Research on Influence of Vibration on Rubber Surface Friction

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Abstract. Friction and vibration are common in mechanical systems. In terms of friction, there is also friction on the surface of rubber components, in addition to the friction between metal components. The friction on the surface of rubber components sometimes affects the production quality. Because the vibration produced by mechanical system will affect the friction between components, it is necessary to study the change of rubber surface friction under the vibration. In this paper, an experimental study about the effect of vibration on rubber surface friction is carried out. An experimental platform is set up independently to measure the friction changes under different vibration parameters. The experimental results show that vibration can reduce the friction of rubber surface, and the greater the amplitude, the smaller the friction. The vibration frequency is also related to friction. These results can provide the support for explaining the change of surface friction of rubber components during mechanical movement.

Keywords: Friction · Rubber surface · Vibration · Normal vibration · Tangential vibration

1 Introduction

Friction is common in the mechanical system. In addition to the friction between metal components, there is also friction on the surface of rubber components in the mechanical system, such as blanket cylinders, rubber rollers for printing and rubber plates for relief printing in the printing mechanical system. The friction between printing components and the friction between the printing components and the substrates can affect the printing quality [1].

Vibration is also widespread in mechanical systems. Existing research results have shown that vibration can reduce friction interface. The friction on the non lubricated vibration interface will decrease compared with the friction on the interface without vibration [2–6]. According to different vibration directions, scholars have studied the effects of normal vibration perpendicular to the interface and tangential vibration parallel to the interface on friction.

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In respect of normal vibration, Chowdhury introduces normal vibration on the interface of various materials. The experimental results show that the friction decreases more and more obviously with the increase of normal amplitude [7]. Yoo proves that the friction reduction effect of normal vibration is greater than that of tangential vibration through experiments [8]. Shi finds that the friction between the FFM tip and the substrate decreases to zero in the microscopic experiment, after the normal amplitude increases [9].

In terms of tangential vibration, Popov uses ultrasonic waves to generate high-frequency vibration. And the experimental results show that the ultrasonic vibration can reduce the friction [10]. Gutowski also measure that the tangential vibration can reduce the friction between metal contact surfaces in the experiment [11].

However, more researches are focused on the change of friction between metal and metal materials, while less research is focused on the influence of vibration on the interface friction of rubber materials. Therefore, it is necessary to study the influence of vibration on rubber interface friction. The research results can clarify the effect of vibration on friction of the rubber components during the operation of mechanical system. The results also can provide relevant support for analyzing the causes of the problems caused by friction of the rubber components.

In this paper, a experimental device is designed independently. The influence of vibration on the friction of rubber surface is studied experimentally, based on this experimental device.

2 Experimental Device and Materials

A piece of rubber is pasted on the bottom of a metal sliding block. The rubber is mainly made of rubber insulating materials. The sliding block is placed on the vibrator. The slider moves on the vibrator under the pull of the horizontal tension machine. The pulling speed of the tension machine is constant, so the average sliding speed of the slider is constant. Because the slider moves at a uniform rate on the vibrator, the force value collected by the sensor of the horizontal tension machine is equal to the average friction force between the rubber and the vibrator.

The signal generator inputs a sinusoidal vibration signal to the vibrator. Under the excitation of this signal, the vibrator generates normal vibration and tangential vibration. The schematic diagram of the experimental device is shown in Fig. 1. Two laser vibrometers are used to measure the amplitude of the vibrator: laser vibrometer 1 measures the normal vibration amplitude of the vibrator, laser vibrometer 2 measures the tangential vibration amplitude of the vibrator. The physical diagram is shown in Fig. 2. The details of the experimental materials and device are shown in the Table 1.

During the experiment, the friction force with no vibration between the interfaces is measured at first. Then, the normal vibration signal is input, and the vibrator begins to produce vibration. As the voltage value of the input normal vibration signal increases under fixed frequency conditions, the amplitude of the vibrator increases. At this time, the change of friction between interfaces is measured, and the influence of vibration on interface friction is observed. The conditions for all the experiment is about 40% in humidity, temperature at 26 °C or so.

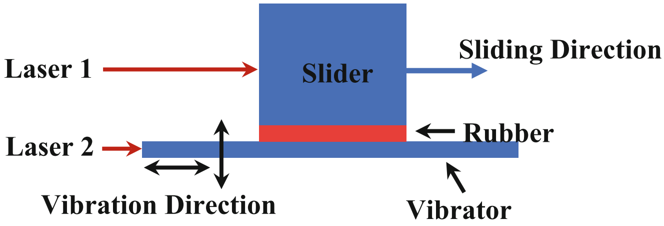


Fig. 1. Schematic diagram of the experimental device

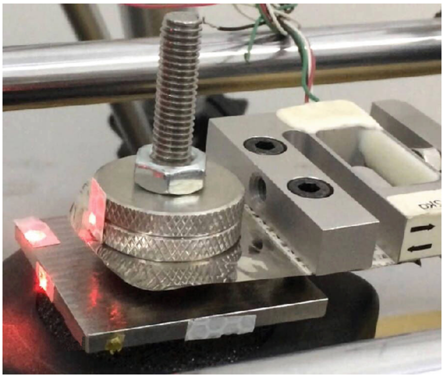


Fig. 2. Physical diagram of the experimental device

Table 1. Details of the experimental materials and device

Materials and device	Details
Slider (stainless steel)	Quality: 0.2kg
Rubber mat (rubber)	Diameter: 30mm, Height: 3mm
Vibrator (stainless steel)	Length: 10mm, Width: 10mm, Height: 3mm

3 Results and Analysis

3.1 Relationship Between Friction and Time

Under the condition of 3000Hz, the normal amplitude A_n of the vibrator is changed, and the influence of vibration on the friction between the interfaces is measured under different normal amplitude. The average horizontal sliding speed of the slider is 2mm/s. The friction between the rubber mat and the vibrator is represented by F_x. The experimental results are shown in Fig. 3.

According to Fig. 3, when $A_n = 0.056\mu m$ and $A_t = 0.018\mu m$, the effect of friction reduction is not obvious. However, as the normal amplitude increases, the friction between the interfaces decreases more and more obviously. The above data suggests that vibration does reduce friction between interfaces.

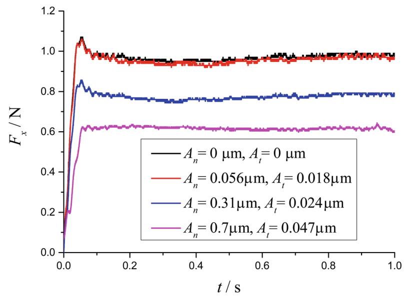


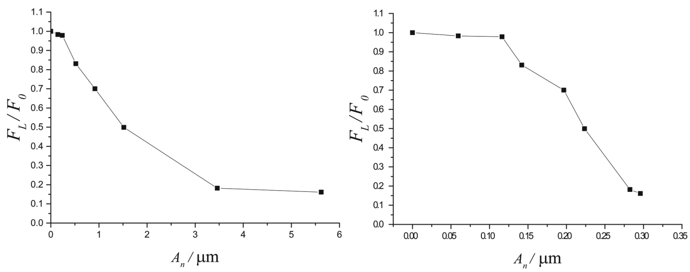
Fig. 3. Relation between friction and time

In order to achieve the research goal, the variation of friction between interfaces under more vibration parameters was measured. In addition, in order to better analyze the effect of vibration on friction, the dimensionless ratio F_L/F_0 is introduced. F_L is the average value of sliding friction under vibration. F_0 is the average value of sliding friction without vibration. The smaller the value F_L/F_0, the more obvious the friction reduction effect.

3.2 Relationship Between Friction and Amplitude

Firstly, the vibrator frequency f is set to be 750Hz, and the average horizontal sliding speed of the slider is 2mm/s. Under the condition of a fixed frequency of 750Hz, the normal amplitude of the vibrator is changed. F_L/F_0 is shown in Fig. 4. Figure 4(a) shows the relation between F_L/F_0 and the normal amplitude. Figure 4(b) shows the relation between F_L/F_0 and the tangential amplitude.

Secondly, the friction between the rubber and the vibrator is measured at 1000Hz. The average horizontal sliding speed of the slider is also 2mm/s. The experimental results are shown in Fig. 5. Figure 5(a) shows the relation between F_L/F_0 and the normal amplitude. Figure 5(b) shows the relation between F_L/F_0 and the tangential amplitude.



(a) (b)

Fig. 4. Relation between friction and amplitude at 750Hz

According to Figs. 4 and 5, the influence of the vibration on the friction is analyzed. With the increase of the excitation signal voltage, the normal and tangential amplitudes

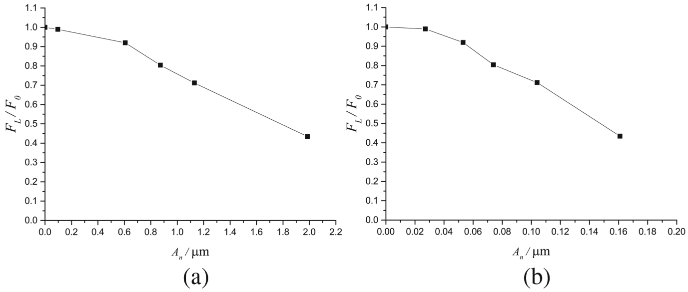


Fig. 5. Relation between friction and amplitude at 1000Hz

of the vibrator increase. It can be seen from Figs. 4 and 5 that the four curves are the variation of interface friction with amplitude when the vibrator vibrates at a fixed frequency of 750Hz and 1000Hz respectively. All the four curves show that, when the vibration frequency remains constant, the friction between the interfaces becomes smaller and smaller with the increase of the normal and tangential amplitude of the vibrator. The above data show that the amplitude is one of the parameters that affect the friction of the rubber interface.

The influence of vibration frequency on friction can also be seen from Figs. 4 and 5. The test point $A_n = 2.0\mu m$ in Figs. 4(a) and 5(a) is taken as an example. F_L/F_0 at 750Hz is close to that at 1000Hz at $A_n = 2.0\mu m$. This shows that the influence of normal vibration frequency on friction is not obvious in the range of 750–100Hz, when the normal amplitude is the same. In addition, the test point $A_n = 0.15\mu m$ in Figs. 4(b) and 5(b) is also taken as an example to determine the influence of tangential vibration frequency on friction. F_L/F_0 at 1000Hz is much lower than that at 750Hz when $A_n = 2.0\mu m$. This shows that the influence of tangential vibration frequency on friction is obvious in the range of 750–100Hz, when the tangential amplitude is the same. Therefore, the vibration frequency can also affect the friction.

4 Conclusions

The experimental system, which is designed and constructed independently, can reflect the relationship between vibration and rubber interface friction. Firstly, it is proved experimentally that vibration can reduce the friction between the rubber and the mental. Secondly, when the average sliding velocity of the slider and vibration frequency remain unchanged, the normal and tangential vibration amplitude are changed. The results show that vibration can reduce the friction of the rubber surface, and the vibration parameters of amplitude has a significant effect on the friction reduction. When the amplitude increases, the friction between the interfaces decreases more obviously. The vibration frequency is also related to the friction of rubber surface.

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