White Paper 4

Single Granule Impact on the Tip of DFF Probe: Experiment

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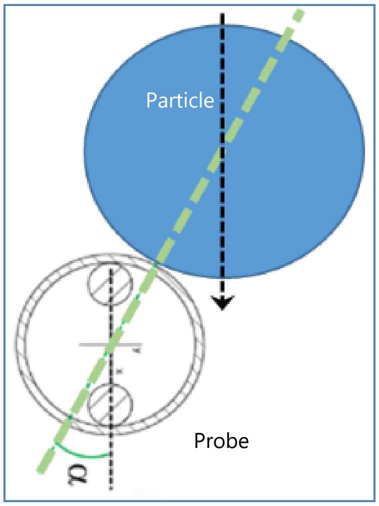
For a perfectly inelastic impact of a spherical particle with the DFF probe tip, force measured by the sensor is estimated as (see White Paper 2):

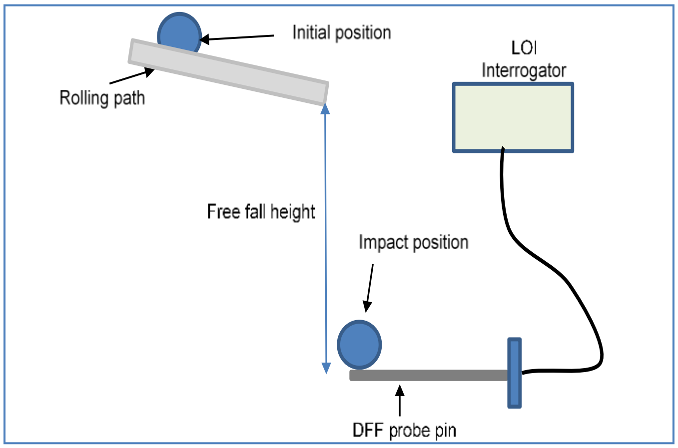
$$F_{\alpha} = \frac{\pi^2}{6} f v \rho d^3 cos\alpha \qquad \text{Eq. 1}$$

Here f is the mechanical frequency of the probe, v is the particle velocity, ρ and d are the density and diameter of the particle, respectively, and α is the angle between the DFF sensor measurement axis and the radius-vector to the contact point between the particle and the pin.



This note compares DFF measurements of single particle impact forces with model calculations according to Eq.1.

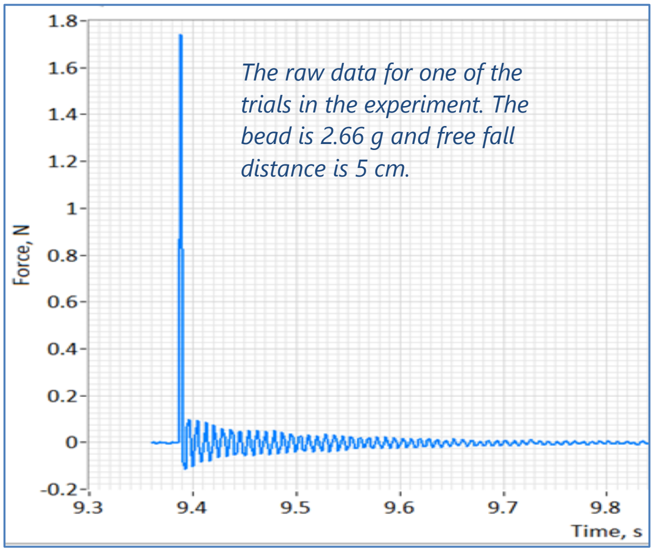
Experiment



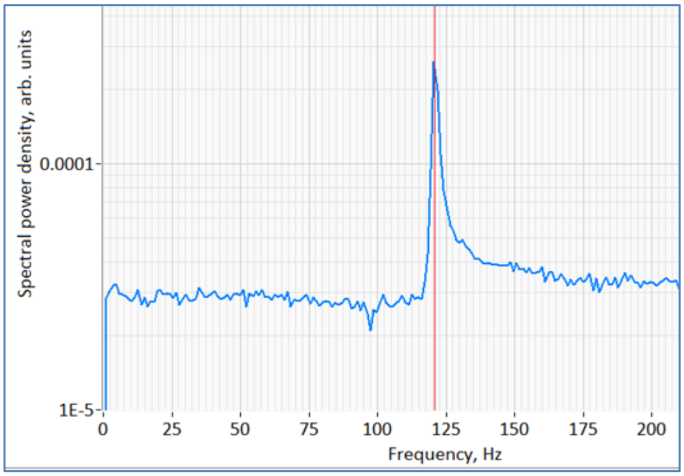
Polymer clay beads, density 1.38 g/cm3, were let to fall on the tip of a DFF sensor probe (type P-4000-40, rated for 4N) after rolling down along a channel as shown in the figure. The rolling path inclination was 10 degrees off-horizon. Initial position of the bead was kept constant in all trials.

Force pulse

The recorded force-vs-time dependence is characterized by a salient positive pulse followed by slowly decaying oscillations.



The pulse fall time is determined by the natural frequency of the probe oscillation. Applying the fast Fourier transformation (FFT) to the measured data shows a peak at 120.9 Hz (oscillation period of 8.2 ms). This is the natural frequency of the probe pin oscillation.



Pulse magnitude vs. bead size and fall distance

Impacts of beads of three different sizes were recorded multiple times at the falling distance of 5 cm, and for the bead of 2.66 g - for three different falling heights.

Accumulated results are summarized in the table. Predicted force was calculated using Eq. 1.

Bead	Mass, g	Diameter, cm	Fall height, cm	Measured Force, N	Predicted force, N	Ratio
1	11.99	2.55	5	4.9	15.7	**0.31**
2	6.72	2.1	10	4.86	16.5	**0.29**
3	2.66	1.54	5	2.07	7.23	**0.29**
3	2.66	1.54	7	2.78	8.53	**0.33**
3	2.66	1.54	10	3.28	10.19	**0.32**

Last column represent ratio between the measured and predicted value that appears to be close for all test series, reflecting the fraction of the impulse transferred to the pin.

Conclusion

In five series of tests, measured and predicted forces are related by a similar factor of 0.3, suggesting that the theoretical formula correctly predicts the functional relationship between the response of the DFF sensor and mass and velocity of the particle. The reduction happens because a clay particle impact is not completely inelastic as assumed in derivation of Eq. 1. For the particle material, only 30% of the momentum is transferred to the probe, therefore the agreement between the measured and experimental values is satisfactory.