(Fig. 4). The quantity ζ typically varies over the range of 1 to 6, a range of important effects in Fig. 5. Convective heat transfer from the sides of the tube, whose coefficient is denoted by $\hat{H}$, has its principle influence at low wear rates (see equations (48)–(51)) but has diminishing effects on the limit of stable operation for $w/w^* \to 1$, as shown in Fig. 8.

Using Figs. 4, 5, 7, and 8 along with the physical property data for a given application, an immediate assessment can be made concerning the significance of cooling, and if cooling effects need be included in the design analysis.

References

1 Dow, T. A., and Burton, R. A., "The Role of Wear in the Initiation of Thermoelastic Instability of Rubbing Contact," JOURNAL OF LUBRICATION TECHNOLOGY, TRANS. ASME, Series F, Vol. 95, No. 1, 1973, pp. 71–75.

2 Lebeck, A. O., "Theory of Thermoelastic Instability of Rotating Rings in Sliding Contact with Wear," ASME Paper No. 75-Lub-22.

3 Archard, J. F., "Contact and Rubbing of Flat Surfaces," *Journal of Applied Physics*, Vol. 24, 1953, p. 981.

4 Heckmann, S. R., and Burton, R. A., "The Effects of Shear and Wear on Instabilities Caused by Frictional Heating in a Seal-Like Configuration," ASLE Paper No. 75-LC-1B-2.

5 Wottreng, J., M. S. Project Report, Northwestern University, Evanston, Ill., 1975.

6 Etemad, G. A., "Free Convection Heat Transfer from a Rotating Horizontal Cylinder to Ambient Air With Interferometric Study of Flow," TRANS. ASME, 1955, pp. 1283–1289.

Acknowledgments

This work was supported by the United States Office of Naval Research Contract Number N00014-75-C-0761.

DISCUSSION

F. E. Kennedy[2]

In this paper the authors have extended their previous studies of thermoelastic contact instabilities in seal-like configurations (reference [4]) to include the effects of heat conduction across the sliding interface and convection to the surroundings. For this they should be congratulated. Their results, given in dimensionless form in Figs. 4, 5, and 8, show that both forms of heat transfer tend to improve the stability of such contacts. Their earlier results (see Fig. 6), which neglected these heat transfer effects, can therefore be used in a worst-case determination of contact stability.

The authors' results for the convective cooling case (Fig. 8) show that in practical applications the effect of natural convection is not very pronounced. Forced convection would be expected to show a greater influence and that influence could easily be determined by using the appropriate Nusselt number in expression (58).

The conductive cooling case was shown to have a much greater influence on contact stability, but I would agree with the authors' statement that "these results show an upper limit on the effects of conductive cooling." The model used in the analysis assumed that one of the contacting bodies was a half-space. In an actual face seal application the material volume would be finite and the amount of heat that could enter the body for a given temperature increase would be smaller. Less heat would, therefore, be conducted across the sliding interface and, in Fig. 4, the effective value of H would be smaller. In addition, it was shown by the authors that the presence of oxide films on the sliding surface would also diminish the effective value of H. It is felt that the results shown in Fig. 4 should be used more as qualitative indication of the influence of conductive cooling than as a quantitative measure.

Several other statements made in the paper may also require some clarification. It should be noted that equation (7) applies only at the sliding interface ($y = 0$). It is not a general relationship between temperature and heat flow, and it depends somewhat on the definition of h (equation (25)). Finally, I believe that careful reading of the recent paper by Lebeck (reference [2]) wlll show that convective heat transfer effects were included in that study.

[2] Thayer School of Engineering, Dartmouth College, Hanover, N.H.

Authors' Closure

We wish to thank Dr. Kennedy for his considered and useful comments, which will help to clarify the paper for other readers. Addressing two specific points:

Forced convection is interpreted to consist of two components, rotational and crosswind effects. Fig. 7 illustrates rotational forced convection and is incorporated in the calculation of $\hat{H}$ in equation (55). Contact stability appears to be weakly dependent upon $\hat{H}$, even at peripheral speeds of about 20 m/s. The effect of crosswind convection is thought to be small also so long as wind speed is comparable in magnitude.

Concerning our comment of Lebeck's paper, we wanted to call attention to the fact that he included a convection term in the derivation of his heat transfer equation; however, we could find no information on the magnitude of heat transfer coefficient used in his stability calculation, and we saw no treatment of the consequences of including or omitting this effect.

In conclusion, we agree with Dr. Kennedy's assessment that the numbers arrived at are somewhat approximate because of film effects and other factors. We may even visualize the instability prediction as an upper bound in the presence of cooling. Nevertheless we feel the important variables are properly sorted out and the general magnitudes are properly estimated.