Tribology International 42 (2009) 946–950

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

# The frictional behavior of mild steel under horizontal vibration

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ARTICLE INFO

*Article history:*
Received 6 April 2007
Received in revised form
13 January 2009
Accepted 19 January 2009
Available online 25 January 2009

*Keywords:*
Friction coefficient
Mild steel
Horizontal vibration

ABSTRACT

The present paper investigates experimentally the effect of external horizontal vibration on friction property of mild steel. To do so, a pin-on-disc apparatus having facility of vibrating the test samples in horizontal direction was designed and fabricated. Horizontal vibration is created along the sliding direction of vibration and perpendicular to the direction of vibration. The experimental setup has the facility to vary the amplitudes and frequencies of vibration while velocity of vibration is kept constant. During the experiment, the frequency and amplitude of vibration were varied from 0 to 500 Hz and 0 to 200 μm, respectively. Results show that the friction coefficient increases with the increase in amplitude and frequency of vibration for mild steel. The horizontal vibration can be of two types: one along the direction of sliding (longitudinal direction) and the other along the perpendicular direction of sliding (transverse direction). For both the cases, test sample slides horizontally. It is found that the magnitude of friction coefficient for longitudinal vibration is less than that for under transverse vibration. These results are analyzed by dimensional analysis to correlate the friction coefficient with sliding velocity, frequency and amplitude of vibration. The experimental results are also compared with those available in literature and simple physical explanations are provided.



## 1. Introduction

The coefficient of friction of a material is dependent upon the interface or mating material, surface preparation and operating conditions [1–7]. It is also known that vibration and friction are dependent on each other. Friction generates vibration in various forms, while vibration affects friction in turns [8–19]. However, the frictional behavior of mild steel and their dimensional analysis under horizontal vibration is yet to be investigated. Therefore, in this study an attempt is made to investigate the frictional behavior of mild steel and their dimensional analysis under horizontal vibration. When pin slides on a plate horizontally, then the plate can vibrate horizontally (along the sliding direction, i.e. longitudinal direction and perpendicular to the sliding direction, i.e. transverse direction).

In this study vibration is generated artificially in such a way that direction, amplitude and frequency of vibration can be controlled.

## 2. Experimental

The experimental setup consists of a pin-on-disc machine, i.e. a pin can slide on a rotating horizontal test surface (disc). The description of the setup and measuring technique of friction coefficient are described in detail in companion paper [20]. This machine has the facility to vibrate the test sample horizontally. The frequency and amplitude can be varied from 0 to 500 Hz and 0 to 200 μm, respectively.

A special arrangement is designed and fabricated for generating horizontal vibration as shown in Fig. 1. For generating horizontal vibration, one end of a coil spring is fixed with the rotating shaft and the other end of the spring is fixed with the rotating table holding the test plate. Around the circumference of the rotating table, there are a number of V-slots. An adjusting rigid barrier with spherical tip is fixed (as shown in Fig. 1) with the basic structure of the setup. This tip can penetrate into the V-slots of the rotating table, whose depth of this penetration can be adjusted. Therefore, when the shaft along with the spring and table rotates, the tip of the rigid barrier creates obstruction to the rotation of the slotted table. Due to spring action and rotation, the table will vibrate horizontally. To ensure the horizontality of vibration three U-shaped adjustable guides are placed 120° apart. These rigid guides are fixed with the basic structure of the setup. The displacement velocity and acceleration diagrams for horizontal vibration ($f = 100$ Hz, $A = 200$ μm) are shown in Fig. 2. The direction of vibration can be either longitudinal or transverse depending on the position of sliding pin on the rotating table. By varying rotation of the shaft and the number of slots of the rotating table, the frequency of vibration can be varied. By

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doi:10.1016/j.triboint.2009.01.003

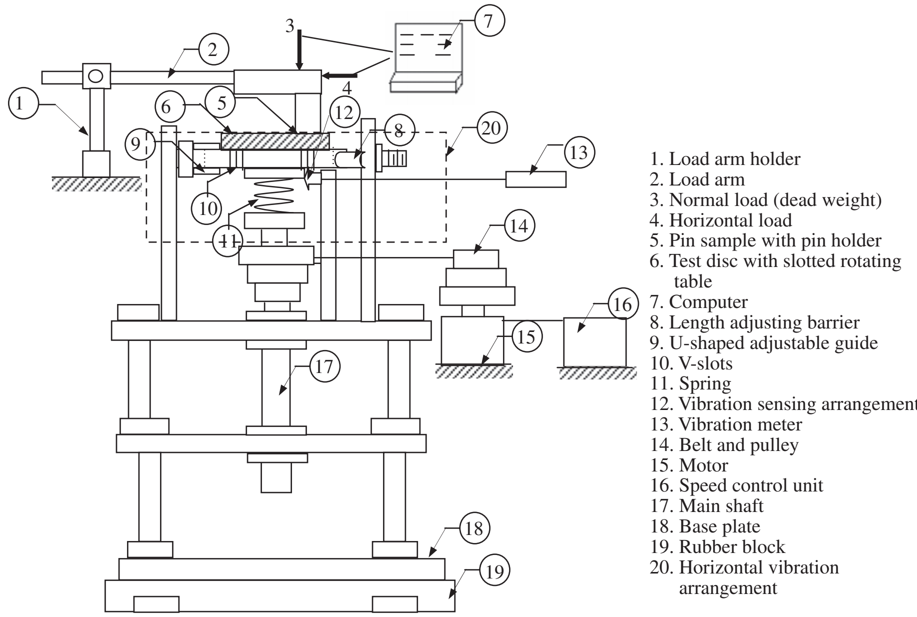


**Fig. 1.** Block diagram of the experimental set-up (horizontal vibration).

adjusting the depth of penetration by the adjustable barrier, the amplitude of the vibration can be varied. With all these supports, some vertical vibration may also arise which is measured as given in Table 1. As the plate is vibrating and rotating, it is not possible to fix directly the vibration sensing pickup of the vibration meter for measuring vibration. So, to measure the vibration of the table, a spring loaded pin is kept in contact with the lower extended portion of the table which transmits vibration of the plate to the vibration sensing pickup.

The natural frequency of the test setup was found to be 480 Hz. It can be noted that the natural frequency of test rig does not interfere in any way with the accuracy of measurements at 500 Hz. That is the consistency of the measured values and the nature of the change of measured data show no variation of accuracy of measurement due to nearness of the resonance frequency. The average roughness of the mild steel test sample were found to be 1.20(±5%) μm (RMS). During tests each experiment was repeated several times.

## 3. Results and discussions

### 3.1. Experimental results

Fig. 3 shows the variation of friction co-efficient of mild steel with amplitude of vibration for two types of horizontal vibration at $f = 100$ Hz. The values of friction coefficient of mild steel increase with the increase in amplitude of vibration from 10 to 200 μm and these are 0.34–0.43 for transverse vibration and 0.33–0.42 for longitudinal vibration. In a similar way as in Fig. 3 variation of friction coefficient of mild steel for 200, 300, and 400 Hz at different amplitudes are presented in Figs. 4–6, respectively. Variations of friction coefficient of mild steel for longitudinal vibration increase with the increase in amplitude of vibration from 10 to 200 μm for 200, 300, and 400 Hz and these are 0.36–0.48, 0.40–0.54, and 0.45–0.64, respectively. For transverse vibration, these variations over the range of amplitude of vibration 10–200 μm are 0.37–0.49, 0.41–0.56, and 0.46–0.66 for 200, 300, and 400 Hz, respectively.

From Fig. 7, it is observed that with the increase in frequency for transverse vibration, the friction coefficient increases from 0.34 (100 Hz) to 0.74 (500 Hz), while that for horizontal (longitudinal) vibration, increases from 0.33 (100 Hz) to 0.72 (500 Hz).

From Figs. 3–7, it is also found that the values of friction coefficient under transverse vibration are slightly higher than those for longitudinal vibration. This may be due to the change of direction of inertia forces of the vibrating body. Effect of length of sliding path may also be responsible for higher friction under transverse vibration. The increase in friction coefficient with the increase in amplitude of vibration for horizontal direction of vibration might be due to the fact that the greater the amplitude of vibration, the higher the distance traveled along the sliding direction at which the slider slides. Therefore, the increase in friction coefficient for the increase in amplitude might be due to the increase in length of rubbing with the increase in amplitude of vibration. In addition to these, the increase in friction coefficient might be due to: (i) fluctuation of inertia force along the direction of friction force (positive and negative); (ii) more sliding causes more abrasion resistance. Higher abrasion results in more shearing due to penetration and ploughing of the asperities between contacting surfaces that might have some effect on the increment of friction force; (iii) micro-welding, reversal of friction vector and mechanical interlocking; (iv) formation and enhancement an electrically charged layer at the interface; (v) increase in solubility due to high temperature [4,18].

### 3.2. Dimensional analysis

Let

$$F_f = F(A, f, V, N) \tag{1}$$

where $F_f$ is the frictional force $= MLT^{-2}$, $A$ is the amplitude $= L$, $V$ is the sliding velocity $= LT^{-1}$, $f$ is the frequency $= T^{-1}$ and $N$ is the normal load $= MLT^{-2}$.

Let "$k$" be a dimensionless constant, then (1) can be written as

$$F_f = k[A^a\ f^b\ V^c\ N^d] \tag{2}$$