Interactions between two close spheres in Stokes flow

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According to the standard lubrication theory, the fluid present in a small gap between two spheres sedimenting in a fluid resists relative motions with a force, which increases indefinitely with the decrease of the gap width. As a result, the contribution to the suspension transport coeffcients, which comes from interactions between pairs of very close particles is significant, even in a semi-dilute case.

However, the singular and non-analytic lubrication phenomena have been derived for ideally smooth spheres, while the real surfaces are rough. The existence of asperities may be a cause of mechanical interactions between two spheres in addition to the hydrodynamic and gravitational ones.

The experimental results are in agreement with the hypothesis that two different spheres settling in a fluid of a low Reynolds number flow actually come into contact. This conclusion follows from the lack of symmetries of the observed relative motion with respect to the time reversal, superposed with the reflection in the horizontal plane, which at a certain instant contains both sphere centers. In the absence of contact, such symmetries would have to be fulfilled due to invariance of the Stokes equations with respect to this transformation, and the corresponding symmetry of the gravitational force. There is no such symmetry at the contact, since the mechanical friction forces act only if the center of the faster particle is higher than the center of the slower one [1].

We adopt a very simple model of the contact. That is, we assume that the hydrodynamic interactions between two spheres balance the gravitational and the mechanical friction forces. The relative motion consists of two parts: the pure rolling, if the ratio of the mechanical friction to the load is larger than the static friction coefficient, and the rolling with slip, in the other case.

The resulting particle relative velocities depend logarithmically on the gap width. Therefore experimental determination of the model parameters is challenging. The effective distance between the particle surfaces is practically not specified by the translational measurements only [1].

Therefore our goal is to analyze also the rotational motion in addition to the translational one. We measure the motion of a sphere, which settles in a silicon oil onto another, fixed sphere of the same size. We use simultaneously two different techniques: a video system, and a laser interferometer coupled with encoders. We determine the rotation and translation from video images, using the other part of the experimental setup, which simultaneously measures the translation, for a calibration, which increases the accuracy.

We evaluate from the model the particle rotational and translational motion. We develop a systematic fitting procedure, based on comparison of positions of the sphere centers and a dot on the moving sphere (for measurement of the angle of rotation) versus time, and we determine the model parameters. Analysis of the rotational motion together with the translational one turns out to be crucial to the experimental verification of the model, because the it allows to give reasonably accurate estimates for the effective distance between the particle surfaces.

References

[1] M.L. Ekiel-Jeżewska, F. Feuillebois, N. Lecoq, K. Masmoudi, R. Anthore, F. Bostel, E. Wajnryb, Phys. Rev. E, **59**, 3182 (1999).