From “solid” to “fluid”: Time-dependent hydrodynamic analysis of dense granular flows.

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When dealing with dense granular flows (not far above the "fluidization point" of the granular material), which cannot be regarded as granular gases, multiple unresolved questions arise. Many of them are related to the necessity of constructing the right framework to handle the dynamics of void occupation, which governs granular flow at high densities. This is a formidable task. However, hydrodynamic fields such as density, velocity,pressure and granular temperature, are easy to produce and study in numerical simulations of particles.

Here we present results from 2D molecular dynamics simulations of vertical and horizontal shaking. Although very similar at the first glance, the convection mechanisms are quite different: shearing and tangential interactions dominate the former; for the latter the properties of normal interaction between particles seem crucial. Moreover, the convection onset is velocity dependent (not acceleration dependent) and is related to void creation and motion, with very precise dependence on $\sqrt{Rg}$, where R is the radius of particles and g the acceleration of gravity [1].

For the normal interaction between particles, the viscoelastic model [2] has been used, which relates the normal dissipative part of the interaction with the Young modulus of the material, its Poisson ratio, density and the effective radius of colliding particles (assumed spherical). An additional parameter, associated with a viscous time-scale of the material, accounts for dissipation. Particles were chosen to have a Young modulus of 0.5 GPa, density 2 g/cm^3 and an average radius of 0.35 mm. The dissipative parameter of the material was 10^{-6} s. For the tangential interaction, we follow Haff and Werner [3]. The number of particles was 10,000, and the container was 10 and 4 cm wide, for horizontal and vertical shaking respectively. The frequency of sinusoidal shaking was 25 Hz and the amplitude 2 mm, providing fully convecting regimes in both cases. A predictor-corrector scheme of integration with a timestep of 2 10^{-7} was used. The code was parallelized for a 32 processor computer, producing 1,000 cycles in less than 2 weeks of total computing time. The convection patterns appear realistic, reproducing those found in experiments, for example in [4,5].

The procedure for generating hydrodynamic fields can be found in [6], which can be briefly summarized as follows. First, for a number of cycles (1,000 in this case), positions of particles are dumped at equispaced values of the phase of vibration (100 per cycle). A grid is associated to the region of interest, and for every cell, every phase of every cycle, hydrodynamic quantities are computed. Averaging over corresponding phases provides the "ensemble averaged", or mean value for that phase, of the various hidrodynamic fields (high resolution grids will require a large number of "samples" for a reasonable elimination of statistical noise). Statistical noise is always present, due to the essentially mesoscopic character of the system, and therefore a compromise must be found between resolution and technical limitations (number of cycles). The 2D fields generated by this procedure can be easily represented and this is done via IDL package. Static images are finally assembled into animated sequences.

The movies show different features. First, that the material is clearly divided into two regions: an almost solid dense region, constituting the main core of the system, and a few layers of material, in contact with the boundaries, which are highly fluidized. Particles in this region are loose, and move and spin quickly.

Very fast changes occur after the collision of the material with the boundaries. Under vertical shaking, a gap is formed due to inertia when the container moves downwards, while the system is still moving upwards. In horizontal shaking, a similar gap can be observed alternatively at both sides, but extending up to the free surface due to the geometry. After the impact, the temperature field indicates that a shock wave propagates through the extremely cold material, which is maximally compressed during this phase. Its energy is dissipated in about a tenth of the cycle. The examination of the velocity fields shows different patterns of particle motion during the expansion and compression phases. The time-resolved images reveal other interesting features like the relation between the pressure, temperature and energy dissipation fields.

References

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