Mechanical Properties of Rough Surfaces in Contact: Including Effects of Wear Particles and Third Bodies

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Some degree of surface roughness is present on all engineered surfaces of machine and structural elements. When two such rough surfaces are pressed together, contact takes place over a small fraction of the nominal area. Most of the "interface" consists of air! Furthermore, dry sliding contacts often contain wear particles and mechanically mixed deformed layers (third bodies) whose behavior needs to be understood and modeled. The effects of the voids and third bodies on interfacial mechanical properties are to generally make the interface considerably more compliant than the bulk and to add some mechanical damping. Appropriate interfacial mechanical properties must be incorporated into analytical and computational models of static or sliding contact. It is particularly important to include reasonable contact properties in problems of tribo-vibro-acoustics (e.g., squeal, friction-induced vibration) and thermomechanical contact (transient thermal distortion of sliding bodies), among others. The use of simple frictional boundary conditions, as is commonly done in analytical or computational mechanics, fails to capture the actual behavior.

In this talk we will discuss the different ways in which rough contacts can be modeled to create equivalent smooth surfaces, e.g., with the correct compliance. This is important for both physical understanding and modeling, considering that the full 3-D surface roughness cannot be practically incorporated into the boundary or finite element analysis of machine elements in sliding contact. The most important contact property remains the normal compliance, although, damping and tangential compliance can also be considered. The appropriate contact or gap elements can be combined with a local friction law to model the behavior of rough and third-body contacts with friction.

We will discuss theoretical and experimental aspects of contact stiffness behavior, including our own measurements. Both the theories and experiments suggest that the stiffness is inversely proportional to roughness amplitude, but the data is sparse. Also it is not generally made clear, if, in the presence of plastic deformation, it is the initial or the final roughness that is relevant. Also, two different power law relationships ($m \approx 0.6$ and $m \approx 1.0$) are found, both experimentally and theoretically, to capture, in different cases, the increase in non-linear stiffness $k \, \alpha \, p^m$ with nominal pressure, p. A better understanding of this problem is still needed.

We also show some data on contact damping were we are, as yet, unsure of the mechanisms. We then show that the presence of wear particles adds additional compliance, apparently in series, to that due to the roughness. Again, detailed quantitative explanations are not available.

Finally, we discuss some practical squeal and thermo-mechanical distortion problems where inclusion of proper contact properties is crucial. A thorough understanding of thermomechanical rough contact with frictional heat generation will challenge us for some time to come.