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A novel state-variable film thickness-dependent friction law for lubricated sliding contacts with the film thickness as the internal variable

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This research presents a novel friction model for lubricated sliding contacts under unsteady or transient dynamic conditions. This friction law represents a state-variable friction by defining the surface gap or lubricant film thickness as the internal state variable. The film thickness, is governed by a first order differential equation in order to attain the steady state. An oscillating dynamic tribometer is used to test this model. Finally, both the numerical and experimental results are compared.

Keywords: friction law, internal state variable, film thickness, dynamic model, oscillating free responses.

1. Introduction

Friction is a nonlinear phenomenon that occurs in many mechanical systems including contacts. In order to simulate the dynamic behavior of such systems, it is required to choose a friction law that is able to optimally describe it. It is shown that although Coulomb and/or viscous friction model is useful [1]; however, it cannot describe accurately the tribological behaviors, especially for lubricated contacts. On the other hand, the Stribeck law can represent lubricated contacts, but it usually ignores their dynamic effects. In this context, the main goal of this study is to introduce a new friction model that represents the film thickness as the internal state variable.

2. Method

2.1. The proposed friction model

A novel friction law for lubricated sliding contacts having the film thickness as an internal state-variable is proposed. It consists of a mixed friction law with two components, written as:

$$T = \alpha(y)T_f + [1 - \alpha(y)]\,T_c \qquad (2)$$

In the above equation, α is defined as a sigmoid function of y. Therefore, when $y = 0$ then, $\alpha = 0$ and $T = T_c$. On the other hand, when y is sufficiently high then, α reaches 1 and $T = T_f$. T_c and T_f correspond to friction respectively at boundary condition and for full film lubrication boundary regime. The internal state equation is expressed as:

$$\dot{y} = \frac{(Y_{ss}(v) - y)}{\tau} \qquad (3)$$

$Y_{ss}(v)$ represents the separation of the surfaces that should be attained at an instant t, which corresponds to the steady state separation at the sliding velocity $v(t)$.

2.2. The Dynamic Tribometer

In order to validate our model with experiments, a dynamic tribometer [1, 2] is used. This experimental setup, shown in Figure 1, is based on the measurement of free responses [3] of a single degree-of-freedom mass-spring oscillator system having a sliding contact. The non-linear equation of motion is represented by:

$$m\ddot{x} + kx = -T \qquad (4)$$

m is the mass, k is the spring stiffness and T is the friction force. Transforming Eq. (4) into a first order differential equation leads to:

$$\begin{cases} \dot{x} = v \\ \dot{v} = (-T(v, y) - kx)/m \\ \dot{y} = (Y_{ss}(v) - y)/\tau \end{cases} \qquad (5)$$

with T defined by equation (2).

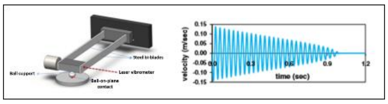

Figure 1: Description of the dynamic tribometer

2.3. Results

The proposed model (Eq. 5) is solved using Runge Kutta of order 4. Numerical and experimental free responses are compared in order to show the validity of the proposed friction law.

3. Discussion

Our new model can capture the transition related to the instantaneous film thickness, which separates the two sliding surfaces, including the lag effect of the thickness dynamics. Moreover, the functions, $Y_{ss}(v)$ and $\alpha(y)$, corresponding to the proposed model are discussed to represent the physical properties of the tribological contact.

4. References

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