



Theoretical and Experimental Investigation of Frictional and Thermal Behavior in Oscillatory Sliding Line Contact -- Pin-Bushing Thermal Model --

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ABSTRACT

A model is developed to predict the thermal behavior of two sliding bodies undergoing oscillatory relative motion. The thermal model is capable of predicting the temperature rise distribution within the pin-bushing pair and the housing. The bodies geometrically form a pin-bushing configuration and the Hertzian line contact theory is used to approximate the contact pressure and the width. A quasi-three dimensional temperature model is developed by averaging the temperature in the axial direction. The resulting dimensionless heat equations and proper boundary conditions are solved by the finite element method. A test rig capable of oscillatory motion under heavy loading is used for measuring friction and temperature. The measured coefficient of friction history, which is curve fit as a function of time, is used in the simulations. The description of the test rig, modeling aspects, and the future extension of the research are presented.

INTRODUCTION

Heavy-duty pin-bushing assemblies used in wheel loaders undergo oscillatory contact under high intermittent contact pressures. Their contact experiences large temperatures making the component susceptible to fail prematurely by thermal galling and scuffing.

This work deals with the theoretical and experimental analysis of frictional and thermal behavior in pin-bushing pairs operating at a sinusoidal sliding speed under a constant applied load. A quasi-three-dimensional thermal analysis is considered where axial effects are accounted for based on an averaging of the 3D heat equation along the axial direction and considering the end boundary conditions. This averaging method leads to an internal heat generation term that depends on the temperature distribution, as well as thermal and geometric properties. A Hertzian model is assumed to approximate the frictional heat flux distribution within the contact region. The formulation of the problem is based on a test rig model that is used for experiments.

EXPERIMENTAL SETUP

Measurements of friction and temperature on an oscillating pin-bushing assembly are conducted on a friction

tester (Lewis Research Inc.; LRI-8H). Figure 1 shows a photo apparatus of the Lewis LRI-8H tester used in experiments. The machine is capable of steady rotational as well as oscillatory motion. For oscillating mode, the pulleys and belts used for rotation are replaced by a crank-rocker arm (15). The crank-arm is connected at the bottom to the DC-motor (16) via a jack-shaft (19) and to spindle-hub (11) at the top. The pin is directly connected to the spindle-hub.

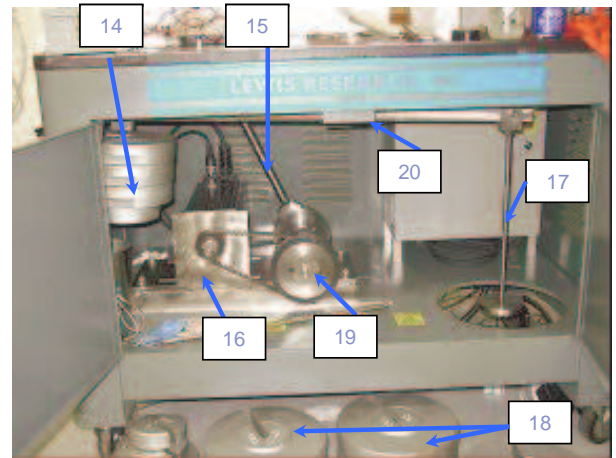
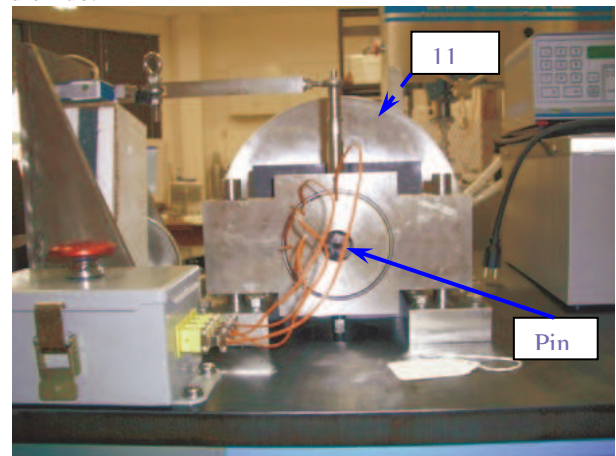


Figure 1. The LRI-8H Tribo-Tester.

THEORETICAL MODEL

In the test rig, the pin is oscillating while the bushing is stationary. The mathematical model derived in [1] is modified to include the convective term in the heat equation for the pin, and implement axial averaging. Figure 2 shows a summary of the simplified 2D model. The Hertzian contact pressure for line contact is used for estimating the contact width [2]. A dimensionless thermal model formulation is considered, and a numerical solution is carried out using the Finite Element method.

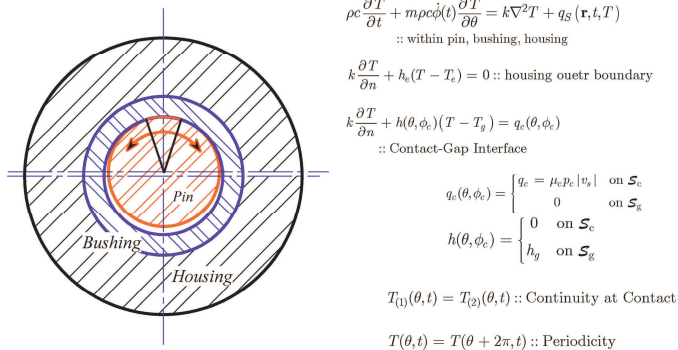


Figure 2. Theoretical model - simplified 2D Schematic.

RESULTS

Figure 3 shows the temperatures and friction measurements for a steel pin-production bushing pair. Under the conditions tested, the steady state was reached in about 4 hours as seen in Figure 3. An average COF of $\mu_c = 0.12$ was observed throughout the test.

Computations were performed with the values of the friction coefficient as input, under the same operating conditions. Presently, the model shows some limitations in its capability to accurately capture the transient behavior of the experiment. Namely, the time constant is lower and generally, larger error is accumulated at locations farther away from the contact.

An iterative scheme was employed to simultaneously solve the thermal problem while minimizing the error between the measured and computed temperatures at the four thermocouple locations. The control parameter is an additional heat term incorporated into the thermal model. The resulting computed temperature rise at thermocouple locations show good agreement with the measured values and the heat term added evolved from a heat sink to a heat source during the transient iterative process. The trend indicates a non-uniform contact behavior along the contact length. A close look at the contact behavior in the pin-bushing tester, using a static 3D structural model revealed that the contact pressure and width, and therefore the frictional heat flux, are not uniform in the axial direction.

While the iterative scheme offers some valuable insight into the thermal behavior of the model, it is limited to the specific experiment and conditions considered. The goal is to develop a general computational model.

Another source of error is the absence of thermomechanical coupling. Work is in progress to include thermomechanical interaction of pin-bushing into the model. It is anticipated that thermal expansion and deformation will play a role in the development of the transient temperature response of the machine.

CONCLUSIONS

The difficulties in developing a computational tool for the frictional and thermal behavior of oscillatory heavily-loaded pin-bushing systems are compounded by the paucity of available experimental results to guide the theoretical development. Continuous measurement of friction coefficient as a function of time is needed to capture these effects in the model. The idealized contact behavior (e.g. Hertzian theory) provides ease of computation but must be considered with caution. Also important is consideration of thermomechanical interaction between the pin and the bushing with proper implementation of the expansion/contraction of the surfaces. Work is in progress toward achieving these goals.

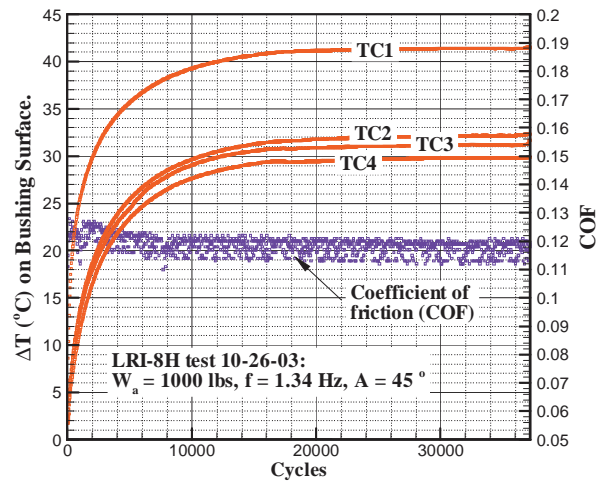


Figure 3. Typical experimental data

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