(or strain) in a cantilever-mass force transducer. The two DOF model was based on the stiffness characteristics of the transducer. Calculations of force were made for a simulated friction test. The results of the two DOF and single DOF models were compared to the solution of the Euler-Bernoulli beam equations (Streator and Bogy, 1992). It was found that the two DOF model can provide improved accuracy compared with the single DOF model over a certain frequency range. As the two DOF model did not accurately describe the transducer's anti-resonance behavior, there was a limited range of frequencies for which the two DOF model was useful. Nevertheless, if the two DOF model is employed in a careful manner, it offers a viable method to increase the accuracy of force calculations over the single DOF method while maintaining much of its simplicity.

The present study has focused on analytical models of the response of a cantilever-mass transducer to dynamic contact forces. These methods provide a means for determining dynamic interfacial forces with a transducer that is statically calibrated. For measurement systems that can be dynamically calibrated, such as with an impact hammer, accurate experimental determination of the frequency response functions is generally preferred over modelling. On the other hand, an analytical model can be used not only to extract information from an actual transducer, but also from hypothetical transducers, a feature which allows for transducers to be designed for optimal performance (i.e., to avoid resonance) for a given tribological test.

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DISCUSSION

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The author is to be congratulated for addressing a problem which undoubtedly affects the interpretation of countless pin-on-disk tests. The effects of system vibrations on friction and their relationship to interfacial conditions are not an easy problem to solve, even when simplifying assumptions are made about the distribution of frictional transients which stimulate the system's response. In a recent paper on "Scale Effects in Steady-State Friction" [1], I qualitatively discussed similar questions with regard to the interpretation of laboratory friction data. When considering samples of pin-on-disk friction data for sliding alumina on alumina and for sliding aluminum on aluminum, taken at a recording rate of 1 kHz, I found that the distribution of friction force values was relatively normal in the former case and quite skewed in the latter. The asymmetry of the friction force distribution for self-mated aluminum was attributed to the face that the periodic relaxation of high friction forces, through the breakage of contact junctions, caused significant spring-back of the force transducer system, at times producing apparent force values less than zero. A further discussion of experimentally-observed asymmetries in kinetic friction are given in my book [2].

A machine designer might ask: What is the friction coefficient of material A upon material B? In the cited scale-effects paper, I state that a single value of the friction coefficient in imperfectly-lubricated systems should be replaced by an expected range and most-likely value for that specific system. Does the author agree with this approach? The implications for producing friction coefficient compilations and using handbook data are obviously significant.

The situation under consideration is one of frictional stimulus and mechanical feedback. Should one take the alternate tack, i.e., that friction is a materials property alone, would it be possible when comparing friction vs. time data from different machines to somehow remove the effects of the machine and compare the interfacial friction on a normalized basis?

In closing, the discusser complements the author on this work and looks forward to future studies in which the influences of materials properties, contact conditions, and asymmetrical friction force distributions might be explicitly taken into account.

Additional References

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2 Blau, P. J., *Friction and Wear Transitions of Materials*, Noyes Publications, 1989, pp. 385-395.

Author's Closure

The author thanks Dr. Blau for his kind remarks. When the measurement of friction is accomplished by a mechanical transducer, the raw data of the transducer will not be friction but elastic deformation. Clearly, to obtain the friction force, we must know the calibration between force and elastic deformation. Under many sliding conditions, the dynamic response of the transducer will not be important, so that the calibration comes via a simple proportionality factor. Under other conditions, however, one must take into consideration the dynamic response of the transducer [1]. In this latter case, the raw output of the transducer may show large variation (due to vibration or spring back) although the actual friction may be relatively constant. In this instance it would be imprecise to estimate the

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