LETTER

Fundamentals and previous experiments of the squeeze film levitation mechanism

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This letter is in reference to a recent paper by Wiertlewski et al. (1) on the squeeze film levitation mechanism observed in vibrated fingertip contacts. The authors should be commended on an important finding about the squeeze film levitation effect in finger contacts. We would also like to take this opportunity to expand on several previous works in this area. In 2008, our research group successfully levitated rectangular geometries by using the same high-frequency air squeeze film mechanism (2). The vibrations applied were at a different frequency (5,000 Hz) with a similar amplitude of 5 μm, although the frequency was still the same order of magnitude. We also created a theoretical model of the problem based on solving the Reynolds equation of an ideal gas. The model also predicted the rough surface contact between the surfaces before vibration and then liftoff as the vibration was initiated. However, the numerically predicted air film thicknesses were much higher than what was experimentally measured. We theorized that it might be due to tilt or waviness of the plates, but in 2015, Huang et al. (3) showed theoretically and experimentally that the lower lift was indeed due to tilt. We suspect that, for fingers, tilt and misalignment between the surfaces may also be important, but perhaps the soft nature of the fingertip tissue allows for the surfaces to conform more easily. This conformity would allow the air to be trapped more easily between the counter plate and the troughs of the rough interface and therefore resist being squeezed out. Thus, each air pocket works like an individual cushion, which is the key factor to the levitation. The same research group, and Tichy and Winer (4, 5), also suggested that inertia and nonlinear effects could be important, especially at larger amplitudes of vibration.

The authors also found an interesting phenomenon on the phase shift (roughly 40°) between the motion of the plate and the motion of the fingertip. This phase shift can be quantitatively predicted using the numerical model shown in refs. 1 and 6. According to refs. 1 and 5, the air film thickness between the excited plate and the squeeze film bearing can be formulated as follows (7):

$$h = h_m[1 + \varepsilon \cos(T)],$$

if the plate is excited by $x_1 = Z_0 \sin(T)$. One numerical example in figure 7 of ref. 1 and figure 4.8 of ref. 6 shows that if the plate is vibrated with the amplitude $Z_0 = 5$ μm with the frequency 5 kHz, then the corresponding unknowns in the above formulation can be determined: $h_m = 81.52$ μm and $\varepsilon = 0.063$. Consequently, the motion of the squeeze film bearing should be the superposition of x_1 and h:

$$x_2 = 81.52 + 5.1345 \sin(T + \theta),$$

where $\theta = 45.7604°$, which is very close to the experimental results reported by the authors in figure 4H of ref. 1. Again, an interesting work, and we are glad to see evidence of this mechanism in a practical application.

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