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Development and Utilization of New Diagnostics for Dense-Phase Pneumatic Transport

Quarterly Technical Progress Report (October 1, 1989 to December 31, 1989)

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Summary

Dense-phase pneumatic transport is an attractive means of conveying solids. Unfortunately, because of the high solid concentrations, this transport method is a difficult regime in which to carry out detailed measurements. Hence most details of the flow are unknown.

In this context, the main objective of this work is to develop probes for local measurements of solid velocity and holdup in dense gas-solid flows. In particular, capacitance probes are designed to measure local, time-dependent particle concentrations. In addition, a new optical fiber probe based on laser-induced-phosphorescence is developed to measure particle velocities.

The principles for the capacitance and optical diagnostics were given in our first and second quarterly reports. In this reporting period, we have demonstrated with success the feasibility of the optical fiber probe.

Another objective of this work is to develop a model of dense-phase conveying and to test this model in a setup that incorporates our diagnostics. In this period, as a prelude to these modeling efforts scheduled for the third year of the contract, we have carried out additional computer simulations of rapid granular flows to verify the theories of Jenkins and Richman (1988) on the anisotropy of the second moment in simple shear.

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Progress Report

1. Fiber-optic anemometer probe

The reader is directed to our first quarterly report for the principles of operation of this anemometer. During this period, we have coated a doped ZnS phosphor on glass particles and measured its lifetime. In addition, we have successfully tested a prototype of the anemometer probe in two distinct experiments.

1.1. Phosphor lifetime

The lifetime of the doped ZnS phosphor is measured by exciting it with 10 nsec pulses of laser radiation at 440nm, and observing the decay of the emitted light on a digital oscilloscope. In these measurements, we have also observed significant levels of fluorescence from this material. As a result, the lifetime measurement is somewhat uncertain, but it is at least 3.6 msec based on 37% (1/e) of the original peak. Figure 1 shows a typical trace for this measurement. Since we have used optical fibers to bring laser light to the ZnS sample and to convey the phosphorescent emission back to the photomultiplier tube (PMT), the signal-to-noise ratio of the trace in Fig. 1 is similar to that of a typical experiment with the probe.

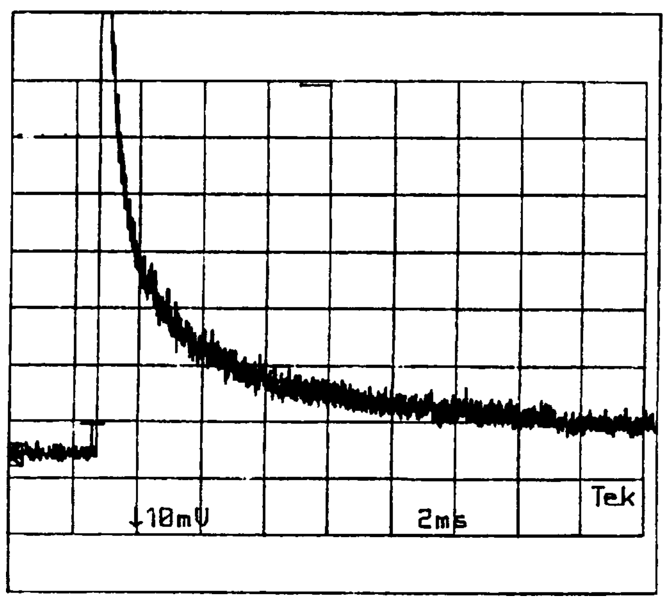

Fig. 1. Typical trace for the measurement of the phosphorescent lifetime of doped ZnS coated on 270μm glass particles.

1.2. Rotating disk calibration

In order to calibrate the response of the anemometer probe, we have coated the face of a 4" ID disk with the same ZnS phosphor used to coat the particles. The probe is placed in front of the disk rotating at a known angular velocity (Fig. 2). By varying the lateral position of the probe and the angular velocity of the disk, we can mimic the passage of particles over a wide range of velocities. For these experiments, we have found it convenient to bring a weak sample of the original laser pulse to the detection PMT using an additional optical fiber. In this way, we have a clear indication of the time when the laser flashes.

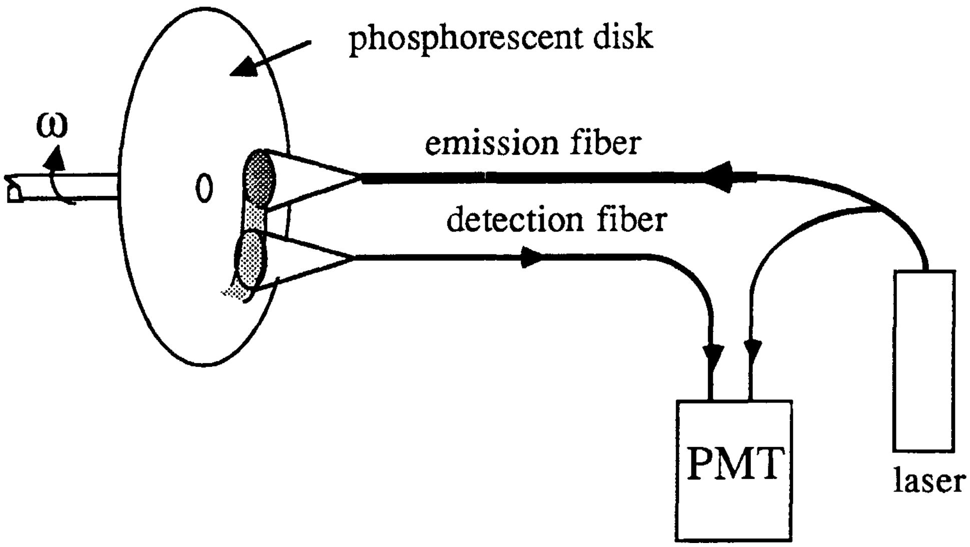

Fig. 2. Optical arrangement with the rotating phosphorescent disk.

Using the probe signal, we infer the speed of the rotating disk from the time separating the original laser pulse and the peak of the detection of the resulting phosphorescence. Figure 3 compares the values of speed measured by the probe with the actual values inferred from the probe location and the angular velocity. Note the excellent linearity of the probe output. From the slope of the line, we infer that the effective distance separating the emission and the detection fiber is not 1.5mm as originally thought, but rather 1.24mm.

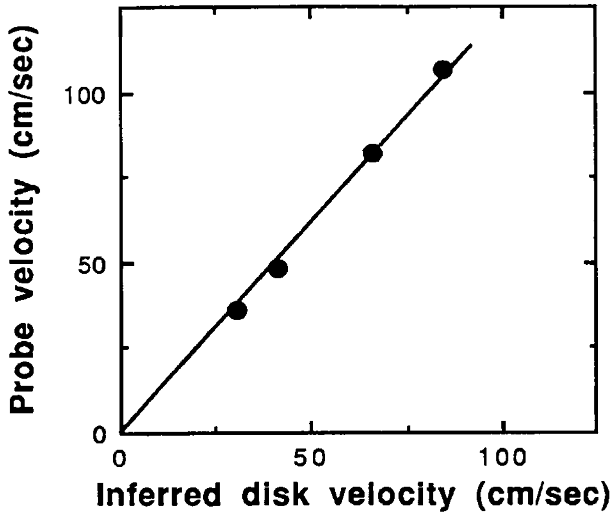

Fig. 3. Velocity measured by the probe and inferred from the known disk rotation.

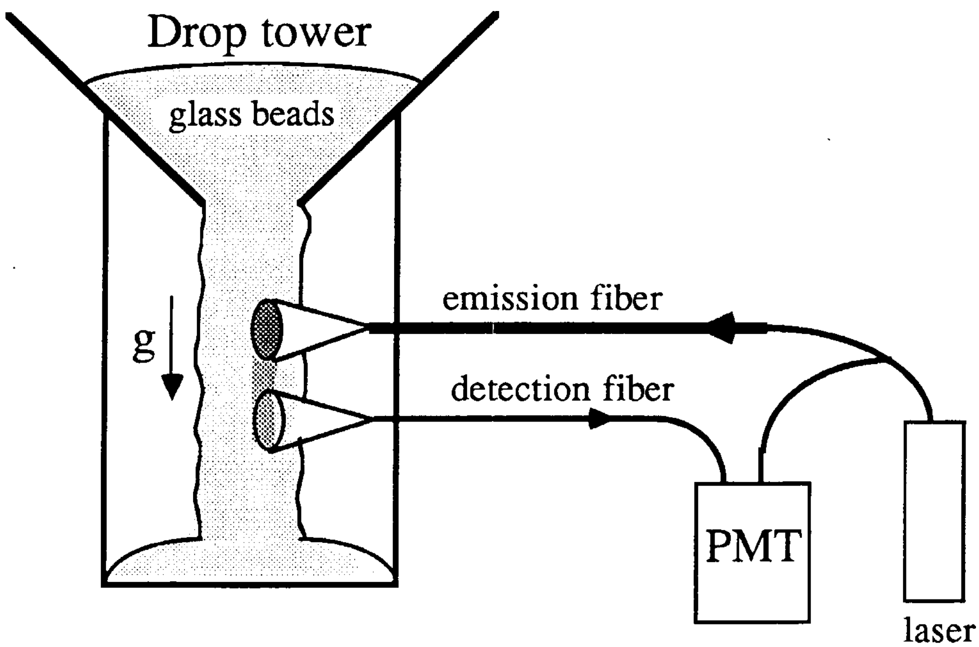

Fig. 4. The drop tower experiment. Dimensions are not to-scale.

1.3. Drop tower experiments

In a second series of experiments, we have dropped 270μm spherical glass particles coated with the doped ZnS phosphor in a small vertical vessel called 'the drop tower' (Fig. 4). In the drop tower, a metal screen located 18cm above the probe is used to sift the particles. Calculations show that the particles have nearly reached terminal velocity when they reach the probe. A typical trace output from the PMT is shown in Fig. 5. There we clearly distinguish the sharp initial laser pulse, and the passage of the particles in front of the detection fiber. For these experiments, the probe measured velocities ranging between 1.4 to 1.6 m/sec. These measurements are in good agreement with the calculated value of 1.4 m/sec, which is based on an empirical expression for the terminal velocity of an isolated particle in air.

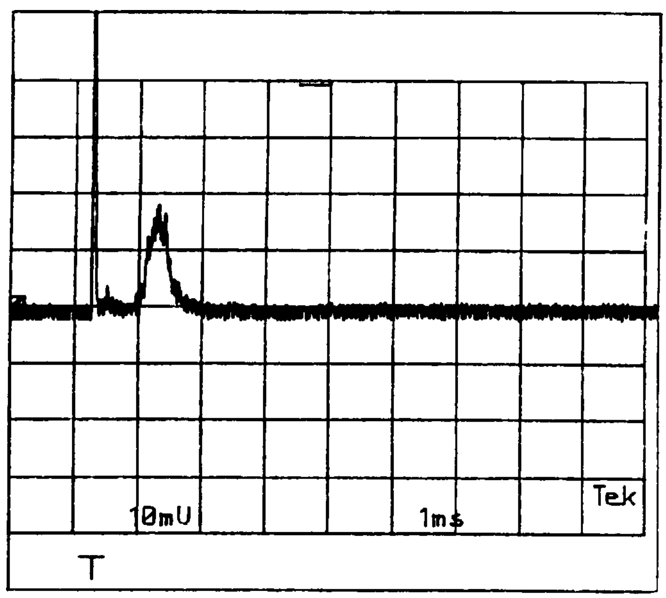

Fig. 5. Typical output from the PMT. The sharp laser pulse defines the origin of time.

By reducing the distance between the sifting screen and the probe, the glass beads were made to fall at lower velocities in the range 40 to 60 cm/sec. Despite the reduction in the signal-to-noise ratio associated with the smaller levels of phosphorescence, the probe was still able to record these velocities. In another, preliminary experiment with a polydisperse powder, we have also recorded two distinct emission peaks that appear to reflect the different free-fall velocities of particles with different sizes. This observation illustrates the versatility of this new probe, and its ability to detect individual - rather than average - velocities.

2. Modeling

We believe that theories of dense, rapid, frictional granular materials are relevant to the behavior of the particle layer adjacent to the wall in a stable plug. In the last reporting period, we conducted computer simulations of sheared rapid granular materials to verify the theories of Hanes, Jenkins and Richman (1988) for the dense limit. In this period, we have focused on the simple shear of a rapid granular flow of inelastic disks. In this context, we have tested the theory of Jenkins and Richman (1988). We have found that this theory is in good agreement with the simulation results when the periodic domain used in the simulation contains a relatively small number of particles. However, when the size of the periodic domain is increased, we have discovered a new type of microstructure in the flow, whereby the particles tend to cluster together for low values of the coefficient of restitution. As such a microstructure develops, the stresses and other statistical measures of the flow become significantly different than the values predicted by the theory of Jenkins and Richman, who postulate spatial isotropy. We are presently writing a paper on this phenomenon, which we plan to append to the next quarterly report.

3. Next Research

In the next reporting period, we plan to record on videotape the particle free-fall in the drop tower. This observation will help establish how many particles are detected simultaneously by the probe. In addition, it will provide an absolute reference for the free-fall velocity, which was merely calculated from an empirical correlation in the experiments described in section 1. Using the well-controlled environments of the drop tower and the rotating disk, we will also evaluate the response of the probe for relatively complex situations: For example, we will tilt the probe to observe the effect of a velocity component aligned with the probe axis.

References

M.Y. Louge & J.T. Jenkins: "Development and Utilization of New Diagnostics for Dense-Phase Pneumatic Transport", 4 Quarterly Technical Progress Reports to the DOE (October 1, 1988 to August 31, 1989), Contract number: DE-AC22-88PC88947.

J.T. Jenkins and M.W. Richman: "Plane Simple Shear of Smooth Inelastic Circular Disks: The Anisotropy of the Second Moment in the Dilute and Dense Limits", *J. Fluid Mech.* **192**, pp. 313-28 (1988).