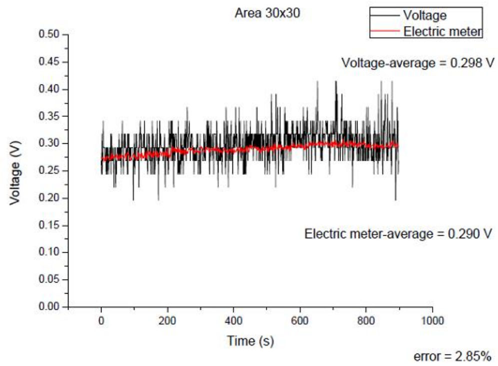
Obtained from Table V below. In the same contact area, when the high oil injection amount, the relative voltage value is high. When the low oil injection amount, the relative voltage value is low.

B. *Analysis of the Same Oil Quantity with Different Contact Area*

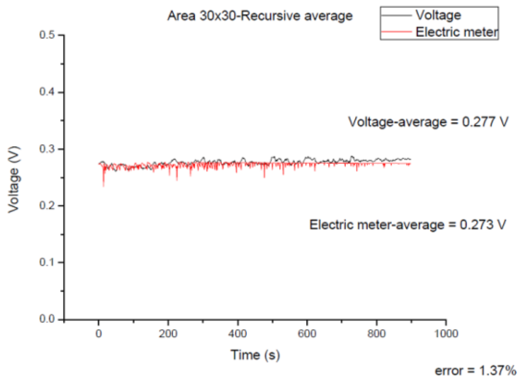
Obtained from Table VI below. In the same contact area, when the large contact area, the relative voltage value is small. When the small contact area, the relative voltage value is high.

C. *Error Correction for R&D Equipment*

The equipment developed in this experiment uses KEITHLEY DMM6500 / 6-digit half-touch screen digital multimeter as the relative voltage value correction device of oil film. At the same time, for the contact area of 30 × 30 mm^2, the fixed oil injection amount is measured by the value of the flow voltage. The error value before correction is 2.85 %, and the error value after filtering correction is 1.37 %, which is within 2% of the error value, reference Fig. 11.

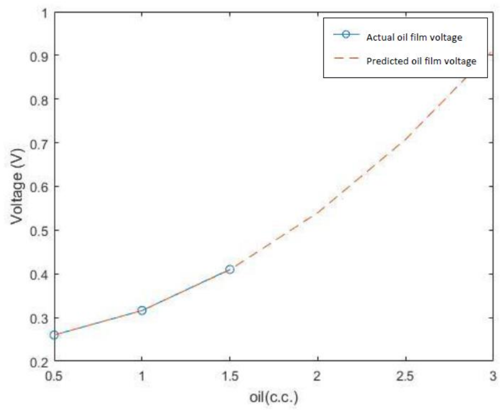


(a) Before

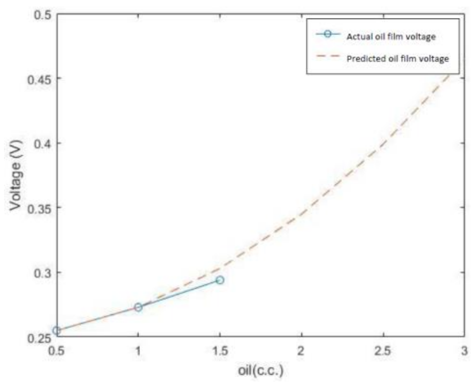


(b) After

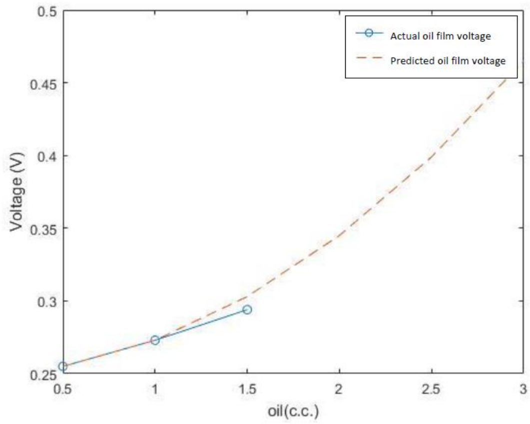
Fig. 11. Filter results.



(a) Area30×30 (mm^2)



(b) Area40×40 (mm^2)



(c) Area50×50 (mm^2)

Fig. 12. Regression prediction.

Area 30 × 30:

$$y = 0.2413 + 0.0747x^2 \tag{3}$$

Area 40 × 40:

$$y = 0.249 + 0.024x^2 \tag{4}$$

Area 50 × 50

$$y = 0.1533 + 0.0547x^2 \tag{5}$$

D. Curve Fitting Linear Regression Analysis

The oil film voltage value prediction results were established using curve fitting linear regression analysis, as shown in Fig. 12

The oil film voltage value prediction results were established using curve fitting linear regression analysis, as shown in Fig. 12.

TABLE V: TRENDS OF THE SAME AREA CORRESPONDING TO DIFFERENT OIL VOLUMES

Oil quantity(c.c.)	Average voltage (30×30 mm^2)
0.5	0.298
1.0	0.308
1.5	0.330
Oil quantity(c.c.)	Average voltage (40×40 mm^2)
0.5	0.261
1.0	0.296
1.5	0.300
Oil quantity(c.c.)	Average voltage (50×50 mm^2)
0.5	0.196
1.0	0.235
1.5	0.257

TABLE VI: THE SAME OIL AMOUNT CORRESPONDS TO DIFFERENT AREA TREND CHART

Contact area(mm^2)	Average voltage (0.5 c.c.)
30×30	0.298
40×40	0.261
50×50	0.196
Contact area(mm^2)	Average voltage (1.0 c.c.)
30×30	0.308
40×40	0.296
50×50	0.235
Contact area(mm^2)	Average voltage (1.5 c.c.)
30×30	0.330
40×40	0.300
50×50	0.257

TABLE VII: CURVE REGRESSION ANALYSIS VOLTAGE (V)

Area (mm^2)	Oil quantity(c.c.) 0.5	1.0	1.5	2.0	2.5	3.0
30×30	0.260	0.316	0.409	0.540	0.708	0.913
40×40	0.255	0.273	0.303	0.345	0.399	0.465
50×50	0.167	0.208	0.276	0.372	0.495	0.645

IV. CONCLUSION

This experiment is mainly aimed at the analysis of the influence of different contact areas on oil film thickness:

1. Under the fixed contact area, more oil is injected, which causes the oil film to become thicker. It has a significant increase in the relative oil film voltage, and vice versa.
2. Under the fixed oil injection amount, the larger contact area causes the oil film to become thinner. It has a significant decrease in the relative oil film voltage value, and vice versa.
3. Use the equation of filtering to do noise isolation. The KEITHLEY DMM6500 meter is used to correct the comparison, and the error value is reduced to 1.37 %, which can improve the reliability of the data.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Shao-Hsien Chen plays the role of program director. He analyzes materials, design of institutions and draws research conclusions.

Zih-Jing Huang is an experimental researcher. He performed oil film experiments, design drawings, data collection, analysis, and unified research results.

Jia-Xin Tsao is the fixture processing staff. He executes the simulation of the slide rail and slide.

Rui-Ke Jian is a circuit analyst. He performs circuit analysis, design, and applications; all authors had approved the final version.

ACKNOWLEDGMENT

Thanks to Quaser Machine tools Inc. (No. 107-302-1-028) for research assistance and funding.

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