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A Statistical Representation of Pyrotechnic Research Igniters

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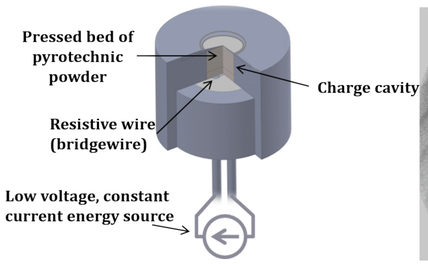
Overview

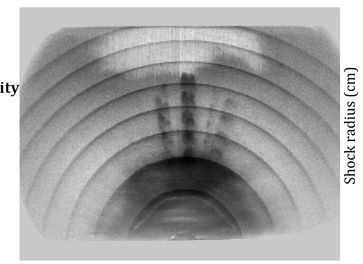
The mechanical work output of pyrotechnic research igniters is quantified and the variability linked to variances during production. Independent variables in the form of igniter dimensions are measured with high fidelity, and response variables in the form of electrical response and shock output are measured using Schlieren imaging and calculated using edge-finding in Matlab. Scalar representations of the output are then linked to independent variables using multivariate statistical analysis.

Independent Variables

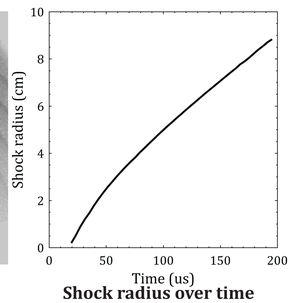


Igniter schematic

Response Variables



Shock output composite image

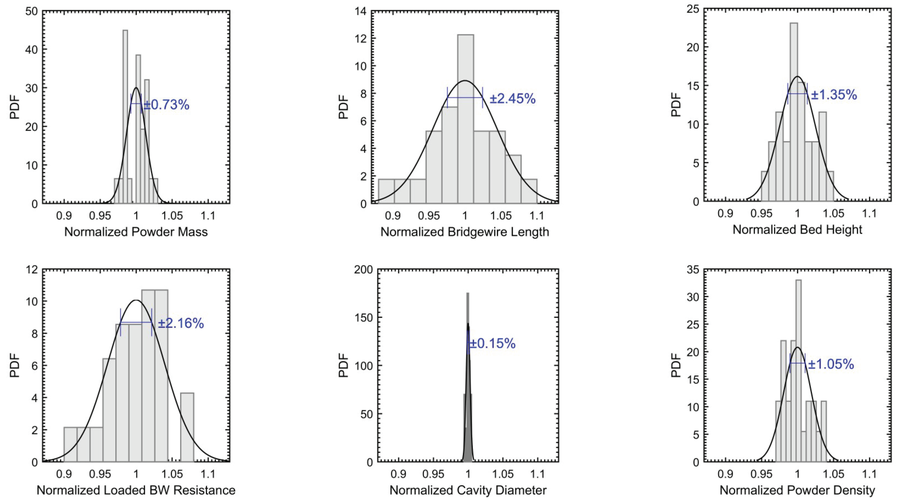


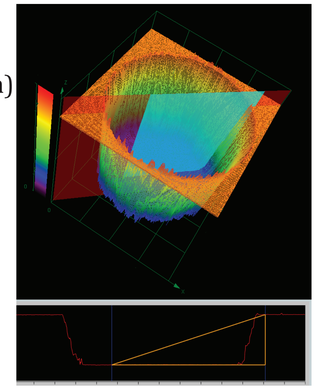
Shock radius over time

Independent variables

Directly measured variables:
- Pyrotechnic powder mass (± 0.1 mg)
- Bridgewire resistance (± 0.02 Ω)

Indirectly measured variables:
- Bridgewire length (± 0.05 mm)
- Charge cavity diameter (± 0.05 mm)
- Powder bed height (± 0.01 mm)





Largest variabilities:
- Bridgewire length
- Bridgewire resistance

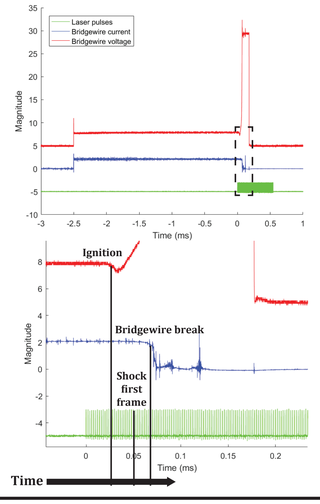
Smallest variabilities:
- Cavity diameter
- Powder mass

Response variables

Current and voltage time histories are recorded and event times are calculated from each tested igniter. High-speed camera images capture the full-field shock motion, which is converted through post-processing into a radius that varies with time.

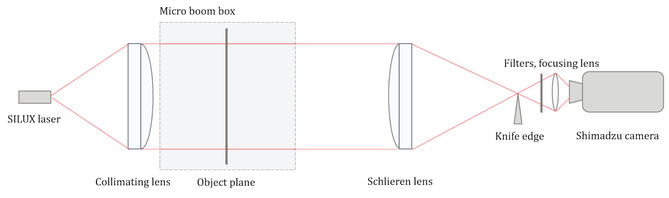
Electrical response

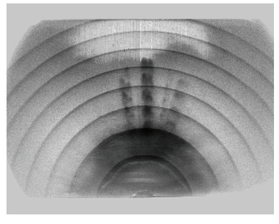
A constant electrical current is applied to bridgewire until powder is thermally ignited.
Sequence of events: ignition, combustion, shock outbreak from powder bed, bridgewire opens.



High-speed imaging response

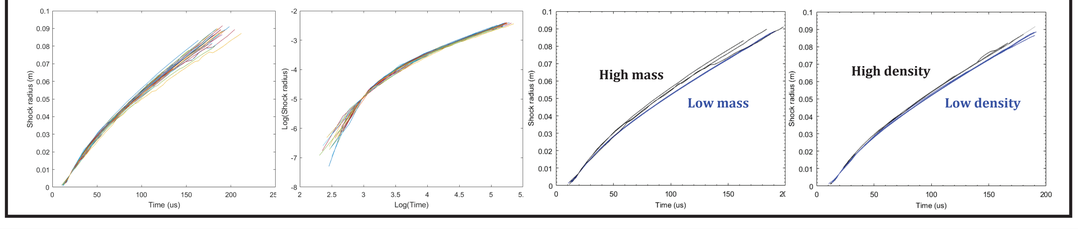
102 frames are collected using a Shimadzu camera in a Schlieren setup, with a 8 cm x 10 cm field-of-view. Spatial resolution is 0.4 mm/pixel, and temporal resolution is 100-150 ns of SI-LUX640 laser illumination per frame, at a rate of 125-500 kfps.





Matlab edge-finding is used to find a characteristic radius of the shock in each frame, which is then plotted versus time to calculate shock velocity and Mach number. These plots show distinct groupings.

Radius vs. time: **log(Radius) vs. log(time):** **High/low mass:** **High/low density:**



Statistical analysis

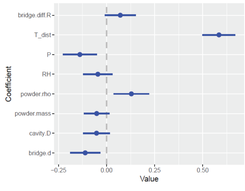
Statistical analysis is used to identify significant correlations and interplay between multiple variables.

Create model that takes into account independent variables:

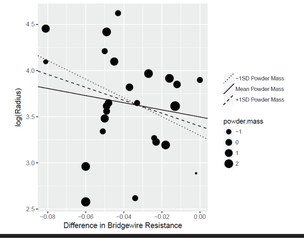
$$log(r_{bridge}) = Intercept + X_{bridge\_d}\beta_{bridge\_d} + X_{cavity\_d}\beta_{cavity\_d} + X_m\beta_m$$
$$X_{rho}\beta_{rho} + +X_{RH}\beta_{RH} + X_P\beta_P + X_{T\_dist}\beta_{T\_dist} + X_{R\_diff}\beta_{R\_diff} + \epsilon$$

Correlate to a scalar representation of the output using:

Correlation plots
(single variable to output)



Interaction plots
(2 variables to output)



Summary

This project relates the physical parameters of igniters with their output experimentally and statistically, without relying on detailed thermo-chemistry of the ignition process. Pinpointing critical parameters for controlling performance informs both production of future parts, and modeling of the chemical behavior.

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