Rotational Transmission Accuracy in Traction Drive of Concave and Convex Roller Pair*

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This paper presents a study on the rotational transmission accuracy in the traction drive of a concave and convex roller pair. The simultaneous measurements of specific sliding, transmitted torque and roller surface temperature in the contact between a concave and convex roller pair under different running conditions were carried out by using a concave and convex roller testing machine and measuring system which had been developed by the authors. The effects of the torque, roller speed and contact pressure on specific sliding, rotational transmission error (variation of specific sliding) and roller surface temperature were investigated.

Key Words: Tribology, Traction Drive, Concave and Convex Roller Pair, Rotational Transmission Error, Specific Sliding, Roller Surface (Oil Film) Temperature

1. Introduction

With increased requirements for speedup, smaller vibration and noise, and higher rotational transmission accuracy for power transmissions, traction drive units have become a matter of great concern. Many studies on traction characteristics (traction coefficient, oil film formation, oil film temperature, etc.) in traction drives have been published^{(1)~(6)}, but there are few on rotational transmission accuracy⁽⁷⁾.

In the present paper, the rotational transmission accuracy in the traction drive of a concave and convex roller pair is investigated. The simultaneous measurements of specific sliding, transmitted torque and roller surface temperature in the contact between a concave and convex roller pair under different running conditions were carried out by means of a concave and convex roller testing machine and

measuring system developed by the authors. The effects of torque, roller speed and contact pressure on specific sliding, rotational transmission error (variation of specific sliding) and roller surface temperature were examined.

2. Experimental Method and Apparatus

2.1 Test rollers

The shapes and dimensions of the test rollers are shown in Fig. 1. The outside diameter of the convex roller is 56 mm and the inside diameter of the concave roller 168 mm. The width of the contact parts between these rollers is 20 mm. The materials, working and

Fig. 1 Shapes and dimensions of test rollers

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Fig. 2 Concave and convex roller testing machine

Table 1 Test rollers

Roller sign	Convex roller	Concave roller
	A1	B1
Materials	S55C	
Treatment conditions	Normalized Fine-ground	
Vickers hardness H_v	225	
Surface roughness $R_{max} \mu m$	0.5	0.6

heat treatment conditions, and surface roughness of the test rollers used are shown in Table 1.

2.2 Concave and convex roller testing machine

Figure 2 shows the concave and convex roller testing machine used in this experiment. The concave roller is supported by bearings fixed to a movable pedestal. The convex roller is inscribed inside the concave roller. Test rollers are loaded by pressing the pedestal with a hydraulic cylinder. The convex roller is coupled to a VS-motor which has a capacity of 7.5 kW, and the concave roller to a direct current (DC) electrical machine (maximum torque 23.5 Nm). The DC electrical machine is able to drive or brake the concave roller, according to its use as a power source or as a power absorber. By varying the field current of the DC electrical machine, it is possible to control the rotational speed of the concave roller and also the amount of sliding between concave and convex rollers. In this way, continuous adjustments of the specific sliding and the transmitted torque are pos-

Fig. 3 Block diagram for simultaneous measurements of specific sliding, transmitted torque and roller surface temperature

sible, and pure rolling can be achieved. The state of the oil film formation between concave and convex rollers suitably insulated can be measured using an electric resistance method.

2.3 Experimental method

The simultaneous measurements of specific sliding, transmitted torque and roller surface temperature, which is an important factor in the performance of a lubricating film, in the contact between a concave and convex roller pair under different running conditions were carried out by using the concave and convex roller testing machine and measuring system shown in Fig. 3. The output signals from rotary encoders I, II (number of output pulses : 1200/rev.), from torquemeter I (Fig. 2) and from a thermocouple embedded in the convex roller side (Fig. 1) were

simultaneously memorized in the data recorder, and then these signals were processed by a microcomputer and the results were recorded on the plotter. The specific sliding is defined as $s = (u_1 - u_2) \times 100 / u_1$ [%], where u_1 and u_2 are the circumferential velocities of convex and concave rollers, respectively.

The state of the oil film formation between concave and convex rollers was measured using an electric resistance method⁽⁸⁾. The electric circuit used is shown in Fig. 4. A voltage of 15 mV was imposed between a-b while the test rollers were isolated, and the variation of the voltage E_{AB} between the test rollers under running conditions was measured on the picture tube of the synchroscope and the variations of E_{ab} were recorded on the penrecorder. The lubricating oil (viscosity: 150 mm²/s at 40°C, 14.6 mm²/s at 100°C, specific gravity: 0.884 at 15°C, viscosity index: 96, flash point: 250°C, pour point: -12.5°C) filtered was supplied to the inlet side of the contact through a nozzle at the rate of 1 L/min. The inlet oil temperature was kept constant at 40°C by means of a thermostat. The measurements of the rotational transmission error were carried out after the running-in operation (maximum Hertz contact pressure $p_{\max} = 324$ MPa, rotational speed of convex roller $n_1 = 1\,000$ rpm, specific sliding $s = 0\%$, number of load cycles $N = 10^5$).

3. Experimental Results and Discussions

3.1 Relationship between oil film formation, transmitted torque and specific sliding

Figures 5 and 6 show the relation between the oil film formation and the specific sliding and that between the transmitted torque and the specific sliding, respectively, under $n_1 = 1\,000, 1\,500, 2\,000$ rpm, $p_{\max} = 486, 583, 687$ MPa (n_1 : rotational speed of convex roller, $p_{\max}$: maximum Hertz contact pressure). The state of the oil film formation is expressed as the

Fig. 4 Measuring circuit of oil film formation

ratio of the average voltage between concave and convex rollers to the voltage (15 mV) between isolated rollers. The bearing friction is excluded from the measured torque⁽⁵⁾.

3.2 Measured results of specific sliding, transmitted torque and roller surface temperature

Figure 7 shows simultaneously measured results of specific sliding, transmitted torque and roller surface temperature under $n_1 = 1\,000$ rpm, $p_{\max} = 583$ MPa. The braking torque was exerted on the concave roller with the DC electrical machine after 10 seconds from the start. The changes of specific sliding, transmitted torque and roller surface temperature due to

Fig. 5 Relation between oil film formation and specific sliding

Fig. 6 Relation between transmitted torque and specific sliding

braking are found to correspond with each other. The variation in the torque is considered to be caused by the torsional vibration of the shafting.

3.3 Effects of transmitted torque, roller speed and contact pressure on specific sliding, rotational transmission error (variation of specific sliding) and roller surface temperature

Figures 8 and 9 show the changes in the specific sliding and the roller surface temperature with time, respectively, for different transmitted torques. The specific sliding and the roller surface temperature tend

(a) $n_1 = 1000$ rpm

(b) $n_1 = 1500$ rpm

Fig. 8 Effects of transmitted torque on specific sliding and on rotational transmission error

Fig. 7 Simultaneously measured results of specific sliding, transmitted torque and roller surface temperature

(a) $n_1 = 1000$ rpm

(b) $n_1 = 1500$ rpm

Fig. 9 Effects of transmitted torque on roller surface temperature

Fig. 10 Effects of roller speed on specific sliding and on rotational transmission error

Fig. 11 Effects of roller speed on roller surface temperature

to increase with the torque. This might be because the shear resistance of the oil film increases with the torque and the heat development becomes more remarkable. The rotational transmission error increases with specific sliding.

Figures 10 and 11 show the changes in the specific sliding and the roller surface temperature with time, respectively, for different roller speeds. The specific sliding and the roller surface temperature tend to increase with roller speed, and the rates increase with the torque. This might be because the oil film thickness increases with roller speed and the heat development due to the shear work becomes more significant. The rotational transmission error increases with specific sliding as in the case of Fig. 8.

Figures 12 and 13 show the changes in the specific sliding and the roller surface temperature with time, respectively, for different contact pressures. The specific sliding and the roller surface temperature tend to increase with a decreasing contact pressure. This might be due to the fact that the viscosity of the oil

Fig. 12 Effects of contact pressure on specific sliding and on rotational transmission error

Fig. 13 Effects of contact pressure on roller surface temperature

film decreases with a decreasing contact pressure, and the shear rate and the shear work thereby increase. The rotational transmission error increases with specific sliding as in the case of Figs. 8 and 10.

4. Conclusions

The main results obtained from this investigation are summarized as follows.

(1) The specific sliding in the contact between the concave and convex roller pair increases with the transmitted torque and the roller speed, and decreases with an increasing contact pressure.

(2) The rotational transmission error (variation of specific sliding) in the contact between the concave and convex roller pair increases with specific sliding.

(3) The change in the roller surface temperature in the contact between the concave and convex roller pair with the transmitted torque, the roller speed and the contact pressure shows the same tendency as the change in the specific sliding.

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