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The Dynamic Response of Piezoelectric Sensors

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The challenge of this research is to understand and characterise the dynamic response of Dynasen piezoelectric sensors in high-stress, high-rate environments. Recent research efforts in large-scale hydrodynamic experiments have concentrated on the possibility of using piezoelectric sensors to study the evolution of ejecta. Ejecta are small particulates, with diameters less than 100 µm, that travel at velocities greater than 1 km s-1. They are produced when a shock wave is incident at a free surface.

Environments where high stress, high rate events occur challenge most diagnostic sensors; the timescales of interest are short, the environment is electrically and physically noisy and the response might differ significantly from low-stress, low-rate conditions. This dissertation presents research that investigates whether Dynasen piezoelectric sensors are reliable and robust enough to measure accurate time-resolved stresses and densities in ejecta-like environments.

The dynamic response of Dynasen sensors has been investigated at low (<150 MPa), intermediate (between 150 and 800 MPa) and high (>800 MPa) stresses using a variety of impact techniques, ranging from low velocity granular and Hopkinson Pressure Bar impacts to high velocity spray, water-jet and laser-driven flyer impacts. A novel gas gun-driven spray technique has been developed to recreate ejecta-like environments in a safe and reproducible manner. A complimentary diagnostic technique, utilising high-speed photography and fast x-radiography to measure the densities of the high-velocity sprays produced by the gas gun, is described in detail. The complimentary diagnostic is used as a cross-reference to density measurements obtained by the Dynasen sensors. Experimental findings indicate that the Dynasen sensors perform relatively well in the spray environments. Their repeatability can be improved by placing various shielding arrangements in front of the sensors, taking the mechanical and impedance characteristics of the sensors into account and compensating for non-normal impacts and material compaction effects.

This dissertation demonstrates that one of the key assumptions made in the sensor analysis – that the piezoelectric response is linear at all times – is not always true. The linearity of the response depends on the magnitude of the stress imparted on the sensing element, the stress rate, temperature, age and the loading history of the sensing element.

Ejecta cloud densities in traditional ejecta experiments are typically around a few tens of kg m^{-3}. Stresses imparted on stationary objects placed in ejecta in such experiments are typically around 300 MPa. From the experimental findings presented in this dissertation, one could remain hopeful that the stress and density measurements obtained by Dynasen PZT sensors in such regimes would be accurate, as long as careful consideration is given to the validity of the analysis.