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Kinetic Theory for Anisotropic Thermalization and Transport of Vibrated Granular Materials

The purpose of this work is to develop a full continuum theory that may be used to predict the effects of anisotropic boundary vibrations on loose granular assemblies. In order to do so, within the flow we extend statistical averaging techniques employed in the kinetic theory to derive an anisotropic flow theory for rapid, dense flows of identical, inelastic spheres. The theory is anisotropic in the sense that it treats the full second moment of velocity fluctuations, rather than only its isotropic piece, as a mean field to be determined. In this manner, the theory can, for example, predict granular temperatures that are different in different directions.

At the boundary, we employ similar statistical techniques to derive boundary conditions that ensure that the flux of momentum as well as the flux of second moment are balanced at a bumpy vibrating boundary. The bumps are hemispheres arranged in regular arrays, and the boundary vibrations are sinusoidal with amplitudes, frequencies, and phase angles that may be adjusted in three perpendicular directions. The bumpiness of the surface may be adjusted by changing the size of the hemispheres, the spacing between the hemispheres in two separate array-directions, and the angle between the two directions.

The focus of the results presented here is on the steady response of unconfined granular assemblies that are thermalized and driven by horizontal bumpy vibrating boundaries. In a first detailed study of the effects of the boundary geometry and boundary motion on the overall response of the assemblies, the anisotropic theory is reduced to a more familiar isotropic form. The resulting theory predicts the manner in which the profiles of isotropic granular temperature and solid volume fraction as well as the uniform velocity and corresponding flow rate vary with spacings between the bumps, angle of the bump-array, energy of vibration, direction of vibration, and phase angles of the vibration.

In a second study, we solve the corresponding, but more elaborate, boundary value problem for anisotropic flows induced by anisotropic boundary vibrations. The main focus in presenting these results is on the differences between granular temperatures in three perpendicular directions normal and tangential to the vibrating surface, and how each is affected by the bumpiness of the boundary and the direction of the vibration. In each case, we calculate the corresponding nonuniform velocity profile, solid volume fraction profile, and mass flow rate.

Mark Richman received his Ph.D. in Theoretical and Applied Mechanics from Cornell University in 1984. He was among the earliest workers to extend the methods employed in the kinetic theory of dilute gases to dense, dissipative, rapidly flowing granular materials. Much of his research has been devoted to developing both constitutive theories and boundary conditions for such flows, including conditions that apply at vibrating boundaries. His past work has been supported by the National Science Foundation and the Department of Energy. Professor Richman has taught mechanical engineering at Worcester Polytechnic Institute since 1985.

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