Application of PDV towards Determination of Constituent Materials Properties

Jason Johnson, Geoffrey Taber, and Glenn Daehn

The Ohio State University, Department of Materials Science & Engineering

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Overview

- New packaging
- Applications of PDV at OSU
  - Powder compaction
    - Acquisition from geometrically tight situations
  - Ring expansion
  - Other examples
- Data reduction
  - Differentiation of velocity histories
  - MatLab based

New Packaging

Totally portable PDV: packed in a ruggedized plastic equipment case (SKB)

Powder Compaction

- Work being done in P/M, ceramics, and modeling
- Consolidation to high densities
    - Ti, SiC/Cu, Al, etc.
  - Optimize processing parameters
- High resolution density evolution
    - P-λ model
  - Coefficient determination
  - Experimental validation of models

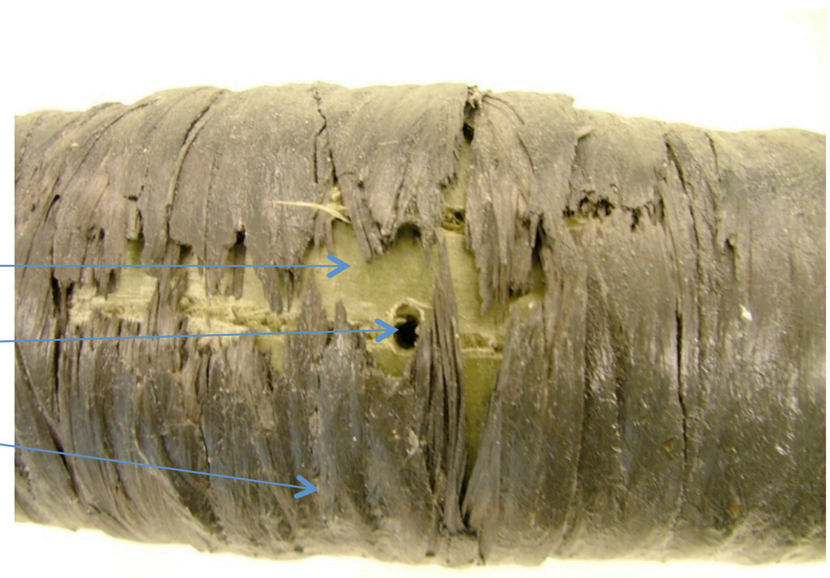
Powder Compaction

- Actuator development
  - Direct drive EM coils
    - Billet construction, fiber reinforcement
    - Repeatability/survivability increased
  - Field shapers
- PDV implementation barriers
  1. Need to maintain magnetic field uniformity
  2. Avoid stress concentrations

Powder Compaction

Oz Optics focuser

Significant field distortion results in highly asymmetric sample deformation



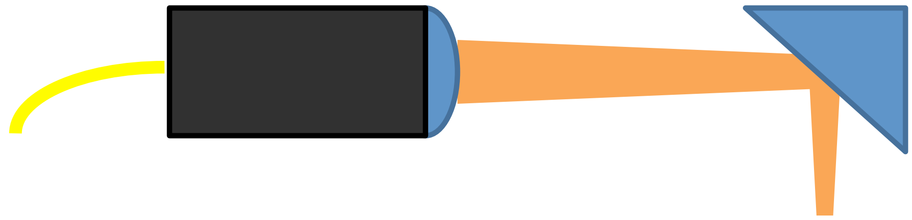
G10 structural fiberglass

0.100” diameter sighting hole

Carbon fiber/epoxy filament winding

Powder Compaction

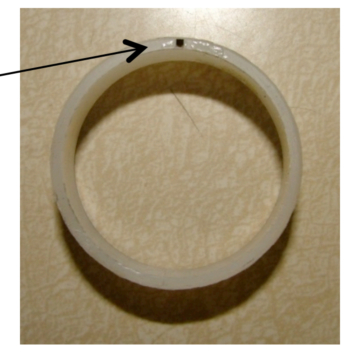
- First generation technology
  - – Periscopic probes have problems with regard to issue 1
  - – Sighting holes in direct drive EM coils difficult due to issue 2
- Provides motivation for new variants on periscope type probes
  - Same basic requirement – light down and back via a 45^{o} mirror



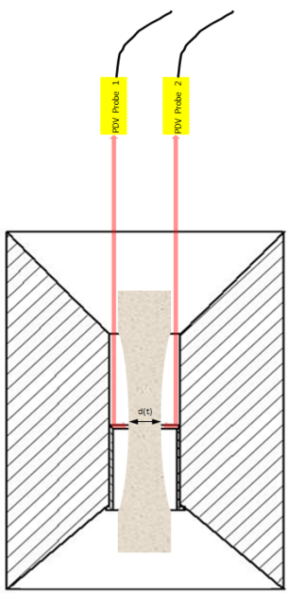
Periscopic Probe Variants

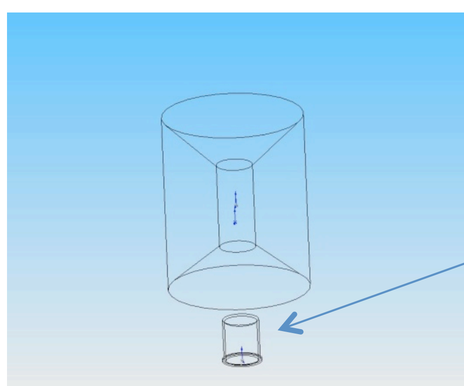
- Miniaturized fiber probes (future)
- Annular mirror, used with focusing probes

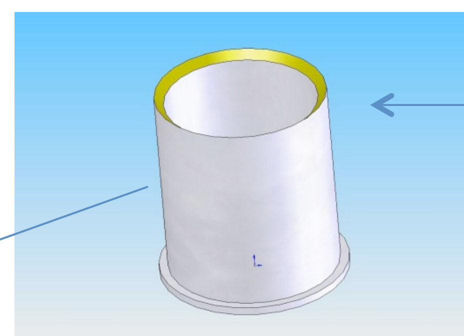
1 x1 mm^2 45^o mirror
Tower Optical ($)



Reduced to practice

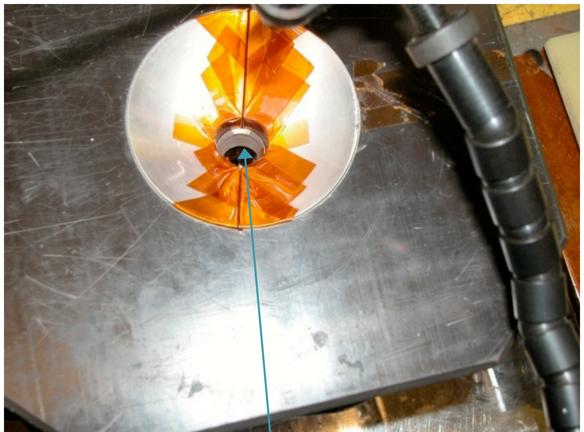




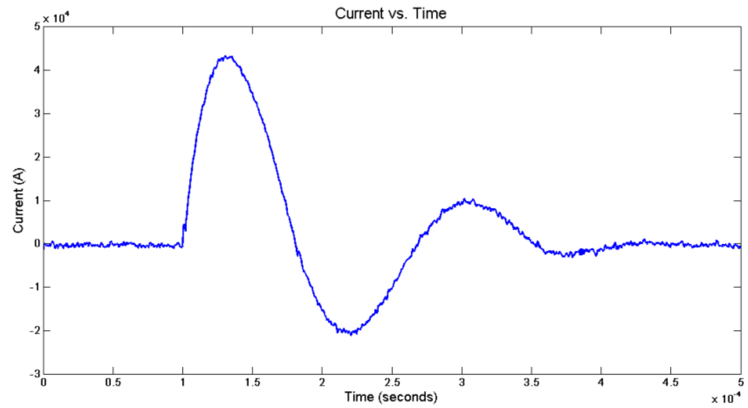


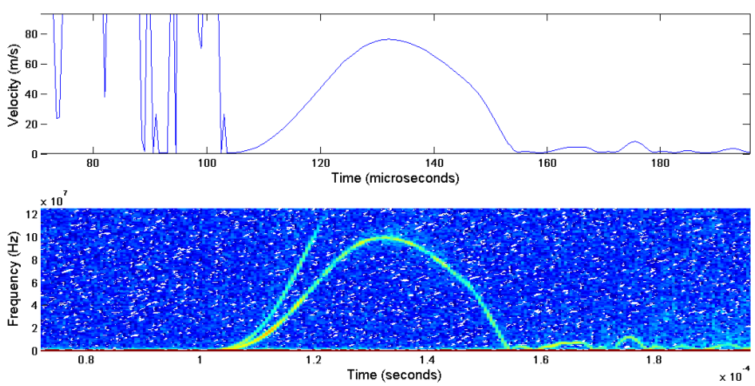
Machined from plastic and sputtered with gold for a mirror face

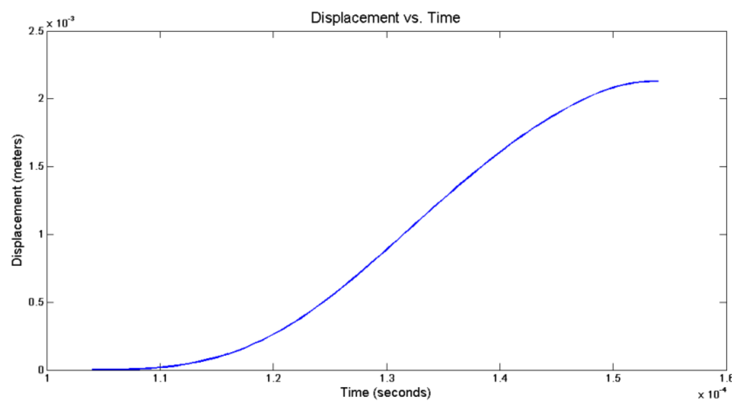
Powder Compaction



Gold sputtered annular mirror



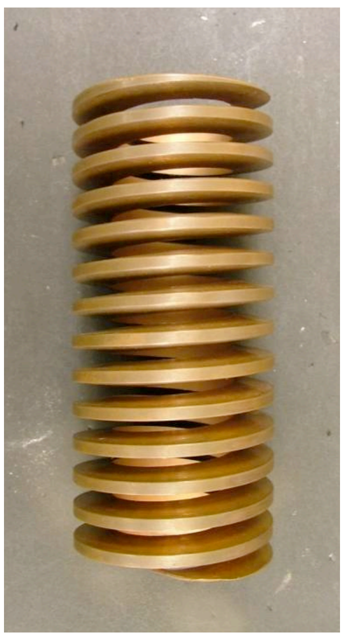




Data shown is from an 8 kJ compression of 19 mm diameter annealed copper tube (empty)

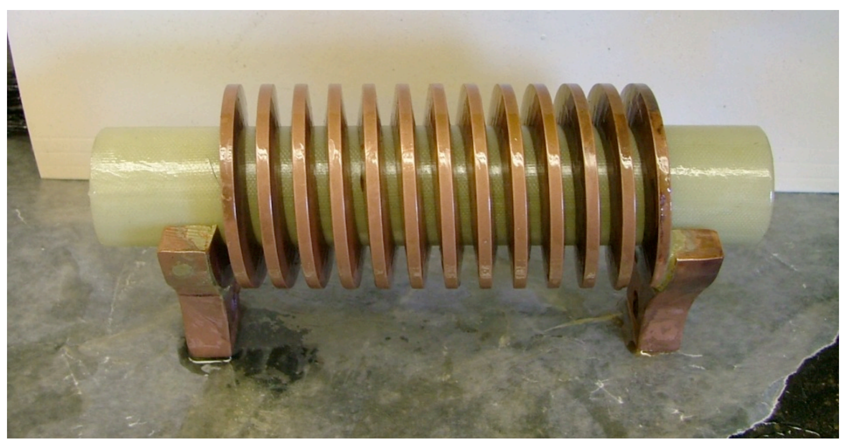
Powder Compaction

- Repeatable use limit
  - 20+ kJ for field shaper
  - 10+ kJ for billet coils

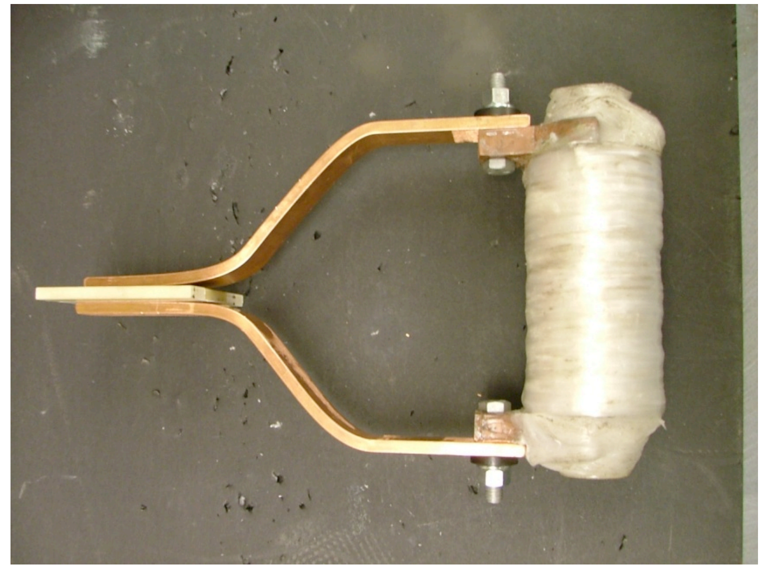


Machined from C18150 Cu

Ends brazed on, added G10 insulating tube and corona dope

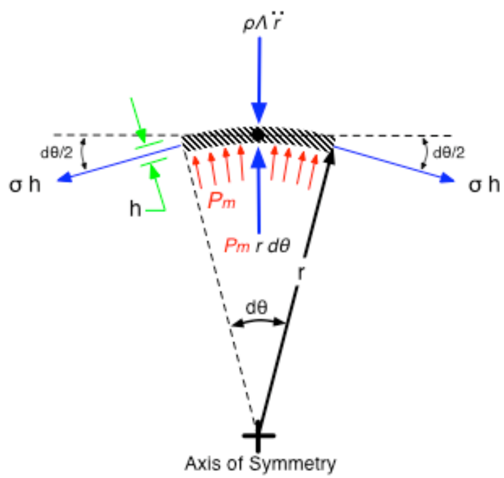


Filament wound with Dyneema fiber, connections added



Ring Expansion

- Great need for reliable tensile ductility and strength information
  - SHPB suffers from lack of standardization
  - Wave effects complicate analysis
- Issues could be resolved with ring expansion technique, but with other difficulties



$$\frac{dV_r}{dt} = \frac{P_m(t)r}{\rho h_o r_o} - \frac{\sigma(\varepsilon(r))}{\rho r}$$

Free body diagram of forces acting on a differential section of a ring. Inertial forces are denoted by ρΛ'r', magnetic forces by $P_m r d\theta$, and hoop forces by σh, where ρ is material density, Λ is the volume, r is the ring radius, Pm is the time varying magnetic pressure, h is the ring wall thickness, and θ is the included angle.

Fully Instrumented Ring Expansion (FIRE) System

- Equipment development stage

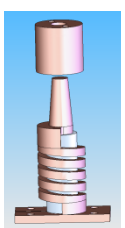
Can handle multiple sizes of direct/ indirect coils and samples, as well as exploding wire experiments

Shrapnel guard

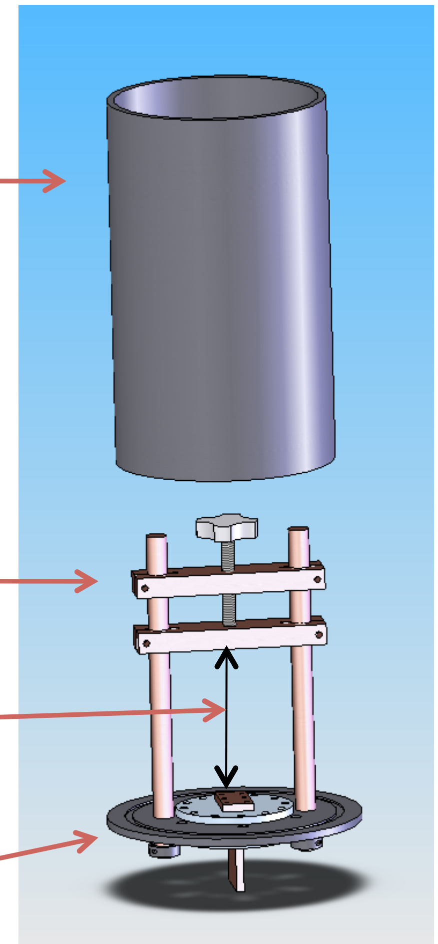
Adjustable screw press

Sample/coil space

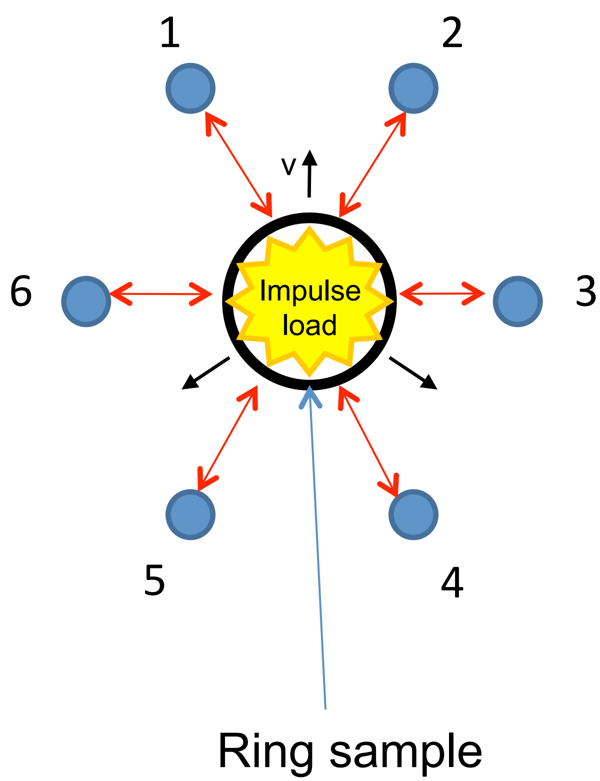
Base plate and HV feed-through

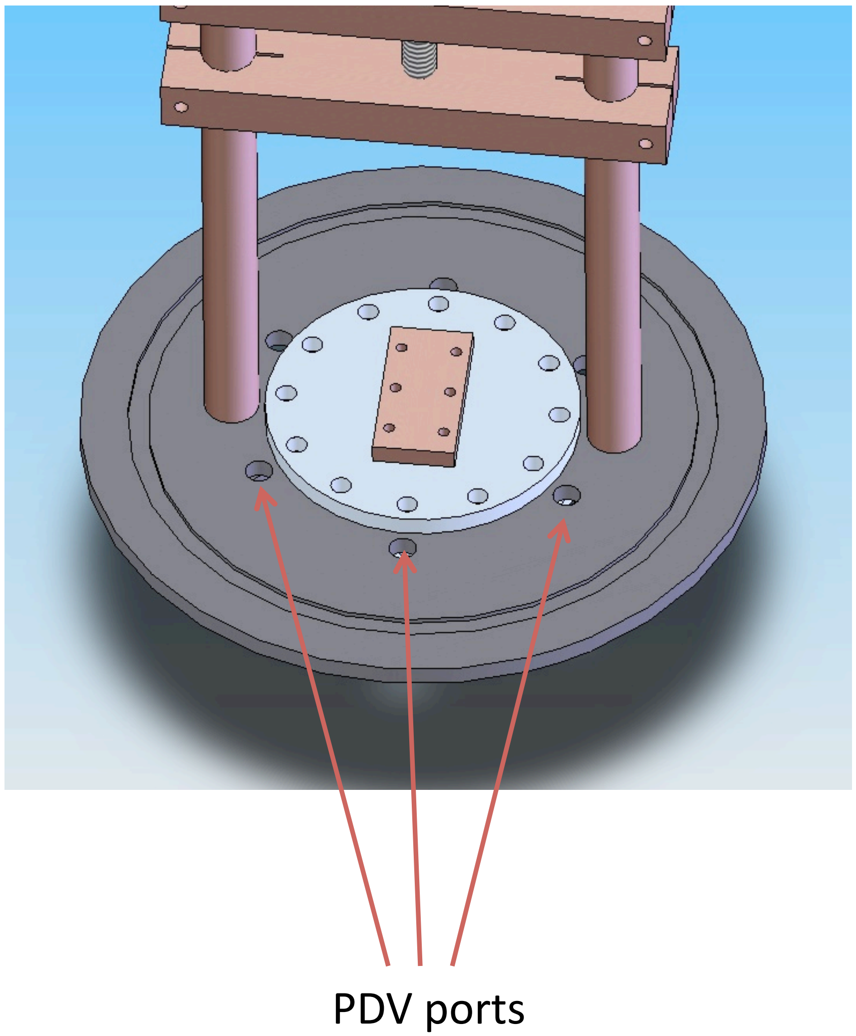


Typical coil and end connector

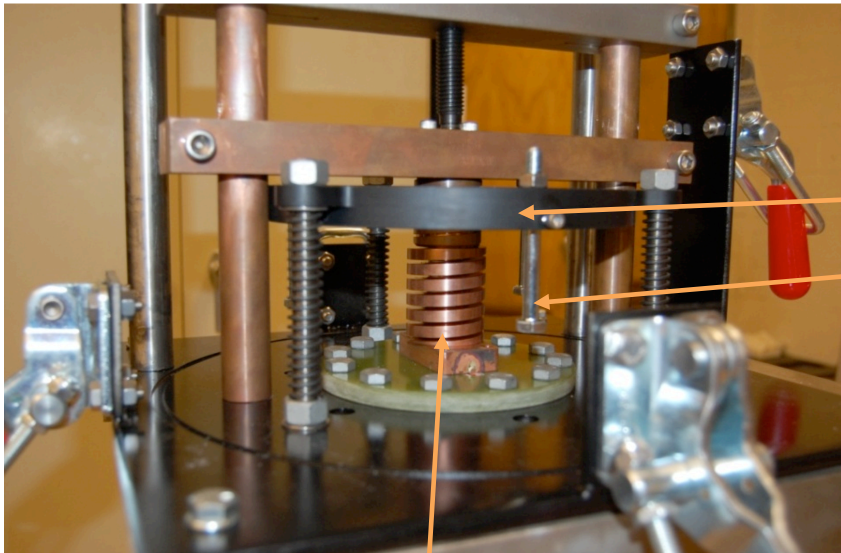


FIRE System





FIRE System



Support ring & PDV mirror posts

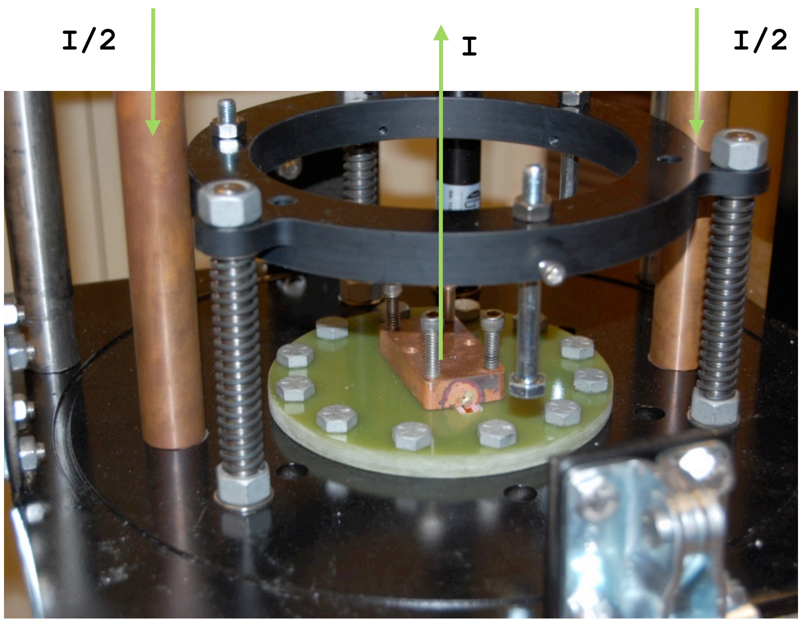
EM actuator

Toggle latches

Support ring for PDV probes

FIRE System

Symmetric current path:



- Support ring is located in a plane via 3 threaded posts
- Can independently adjust any of the 6 PDV channels for axial height
  - Useful on long cylindrical samples

Other OSU Applications

- Exploding wire/foil launch
- “High speed” air press
- Impact welding

Data Reduction

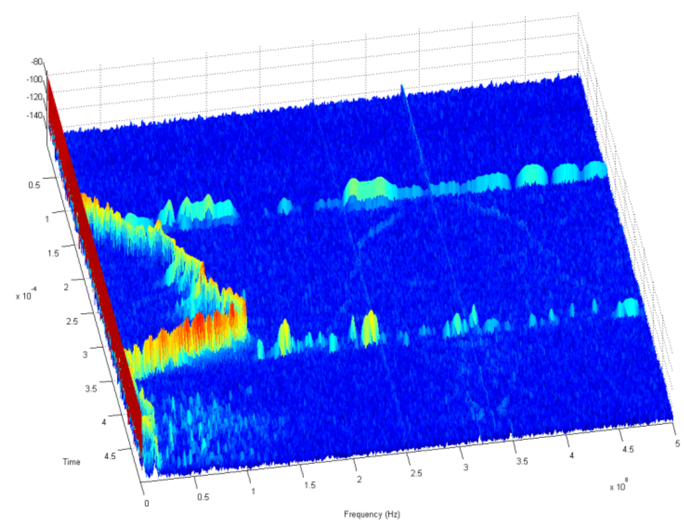
$$\frac{dV_r}{dt} = \frac{P_m(t)r}{\rho h_o r_o} - \frac{\sigma(\varepsilon(r))}{\rho r}$$

- Differentiation of signals with high frequency noise can be difficult (integration is much less problematic)
- Currently, determining acceleration histories requires fine tuning of smoothing parameters
  - What is justified when filtering?
  - Which avenue to take?
- A robust algorithm is desired, without the need for human judgment
  - [PDV raw data → velocity → acceleration]

Current Procedure

- Matlab’s Spectrogram function
  - Produces a surface in 3-space
  - We are interested in *some* of the local peaks of this surface
    - Dominant frequency contribution

```
[S,F,T,P] = spectrogram(pdvdat,t,(t/2),f,fs);

mdense = zeros(1,lP);

for u = 1:lP;
    [c,i]=max(P(3:(length(F)),u));

    mdense(1,u)=i;

end

smdense = smooth(mdense,s,'rlowess');    % Smoothing filter
vel = smdense.*(775*(fs/1e9)/f);
```

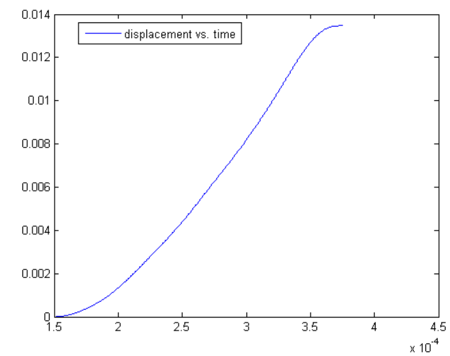


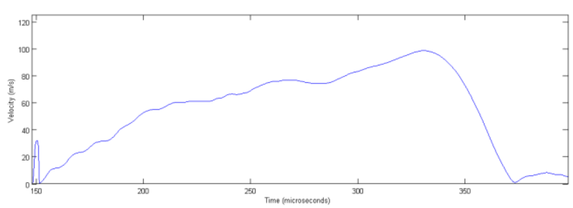
Current Procedure

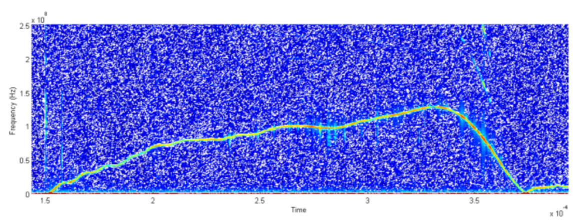
- Preliminarily process entire data file – low resolution spectrogram
  - Select time frame of interest, identify max velocity, this is used to do a local, higher resolution spectrogram
- Define an extraction window around the velocity signal in Hi-Res spectrogram plot
  - ginput function
- Peaks are then extracted locally within the area defined by the user
  - Ignores spurious signals and other noise

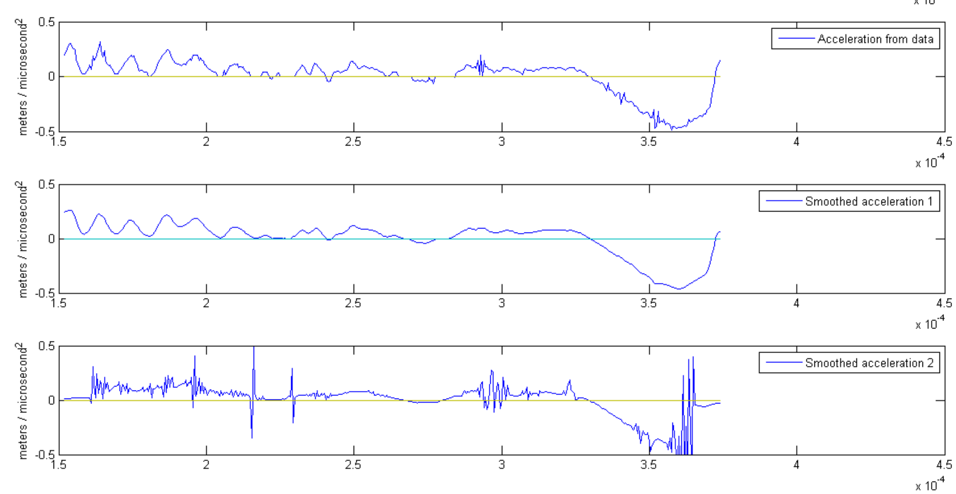
Current Procedure

- Extracted peaks are fitted with a spline
  - Generates velocity history (with possible artefacts – related to smoothing and window size)
  - Fine features can be lost
- Integrate to get displacement
- Differentiate for acceleration







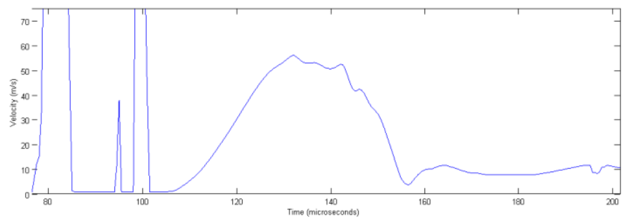


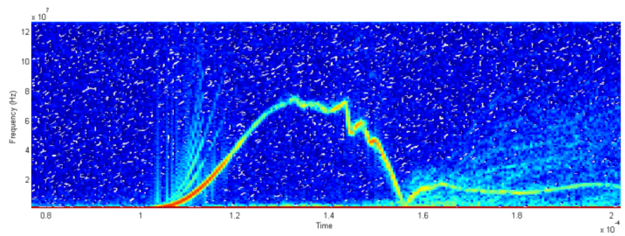
Data shown is from a circular copper flyer accelerated with ~525 J, then striking a fiberglass plate with a hole in it.

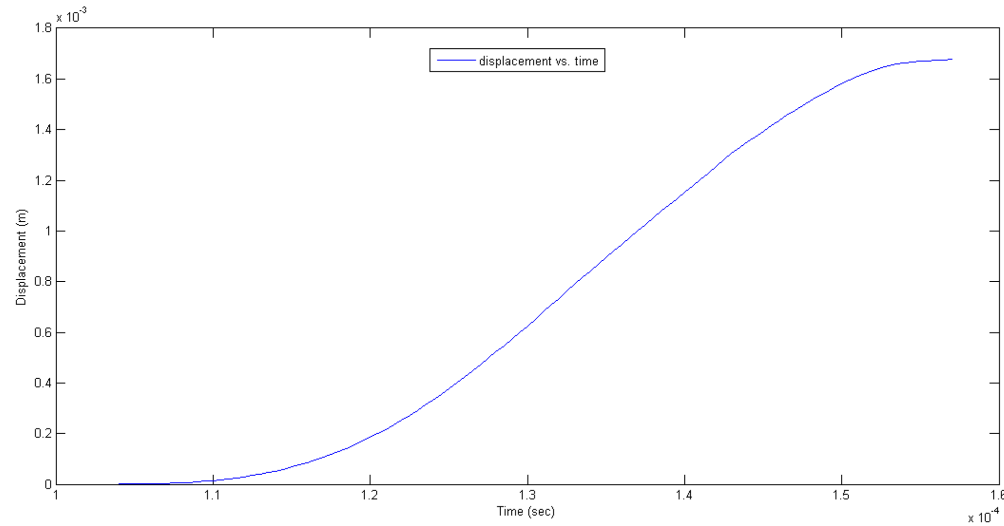
Current Procedure

10 kJ sand compaction

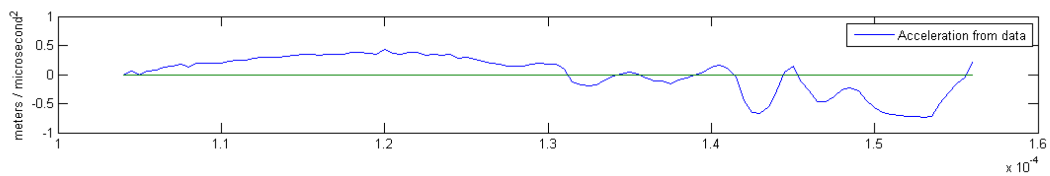
Smoothed with s = 8 and method = 'rlowess'



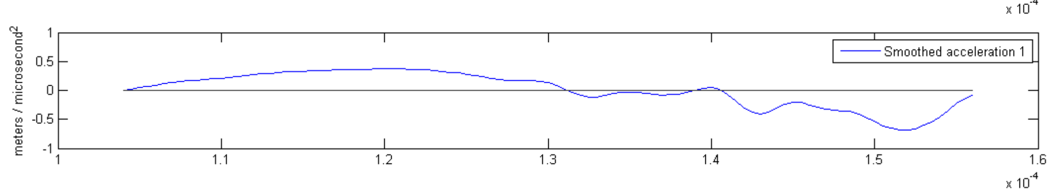




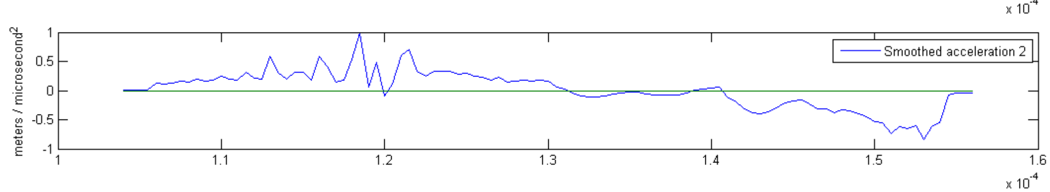
Differentiated from velocity



Differentiated from velocity, smoothed again with s = 10



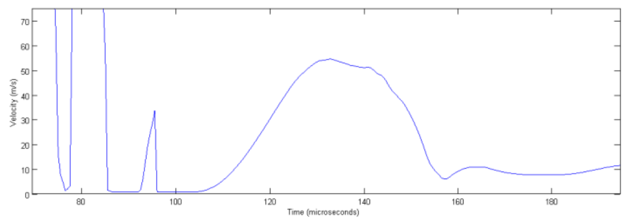
Double differentiated from displacement, smoothed again with s = 10

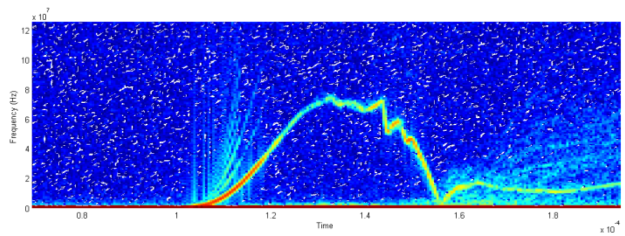


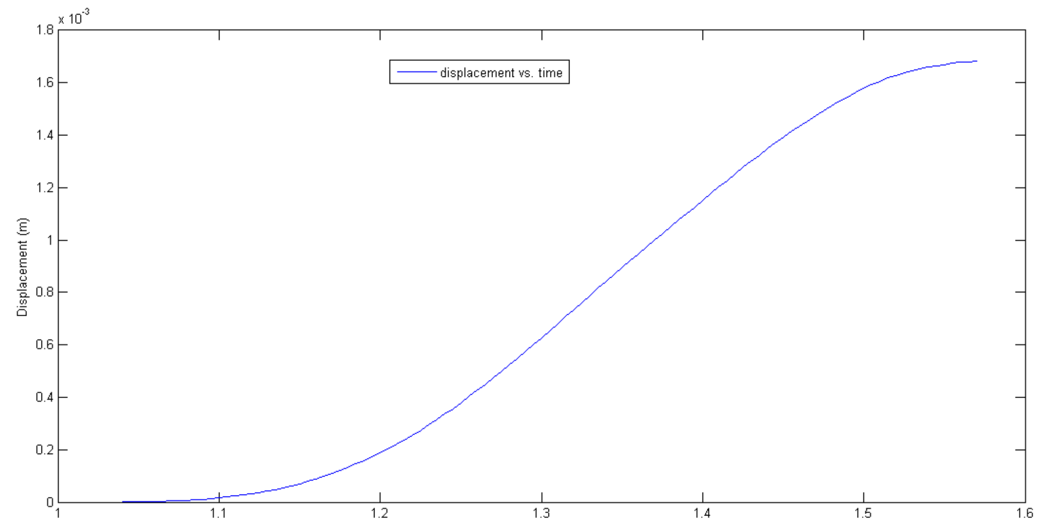
Current Procedure

10 kJ sand compaction

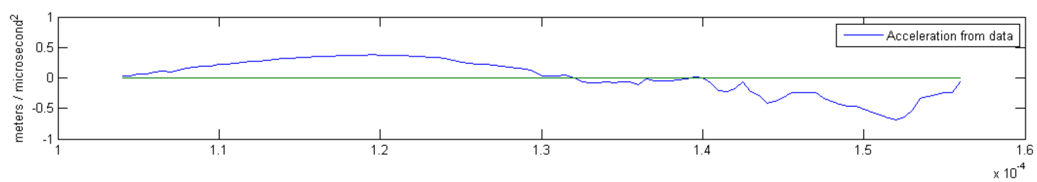
Smoothed with s = 16 and method = ‘rlowess’



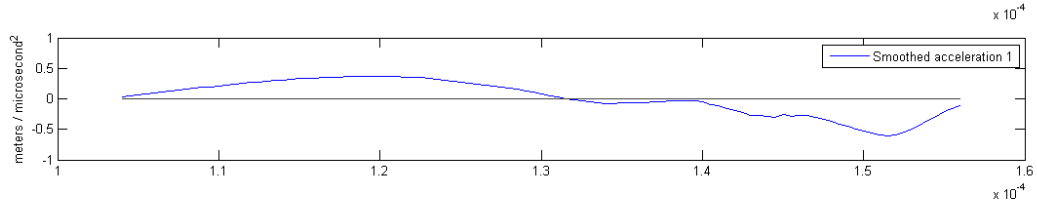




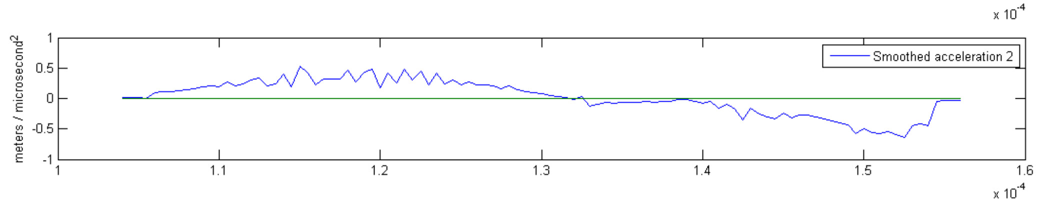
Differentiated from velocity



Differentiated from velocity, smoothed again with s = 10



Double differentiated from displacement, smoothed again with s = 10



Current Procedure

- MatLab has many built in filters and smoothing functions
  - smooth, spline, filt, fftfilt, etc.
    - Like spectral analysis functions, each has pros/cons
    - Each can utilize multiple methods
- Can also use fit/fitoptions

`yy = smooth(y,method)` smooths the data in `y` using the method *method* and the default span. Supported values for *method* are listed in the table below.

method	Description
'moving'	Moving average (default). A lowpass filter with filter coefficients equal to the reciprocal of the span.
'lowess'	Local regression using weighted linear least squares and a 1st degree polynomial model
'loess'	Local regression using weighted linear least squares and a 2nd degree polynomial model
'sgolay'	Savitzky-Golay filter. A generalized moving average with filter coefficients determined by an unweighted linear least squares regression and a polynomial model of specified degree (default is 2). The method can accept nonuniform predictor data.
'rlowess'	A robust version of 'lowess' that assigns lower weight to outliers in the regression. The method assigns zero weight to data outside six mean absolute deviations.
'rloess'	A robust version of 'loess' that assigns lower weight to outliers in the regression. The method assigns zero weight to data outside six mean absolute deviations.

Other Thoughts

- Acquisition rate vs. window and frequency binning…
  - Should we always record data at the highest available sample rate?
    - Large files, but high fidelity
  - Is there an optimal frequency or time bin size for analysis?
    - A lot of fiddling around so far…

```
fs = 1e9;     % Sampling frequency
t = 1000;     % Time resolution (window length, default overlap is 1/2 window length)
f = 1000;     % Frequency resolution (# of frequency bins)

[S,F,T,P] = spectrogram(pdvdat,t,(t/2),f,fs);
```

Other Thoughts

- Assume a formalism for the deceleration curve *a priori*
  - May be O.K. for certain special cases
- Averaging over several channels
  - FIRE nominally incorporates 3 high speed and 3 differential channels of PDV
- Is there another method that is fundamentally better for acceleration?

Questions/Comments?