ME – PhD Thesis Defence

Design and development of lateral force-controlled tribosystems

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ABSTRACT

In a tribo-system, the frictional resistance during a sliding process depends on several parameters. These parameters include the interacting materials, their surface topography, contact conditions such as normal load, sliding speed, contact pressure and the nature of lubrication at the interface. In addition, the dynamics of the tribo-system become important as it influences the nature of the asperity interaction at the sliding interface. The dynamics of a tribo-system is governed by the various forces in the system. For a given external loading and surfaces, changing the system's mass, stiffness, and damping changes the inertial, spring and damping forces in the tribo-system. This result in different accelerations and relative sliding velocities at the interface, and the asperities of the two surfaces would interact at different rates. Thus changing the system parameters (mass, stiffness and damping) would result in a different frictional response for given surfaces and external forcing. Therefore, it is important to consider these parameters (mass, stiffness and damping) during the tribometer design stage so that the tribo-system is close to the actual tribo-system to be studied.

Now, based on these three parameters (mass, stiffness and damping) and the surface topography of the interacting surfaces, we propose that a tribo-system can be classified as a Lateral Force Controlled (LFCS) and a Lateral Displacement Controlled System (LDCS). The principle difference between the two types of tribo-systems is the nature of the asperities interaction during the sliding motion. At the asperity level, in LDCS, two surfaces are constrained to move at a certain velocity, forcing the asperities to shear at the specified rate. The resistance to the motion is measured by measuring the frictional force using load cells. Contrary to this, in LFCS, a known tangential force is applied, and the surfaces (bodies) are allowed relative motion under the applied force. Therefore, in LFCS, it is not the velocity but rather the acceleration (rate of change of velocity) which dictates the nature of asperity interaction and the frictional response. In this regard, the surface topography of the two interacting surfaces plays a crucial role in dictating the interaction rate and the frictional response during sliding. If there is a continuous change in the real area of contact during the sliding motion, the interaction of asperities at contact is analogous to intermittent loading. The loading frequency of the asperities depends upon the surface topography and the sliding speed at the interface. If this loading frequency of asperities matches the system's natural frequency, the structure's vibration magnitude increases. These conditions exist at very low sliding velocities, especially during the start and stop of the motion. In lubricated contacts, such conditions exist in the boundary lubrication regime of the Stribeck curve. At such lower speeds, the system is predominantly a force-controlled system instead of a displacement-controlled one. Under these conditions, contact stiffness is critical and dictates the frictional response. However, this contact stiffness is altered when a sensor is integrated into the system. This, often, is a case in LDCS. In LDCS, a known displacement/velocity is input, and the frictional force under these conditions is measured generally with the help of load cells. Load cell, when integrated into the system, changes the system's characteristics (stiffness, damping) and influences the contact stiffness of the tribo-system. This leads to a change in the nature of the asperity interactions resulting in a different frictional response as the contact conditions are no longer the same. In LFCS, the frictional force is not measured directly using force-measuring sensors. However, it is determined indirectly by calculating the acceleration/deceleration from the displacement response obtained using non-contact sensors. This eliminates the effect of sensor stiffness on the contact stiffness and results in asperity interactions closer to the actual conditions being simulated. This helps us calculate the accurate frictional force values closer to zero velocity in transient sliding conditions.

In the present work, two lateral force-controlled tribometers are designed. A parallel pendulum setup is designed to study the boundary lubrication regime of the Stribeck curve. A lateral force tribometer is designed to study the nature of friction between two surfaces subjected to suddenly applied forces.

The parallel pendulum tribometer is an energy-based tribometer designed to study the boundary lubrication regime of the Stribeck curve. This tribometer simulates the condition of combined rolling and sliding motion at the interfaces prevalent in many practical applications such as bearings, human body joints etc. The designed machine has high stiffness and is a highly under-damped system. Since the designed machine is a highly under-damped system, the energy input to the system is dissipated at much lower rates, resulting in many cycles of pendulum oscillations. As a result, we obtain many cycles/data points in the boundary lubrication regime of the Stribeck curve.

A lateral force tribometer is designed to conduct sliding experiments under tangential force-controlled transient conditions. These sliding conditions are prevalent in many tribo-systems, such as the seat belt-fabric tribo-system. The lateral force tribometer simulates the sliding conditions between two bodies in contact with each other when a sudden lateral force is applied to one body. Experiments are conducted using a seat belt-fabric, and a seat belt-polymer tribo-pair for different normal loads (in the range 10 N to 80 N) and three different initial tangential forces, 40 N, 60 N, and 80 N. Results show two regimes in the frictional response for different material pairs. The first region is the transient region in which there exists peak friction. This peak friction region is followed by a steady-state region in which constant friction is within the measured sliding distance. The occurrence of the peak friction and the value of the steady-state friction are found to be dependent on the contact stiffness of the interacting material pairs. This dependency of the CoF on the tangential contact stiffness is demonstrated by sliding experiments using stiffened fabric and steel-steel tribo-pairs.

ABOUT THE SPEAKER

Pranay Vinayak Likhar is a PhD student in the Department of Mechanical Engineering, IISc Bangalore. He is working with Prof. Satish V. Kailas in Surface Interaction and Manufacturing (SIAM) Lab. He has completed his B.Tech. from IIT Roorkee and ME from IISc Bangalore in Mechanical Engineering. His research interests are tribology and machine design.