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Dense Inclined Flows: Theory and Experiments*Quarterly Technical Progress Report (January 1, 1994 to March 31, 1994)***Contract number:** DE-AC22-91PC90183**Contract Period of Performance:** January 1, 1991 to December 31, 1994**Contractor:** Cornell University, Ithaca, NY 14853**Contract Participants:** James T. Jenkins, Michel Y. Louge**DOE Project Manager:** William C. Peters

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Summary of accomplishments

Rapid, gravity-driven flows of granular materials down inclines pose a challenge to our understanding. Even in situations in which the flow is steady and two-dimensional, the details of how momentum and energy are balanced within the flow and at the bottom boundary are not well understood. Thus we have undertaken a research program integrating theory, computer simulation, and experiment that will focus on dense entry flows down inclines. The effort involves the development of theory informed by the results of simultaneous computer simulations and the construction, instrumentation, and use of an experimental facility in which the variables necessary to assess the success or failure of the theory can be measured.

In the present reporting period, we have improved the operations of the chute facility to permit a precise setting of its angle. We have also improved the microphone probe and collection vessel that records the mass holdup of particles. We have completed a series of measurements of the impact properties of acrylic and polystyrene spheres. Finally, we have interrogated our computer simulations in an effort to refine our theoretical predictions for the flux of fluctuating energy through a flat, frictional wall.

1. Improvements of the Chute

Guided by the preliminary experiments summarized in the last quarterly report, we have decided to improve the construction of our chute. These improvements include the implementation of an on-line cleaning system of the beads, the articulation of the chute near its summit, the introduction of a new suspension system that reduces low frequency oscillations, the use of a faster computer data acquisition system, the design of a more rigid collection vessel for the mass holdup measurement, and the construction of a precise

traverse system for the microphone probe that records the location of the free surface of the granular flow above the chute. With these new features, the chute is more versatile and reliable, and it is simpler to use.

2. Measurements of Particle Properties

In this reporting period, we have also completed a series of measurements of the impact properties of polystyrene and acrylic spheres (Figs. 1 and 2). We expect to employ a DCS-100 digital camera to perform our next series of experiments with the particles used by the GFARO participants.

Fig. 1. Results for binary collisions of 4mm polystyrene spheres. The corresponding values of the normal restitution, the friction and the tangential restitution are, respectively, $e=0.952$, $\mu=0.188$, $\beta_0=0.5$. The circles and triangles represent the sticking and slipping regime, respectively.

Fig. 2. Results for binary collisions of 4mm acrylic spheres. For these experiments, $e=0.93$, $\mu=0.096$ and $\beta_0=0.28$.

3. Theory

We have further refined our calculations of the flux of fluctuating energy through a flat, frictional wall. We have interrogated computer simulations to determine why our predictions for the flux differed from the results of the simulations in the limit of large sliding.

4. Computer Simulations

In our study of the interactions between the rapid granular flow of spheres and a flat, frictional wall, we have investigated the spatial distribution adopted by the spheres near the wall. We have shown that the representation of that distribution depends strongly on the form of the averaging adopted in the simulations. In the case of center-averages, we have found that the measured distribution agrees well with the theory of Henderson, Abraham and Barker (HAB) (Fig. 3).

Fig. 3. Profiles of center-average volume fraction $\langle v \rangle$ with relative distance from the wall for the conditions $e = 0.9$, $\mu = 0.3$, $\beta_0 = 0$, $L_x/\sigma = L_y/\sigma = L_z/\sigma = 5.9$, and $r = 0.65$. The circles are theoretical predictions of the HAB theory that matches the measured $\langle v \rangle$ at $y = \sigma/2$ using $v^* = 51.8\%$.

In these new simulations, we have also observed a phase transition for the two dimensional array of spheres adjacent to the wall. Evidence of this phase transition can be seen in Fig. 4. The transition occurs near the surface fraction $v_{\Delta}^* \approx 0.665$, in excellent agreement with the theory of Jenkins and Shahinpoor for identical arrays of disks.

Fig. 4. Relative normal stress η versus $\langle v \rangle \sigma / 2$ for the conditions $e = 0.9$, $\mu = \infty$, $\beta_0 = 0$, $L_y/\sigma = 22.3$ and $L_x/\sigma = L_z/\sigma = 5.9$. The squares are the simulation results. The vertical dashed and solid lines represent $\langle v \rangle \sigma / 2 = 0.665$ and $\pi/4$, respectively.

References

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