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Lean theoretical approaches to contact mechanics and leakage

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Persson's contact mechanics theory for idealized, nominally flat contacts has proven to accurately predict how contact area, mean interfacial gap, or the Reynolds leakage current depend on the normal pressure squeezing two solids against each other. In this contribution, we show that making some refinements to the theory allows its accuracy to be maintained even when some of the idealizing assumptions are abandoned, e.g., when the elastic bodies are graded, the surface topographies anisotropic, or the height distributions non-Gaussian.

Keywords (from 3 to 5 max): contact mechanics, nominally flat surfaces, leakage, modeling

1. Introduction

Most surfaces have a large degree of roughness, which crucially effects their tribological properties, such as partial contact, large local stresses, and leakage. They are generally challenging to predict even when a large number of idealizations is made. One main difficulty is that surface roughness has a multi-scale nature placing large demands on brute-force simulations. Persson theory [1] allows many tribological quantities to be calculated with a modest numerical effort. In contrast to bearing-area models, it succeeds to predict all relevant interfacial properties in the limiting case of three-dimensional elastic bodies that are squeezed against randomly rough indenters, whose surface profiles satisfy the random-phase approximation. This includes the distribution of interfacial gaps, whose knowledge allows the leakage rate of seals to be predicted using so-called effective-medium theories. In this contribution we run large-scale simulations of contacts, for which some of the commonly made assumptions are abandoned and test to what degree Persson theory, including minor modifications to it, allow interfacial properties to be predicted.

2. Methods

We study elastic contacts using Green's function molecular dynamics (GFMD) of an elastomer in contact with a randomly rough, rigid substrate. In the first part of our contribution [2], we consider generalized elastic manifolds, for which the areal energy density of a surface undulation no longer scales proportionally with the wave number q (as for regular, isotropic three-dimensional elastomers) but more generally as q^n, where an exponent n = 0, 2, and 4 would be characteristic for ``mean-field elasticity'' (e.g., Winkler foundation), human skin, and thin sheets, respectively. Persson theory is adjusted to reflect these cases. The random-phase approximation and thus Gaussian height-distributions are also abandoned, however, only for contacts with regular (n=1) elastomers.

In the second part [3], we consider regular elastomers in contact with randomly rough surfaces, which, however, may be anisotropic. The gap topography obtained using GFMD is then used in a calculation solving the Reynolds thin-film equation, which determines the fluid conductance σ across the contact. To obtain lean approximations to σ we also use the effective-medium theory (EMT), which formulates a self-consistent equation for σ as an integral over the probability density of interfacial separations. By reformulating EMT, we motivate an approximate solution for the self-consistent EMT equation, which allows σ to be estimated with simple means. Knowing the entire gap distribution function is not longer required but instead the percolation threshold (i.e., the relative contact area at which no fluid channels percolate across the interface) and the critical behavior near the percolation threshold. The latter differs between repulsive and adhesive interfaces.

3. Results and discussion

Figure 1 shows examples for the comparison between full simulations with Persson's contact-mechanics theory (dependence of mean gap on pressure) and with slightly modified effective-medium theories (dependence of fluid conductance on relative contact area). Although overall trends are very satisfactory, as shown in Figure 1, room for further improvement remains, for example, regarding the precise determination of contact area and the effect of elasticity on the anisotropy of the displacement field, which is enhanced compared to the height anisotropy.

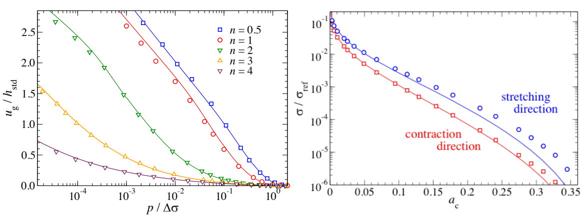

Figure 1: *Left*: Reduced mean gap as a function of reduced pressure, from Ref. [2]. *Right*: Reduced conductance as a function of relative contact area, from Ref. [3]. Symbols reflect simulations, full lines theory.

4. References

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