APPLICATION NOTE 4

Single Granule Impact on the Tip of DFF Sensor Probe: Comparison of Theory and Experiment

Valery Sheverev and Vadim Stepaniuk

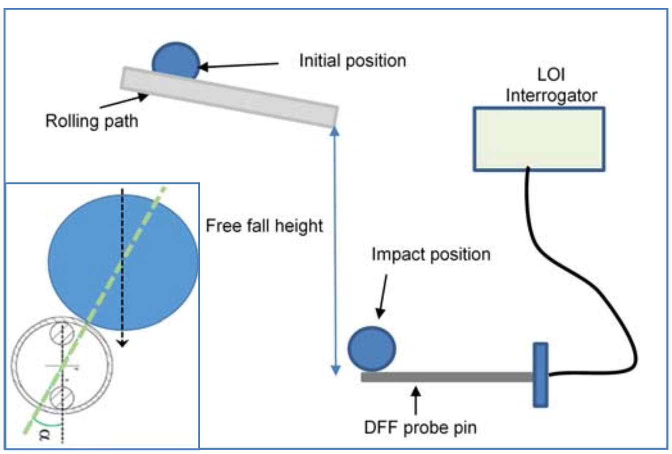
For a perfectly inelastic impact of a spherical particle with the DFF probe pin tip, the force measured by the sensor is found using Eq. 2a of Application Note 02:

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

Here $\boldsymbol{f}$ is the mechanical natural frequency of the probe, $\boldsymbol{v}$ is the particle velocity magnitude, $\boldsymbol{\rho}$ and $\boldsymbol{d}$ are the density and diameter of the particle, respectively, and $\boldsymbol{\alpha}$ is the angle between the DFF sensor measurement axis and the radius to the contact point between the particle and the pin.

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

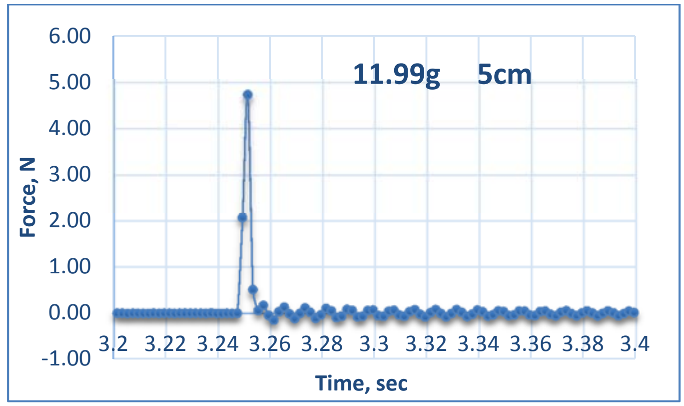
Experiment



Experimental arrangement for the single particle impact tests. The off-axis impacts lead to α>0 (cosα<1) as shown in the insert.

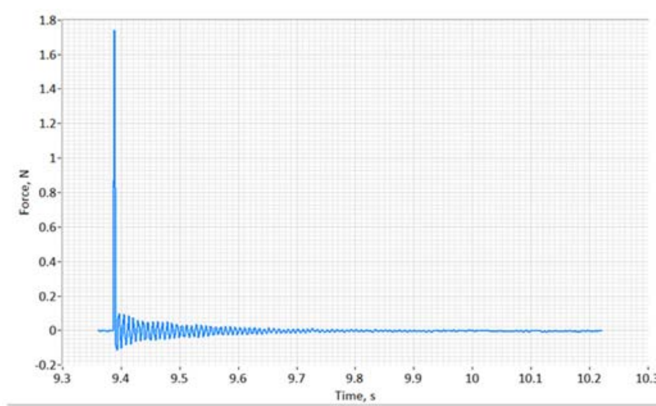
Polymer clay beads, density 1.38 g/cm3, were let to fall on the tip of a DFF sensor probe (type P-4000-40, rated for 4N) after rolling down along a channel as shown in the figure. The rolling path inclination was 10 degrees off-horizon. Initial position of the bead was kept constant in all trials.

Force pulse



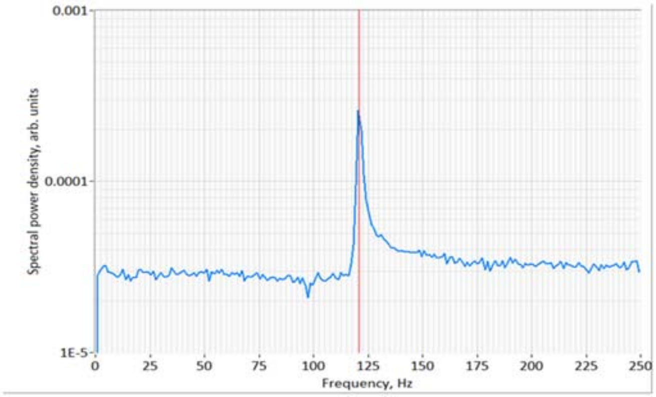
A DFF sensor signal measured during a free fall of a polymer clay bead on the tip of a DFF probe. Measurements taken every 2 ms, are represented with blue dots. The mass of the bead was 11.99 g and the free fall distance was 5 cm.

The recorded force-vs-time dependence is characterized by a salient positive pulse followed by slowly decaying oscillations. Measurements indicated with dots on the plot, were taken every 2 ms, therefore, showing the total duration of the impact (pulse rise time) of around 4 ms.



The raw data for one of the trials in the experiment. The bead mass was 2.66 g and the free fall distance was 5 cm.

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 that gives a value for the oscillation

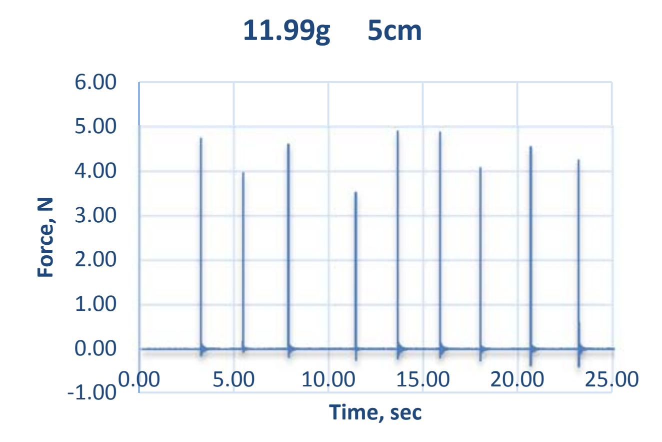


The FFT spectrum for the data shown in the previous plot. Resonant frequency of 120.86 Hz in the FFT spectrum is the frequency of the probe oscillation that followed the impact.

period of 8.2 ms. The pulse fall time, projected to be close to half of the oscillation period, is consistent with expectation.

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 one of the beads - for three different falling heights. The magnitudes of the force pulse varied from one trial to another, even for the same bead falling from the same height. This is due to off-axis impacts occurring in some trials. The largest peak was selected as that most closely describing a head-on collision along the sensor measurement axis.



Comparison of measurements of the force exerted by a 1.99 g bead falling from a height of 5 cm. The pulse magnitudes are reduced for off-axis bead impacts.

Accumulated results are summarized in the table. Predicted force in each set of trials was found using Eq. 1. Last column represent the ratio between the measured and predicted value that appears to be close in all test series.

Bead	Mass, g	Diameter, cm	Fall height, cm	Pulse magnitude, N									Max, N	Predicted force, N	Ratio
1	11.99	2.55	5	4.74	3.96	4.62	3.55	4.9	4.88	4.07	4.55	4.25	4.9	15.7	**0.31**
2	6.72	2.1	10	4.79	4.79	4.86	4.53	4.42					4.86	16.5	**0.29**
3	2.66	1.54	5	1.82	1.89	1.74	1.69	2.07	2.03				2.07	7.23	**0.29**
3	2.66	1.54	7	2.57	2.32	2.78	2.13	2.39					2.78	8.53	**0.33**
3	2.66	1.54	10	2.98	3.28	3.27							3.28	10.19	**0.32**

Conclusion

In each series of tests, measured and predicted forces are related by approximately same 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, consistently underestimating the magnitude. The reduction happens because a clay particle impact, while being soft, is not completely inelastic as assumed in derivation of Eq. 1. If only 30% of the momentum is transferred in the collision studied, the agreement between the measured and experimental values would be quite satisfactory.