APPLICATION NOTE 5

Force Exerted by Powder Flow on the DFF Sensor Probe: Comparison of Theory and Experiment

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When the DFF sensor probe is positioned normally to a continuous, one-dimensional flow of small spherical particles, the force on the tip of the pin is given by (see Application 02):

$$F_0 = \frac{3}{8} A\hat{\rho}v^2 \qquad \text{Eq. 1}$$

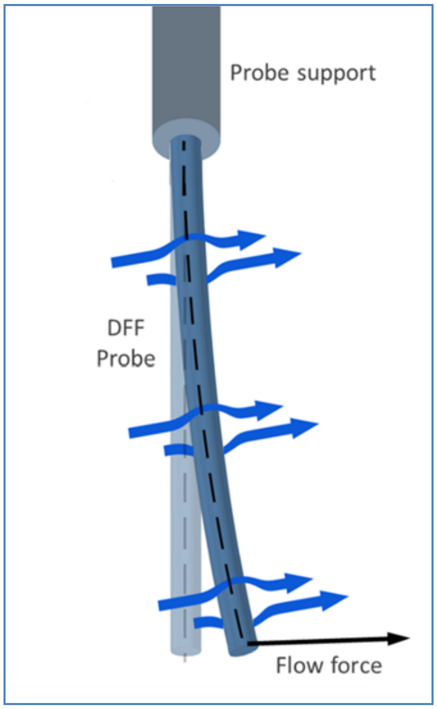


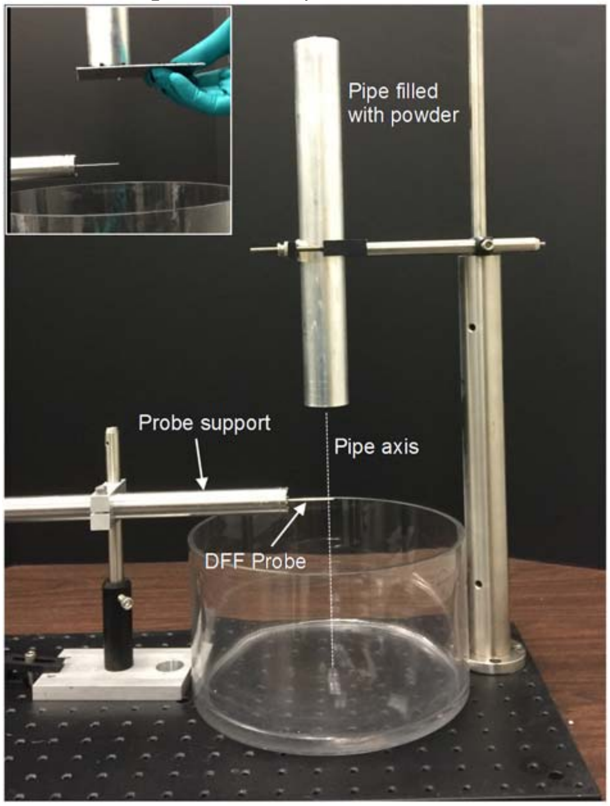
Illustration of the origin of shear force exerted by a flow on Lenterra's Drag Flow Force (DFF) sensor probe. Deviation of the pin tip is exaggerated for clarity of illustration. Pin deflection of as small as 0.1 micrometer is detectable for a pin length of 40 mm.

Here A is the total cross sectional area of interaction between the flow and the pin, $\hat{\rho}$ is the powder density (not the particle density), and v is the velocity of the flow at impact.

This note compares DFF sensor measurements of a powder flow force with model calculations via Eq. 1.

Experiment

The setup can be understood from the photograph. A vertically held pipe (1 foot long, 1 inch ID) was filled with the test powder that subsequently fell onto a horizontally held DFF sensor probe (type P-300-40, rated for 0.3N) in a variation of hopper discharge. The test powder was produced by granulating a pharmaceutical placebo formulation consisting of 37% anhydrous lactose, 1% croscarmellose sodium, and 3% hydropropyl cellulose (HPC) with 57% microcrystalline cellulose with 40% water, wetmassed for 23 minutes in a 4L Bohle high shear granulator. After letting it dry, the powder was sieved through a 0.8 mm plastic mesh.



A photograph of the experiment. The tip of the horizontally placed DFF probe was positioned at the continuation of the pipe axis, 8.5 cm below the lower end of the pipe. The powder was manually discharged as shown in the insert.

Results

DFF sensor measurements for five consecutive loads show the initial impact force of the falling powder as $\mathbf{0.014 \mp 0.002\ N}$. In each trial, force gradually increases with time because later impacts involve particles that are

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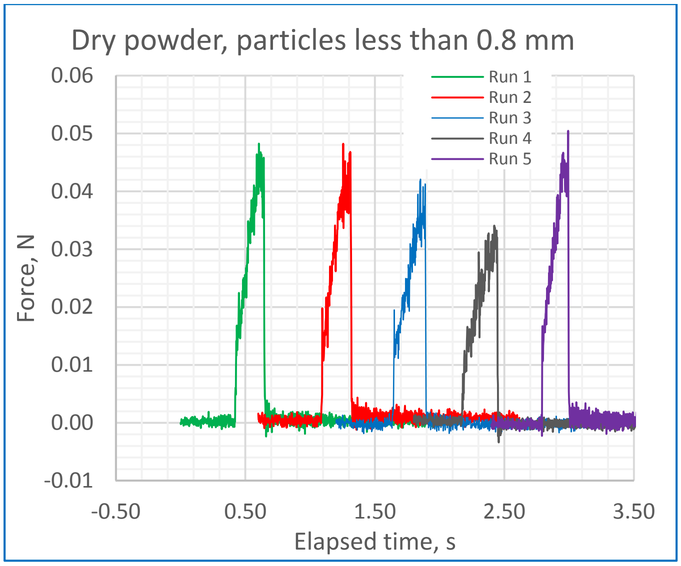
higher in the stack, so they reach the probe at a higher velocity.



To calculate the force theoretically, using Eq. 1, one requires to evaluate the density of the powder, ρ^0 at the time of initial impact. Weighing the powder in a calibrated flask provided a density of 0.76 g/cm^3. Following the discharge, the density of the falling powder decreases. We will estimate the reduction factor by evaluating the duration of the measured signal. Assuming free fall, the bottom edge of the powder stack reaches the pin in time of

$$t_1 = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2\cdot 0.085m}{9.8ms^{-1}}} = 0.13\ s \qquad \text{Eq. 2}$$

after the release. Here h = 8.5 cm is the distance between the pipe and the probe, and g is the acceleration due to gravity. Neglecting friction, one estimates the time when the top portion of the powder stack reaches the probe as

$$t_2 = \sqrt{\frac{2(h+l)}{g}} = \sqrt{\frac{2\cdot(0.085+0.35)m}{9.8ms^{-2}}} = 0.28\ s \qquad \text{Eq. 3}$$

where l=30.5 cm is the pipe length. This leads to a total duration of the force action of

$$t_2 - t_1 = 0.15\ s. \qquad \text{Eq. 4}$$

In the actual tests, the duration of the force signal was 0.26 s in average. Visual observations confirmed that the diameter of the flow stack does not change in the fall, therefore the density of the powder at the initial time of contact was that measured in the flask reduced by a factor of $\frac{0.15s}{0.26s} = 0.57$:

$$\rho^0 = 0.76\frac{g}{cm^3}\cdot 0.57 = 0.43\frac{g}{cm^3} = 430\frac{kg}{m^3} \qquad \text{Eq. 5}$$

Substituting this value into Eq. 1 and calculating cross section, *A*, as the product of the length of the DFF sensor probe (40 mm) and its diameter (1.3 mm), for $v^2 = 2gh = 2\cdot 9.8ms^{-2}\cdot 0.085m = 1.7m^2s^{-2}$

$$F_0 = \frac{3}{8}A\rho^0v^2 = \frac{3}{8}\cdot 0.04m\cdot 0.0013m\cdot 430\frac{kg}{m^3}\cdot 1.7m^2s^{-2} = \mathbf{0.014}\ N \qquad \text{Eq. 6}$$

The predicted force therefore is in excellent agreement with the measured value.

Conclusion

The free falling powder tests has shown that DFF sensor is a reliable tool for measuring density of dry powder flows, specifically for fine powders where the maximum particle size does not exceed one millimeter.