PDV Measurements in the Electromagnetically Driven Expanding Ring Experiments

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Overview

- Background
  - High temperature material properties
  - Expanding ring experiment
- Apparatus
  - Primary circuit
  - Pre-heater
  - Instrumentation
    - IR Camera
    - PDV
- Data analysis in Matlab
  - Spectrogram
  - Error estimates
  - Comparison with VISAR (circa 1990?)
- Conclusion

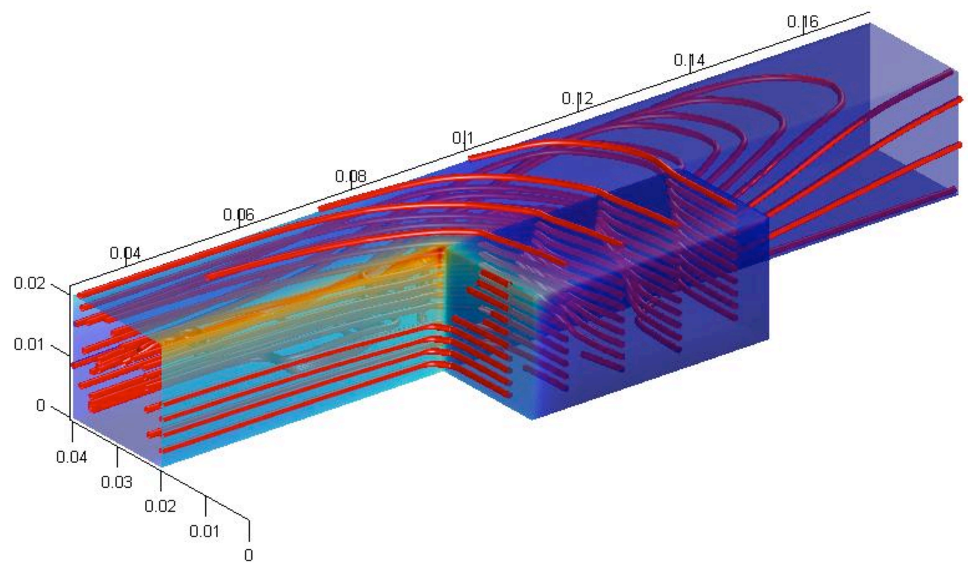
High Temperature Properties

- Material strength is a function of temperature
  - Heating degrades strength
  - Short duration or pulsed heating different from equilibrium
  - Duration of heating event is much smaller than diffusion time thus assumed adiabatic

- Mechanisms
  - Moduli change
  - Microstructure change
  - Thermally activated dislocation motion
  - Precipitate growth…

High Temperature Properties

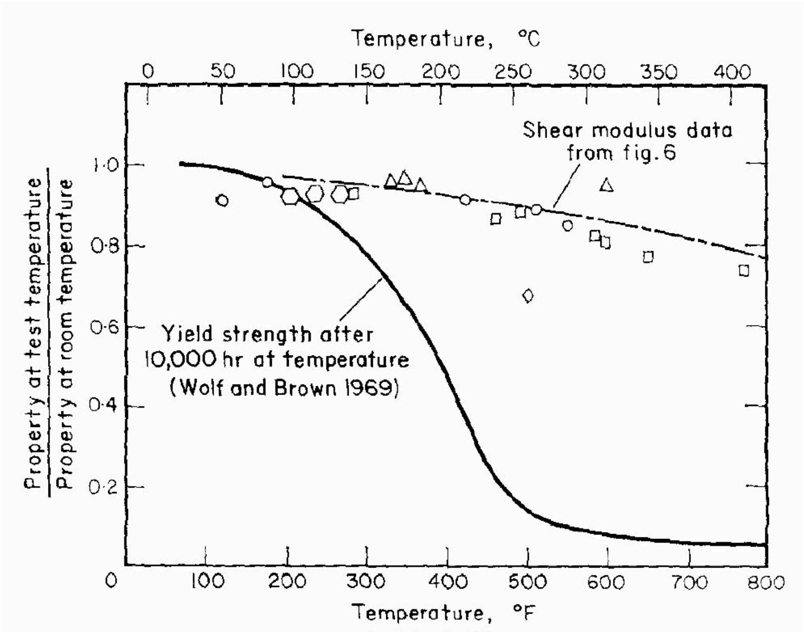
- **Such data is critical to successful modeling of short duration high temperature events such as hypervelocity impacts and electromagnetic launch.**



Simulation of a block armature

High Temperature Properties

- **Lipkin, Swearengen, and Karnes (1973)**
  - **Measured strength with Hopkinson's bar experiment**
  - **Pulse heating using electron beam**
  - **Results for 6061 T6**



From Lipkin, Swearengen, and Karnes
"Mechanical Properties of 6061 Al-Mg-Si Alloy
After Very Rapid Heating"

Expanding Ring Experiment

- **Needs**
  - **In-situ heating of material**
  - **Short loading duration to prevent heat dissipation**
  - **Measurement of deformation and temperature**
- **Choices**
  - **Split Hopkinson's bar experiment**
    - Stain rates ~ 1000/s
    - Heating not easily achieved
  - **Electromagnetically driven expanding ring experiment**
    - Strain rates > 1000/s
    - Built in heating

Expanding Ring Experiment

- **Nirodson (1965)**
  - Rotational symmetry => uniform tangential strain
  - Thin rings => negligible radial stress
  - No end effects
  - Fragmentation study

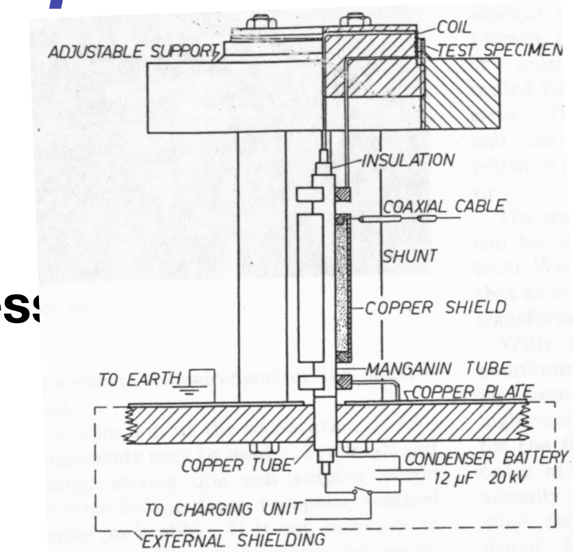


Fig. 1—Schematic arrangement of the test unit

- **Walling and Forrestal (1973)**
  - Elastic vibration after initial plastic loading
  - Strain Gages

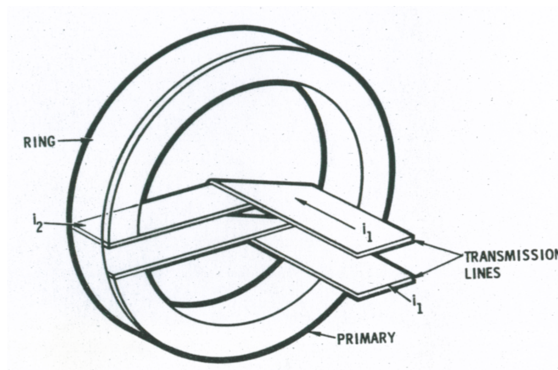


Fig. 1 Experimental arrangement.

Expanding Ring Experiment

- Grady and Benson (1983)
  - Used MMF from solenoid to expand a ring sample
  - No pre-conditioning shock effects
  - Controlled loading rate
  - Conducive to lab environment compared to explosively driven experiment
  - Fragmentation study
  - Drawback- pre-conditioning effects of inductive heating

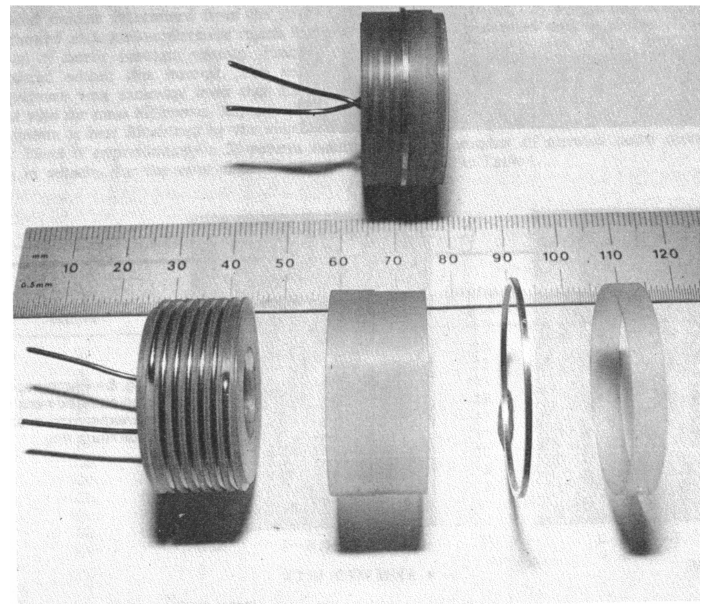
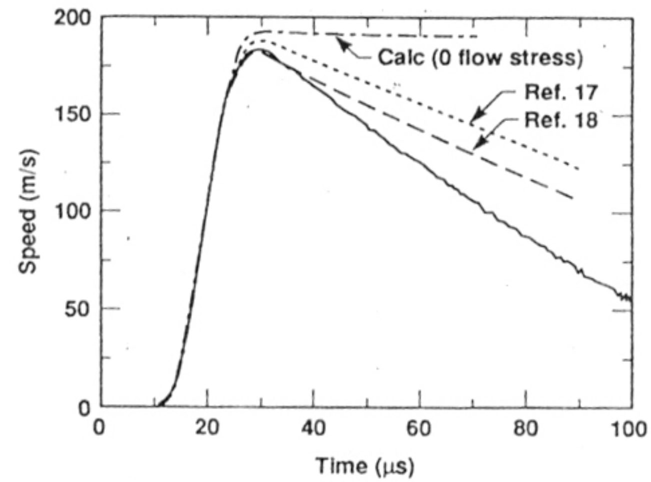
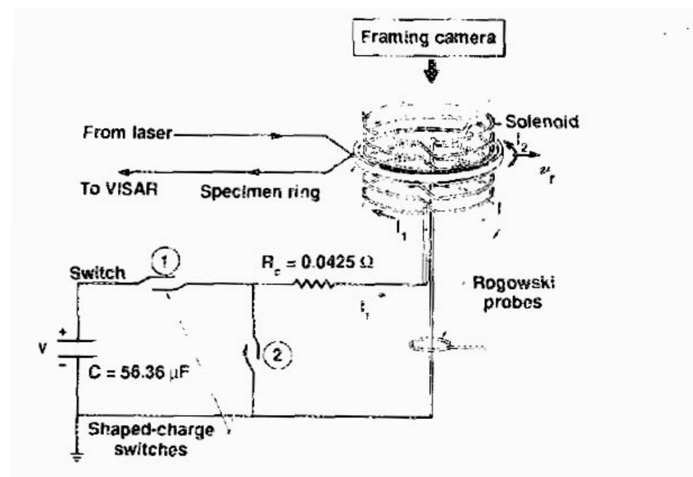


Fig. 3—Components of electromagnetic-expanding-ring system

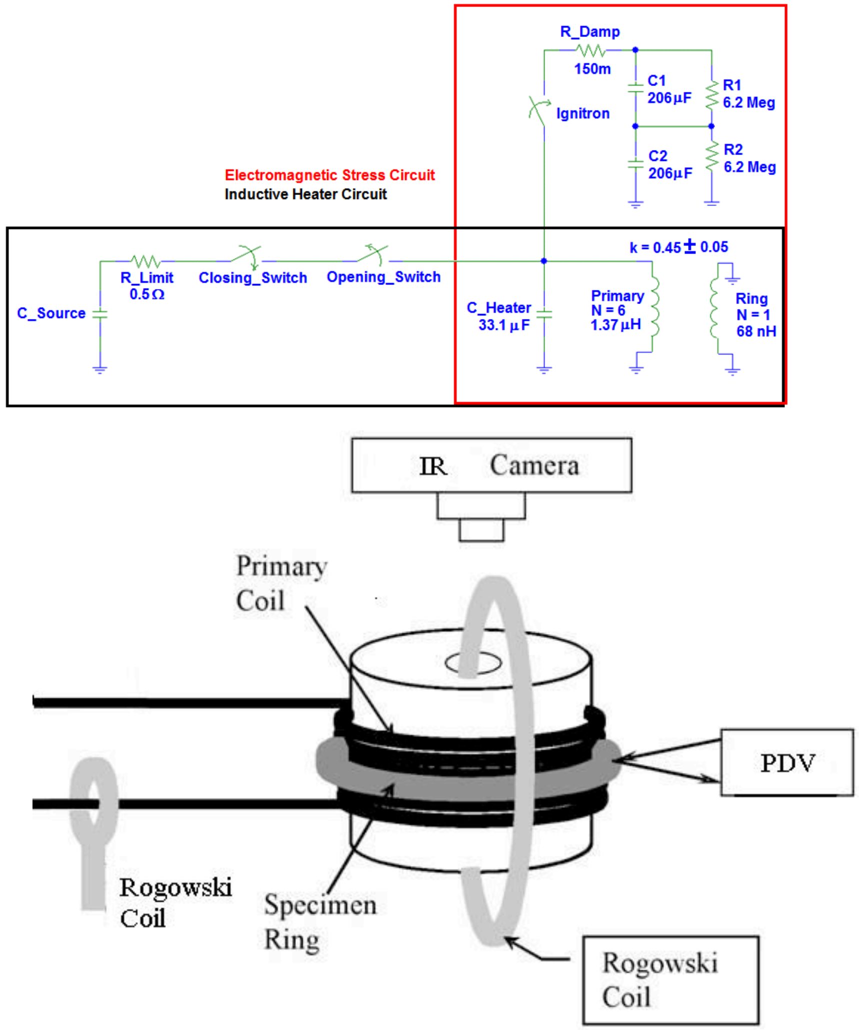
Expanding Ring Experiment

- **Gourdin, Weinland, and Boling (1989)**
  - Used MMF from solenoid to expand a ring sample
  - Used VISAR to measure surface motion.
  - Ignored thermal effects
  - Obtained stress-strain data (after load pulse)



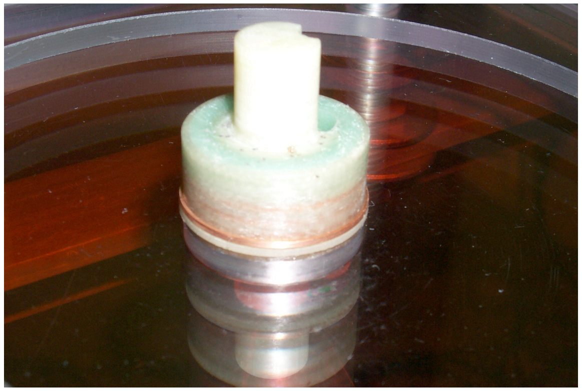


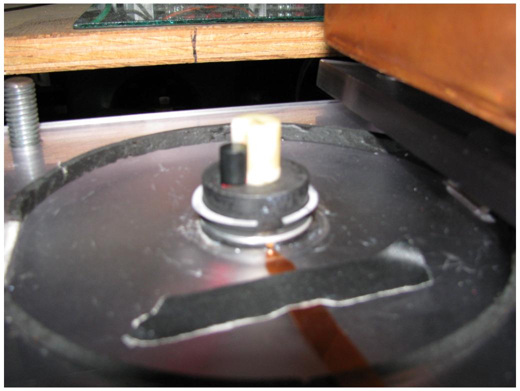
Apparatus

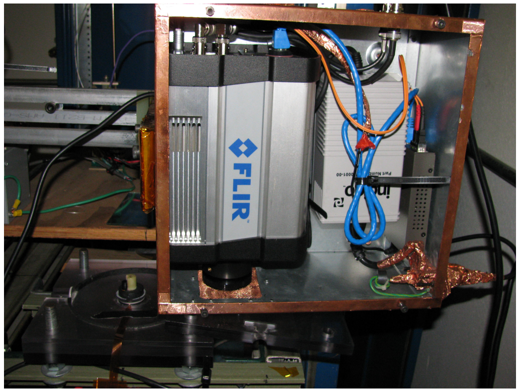


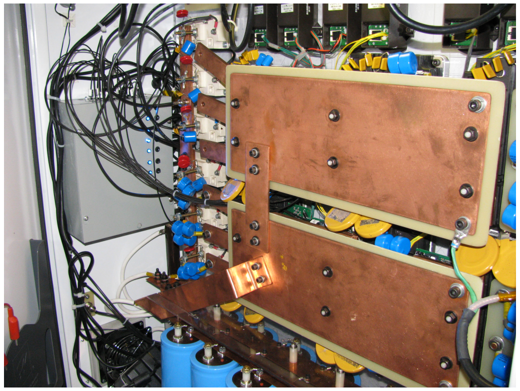
- Setup is two RLC circuits
  - Inductive heater
  - Electromagnetic stress
  - Creates a low and nearly sinusoidal current for a programmable time followed by a 50 ms pulse
- Instrumentation
  - IR Camera
  - Photodoppler velocimetry (PDV)
  - Rogowski's on primary and through solenoid and ring sample with active integration (PEM)

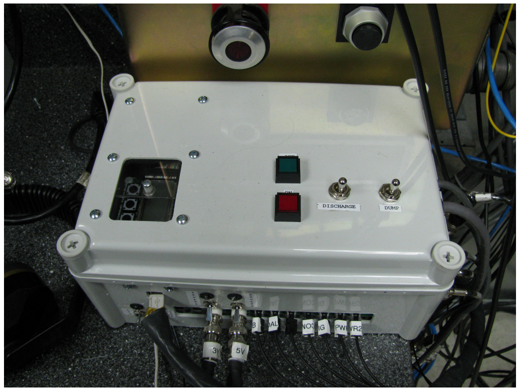
Apparatus

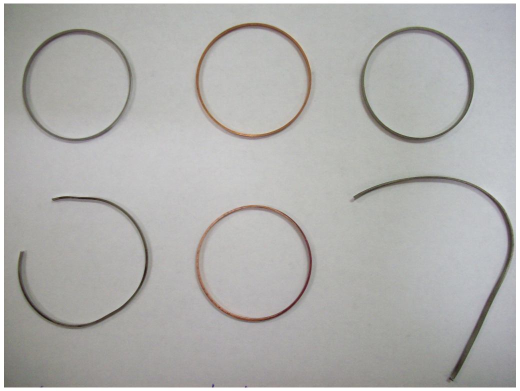








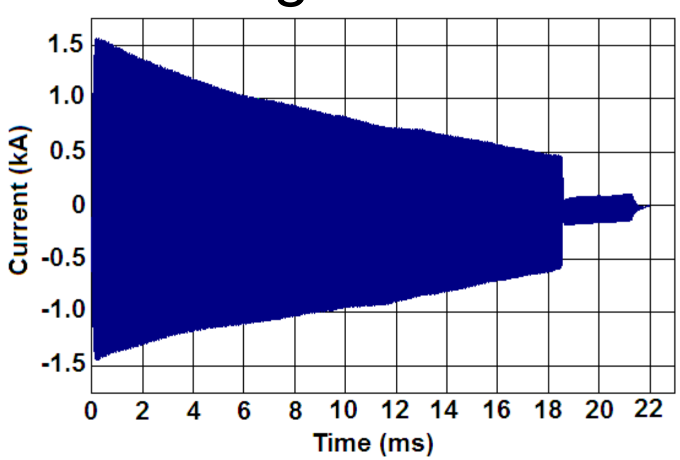


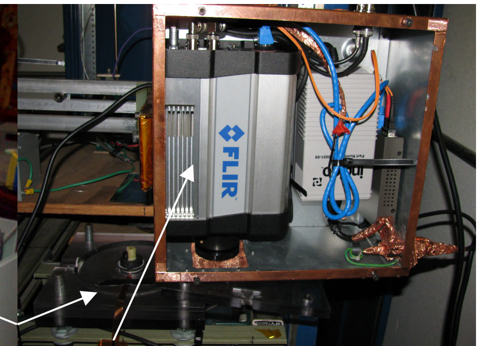


Inductive Heater

- **Ten 450V, 3.2 mF electrolytic capacitors**
- **Switched in each positive half cycle microcontroller**

Ring Current





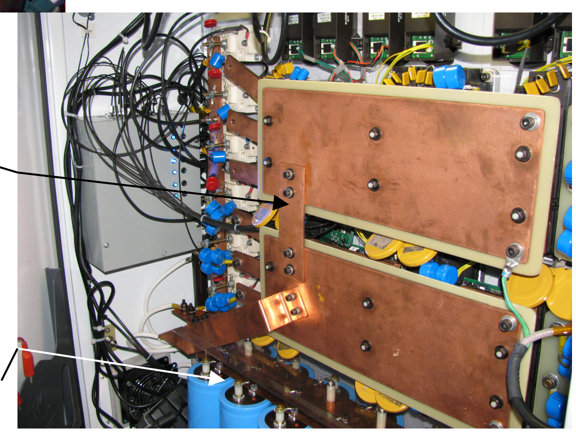
IR Camera

Containment

Heater

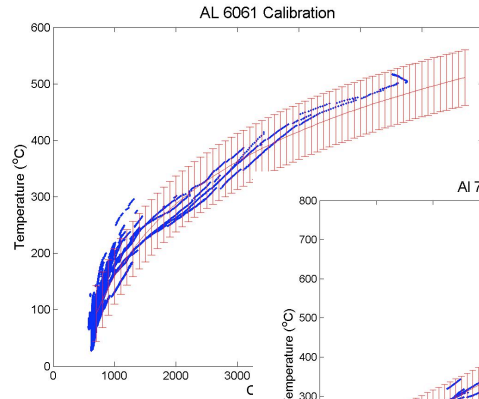
Ring Capacitor

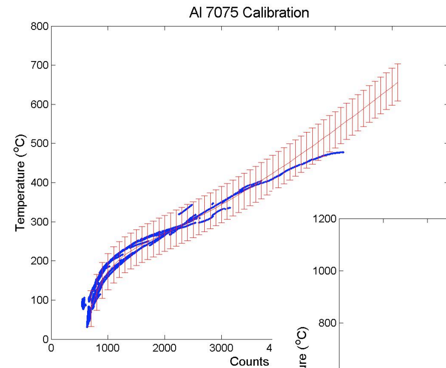
Capacitor Bank

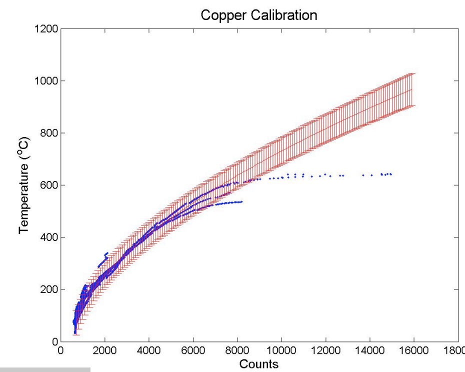


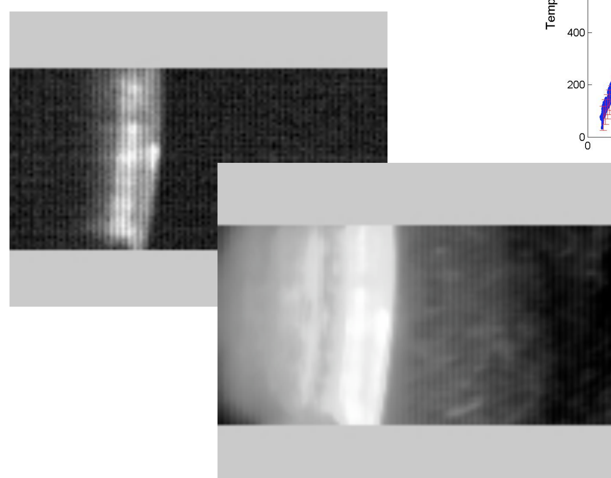
IR Camera

- **Flir SC6000 IR camera**
  - **Up to 17 kHz with an 128x8 window**
  - **Integration time as low as 9ms**
- **Using 128x64 window@ 1kHz and 9ms integration time**
- **Measurements with Al 6061, Al 7074, and ETP Cu**
  - **Al sample heated to near melting in < 15 ms**
  - **Cu heated to >700 ^{o}C in 40 ms.**









Al 7075 @ 2ms and 15 ms

IR Camera

- **Using 128x8 window@ 17kHz and 9ms integration time**
- **Can sometimes get expansion**
- **Problems**
  - **Surface emissivity varies for different surface finishes**
  - **~3 pixel smear**

Cu @20.64 ms

.....

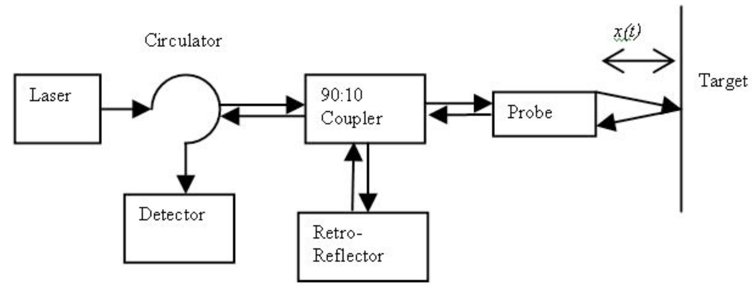
Cu @27.06 ms

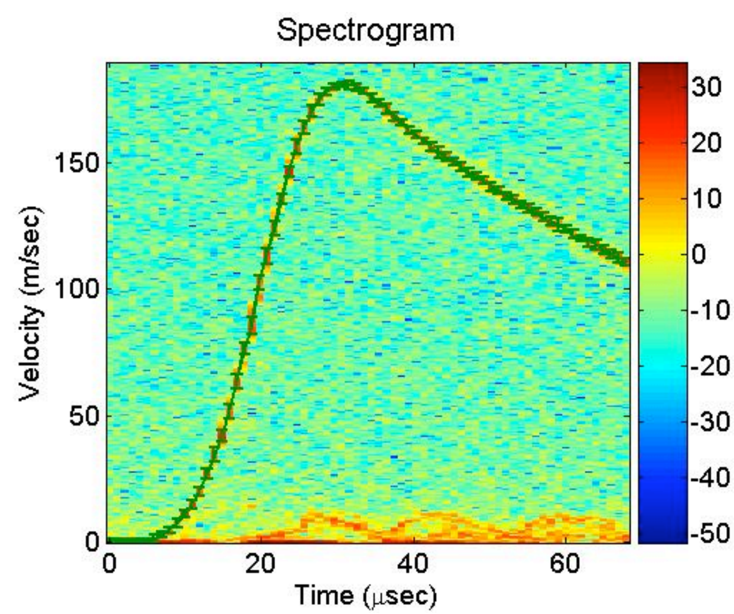
Cu @27.12 ms

Cu @27.18ms

PDV

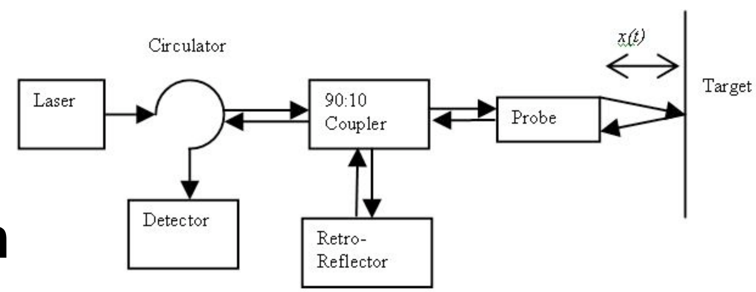
- Material strength is proportional to acceleration
- Any noise in the measurement is amplified by taking the numerical derivative
- Velocity measurement must have high signal to noise ratio
- Heterodyning enables PDV to amplify signal

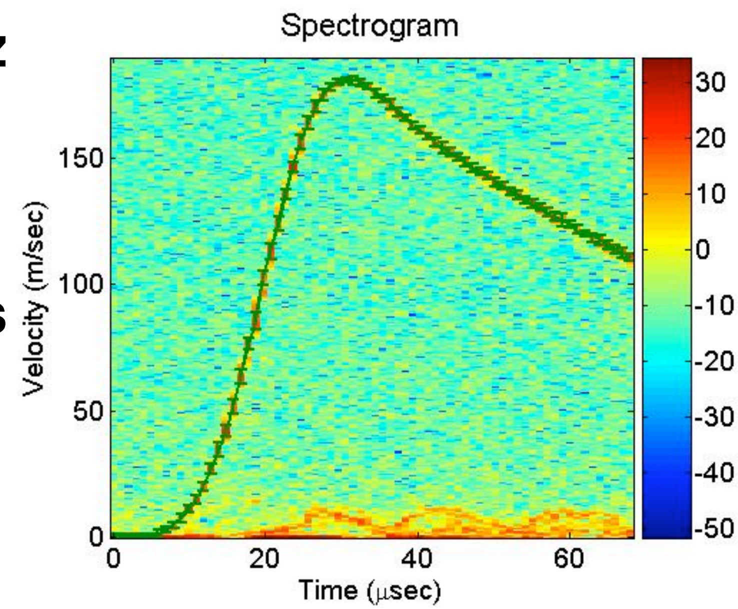




PDV

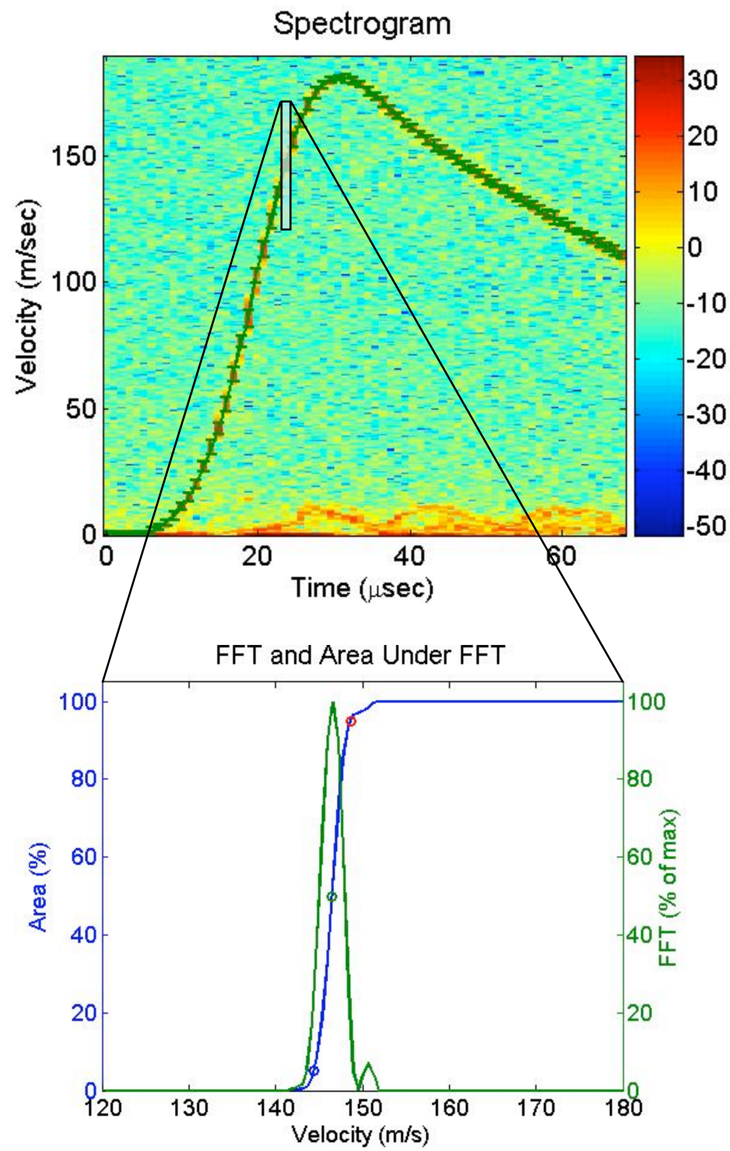
- **Measures velocity using Doppler shifted light**
- **Ring sample reach peak velocity of about 180 m/sec in 20-30 ms**
- **Beat signal sampled at ~6 GHz or 12 GHz**
  - **6 GHz;N=2^{13};DV=0. 591 m/s**
  - **12 GHz;N=2^{14};DV=0.591 m/s**
- **Velocity is extracted via spectrogram**





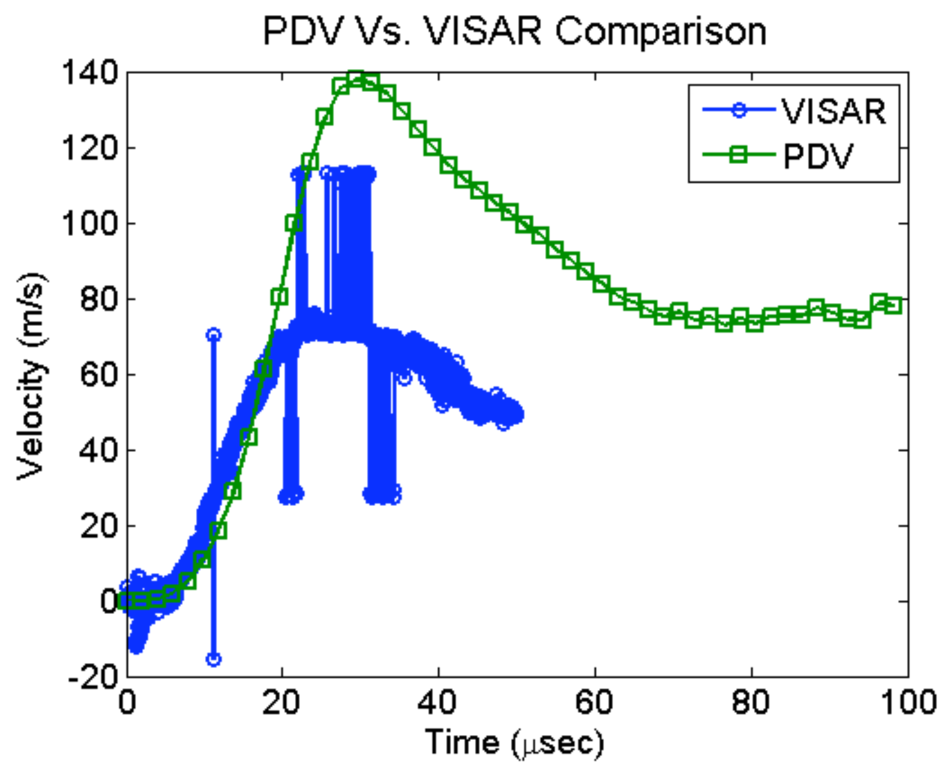
Error Bounds

- Treat each column as a probability distribution
- Find 5%, 50% and 95% cumulative area under the probability curve
- Analogous to a confidence interval
- These are the minimum, average and maximum velocities
- Maximum uncertainty of ~5 m/s



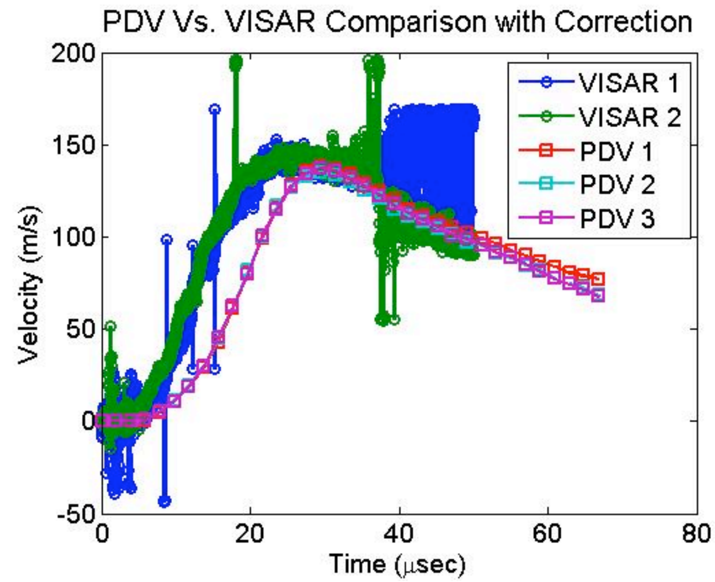
PDV vs. VISAR

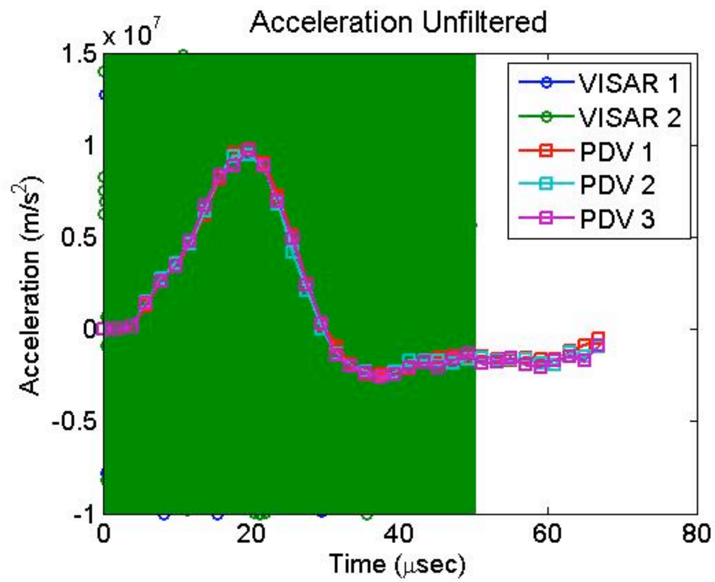
- **Comparing experiments with the same impulse**
- **VISAR off by > 50% in previous experiments**
  - **Lost fringe?**
  - **Wrong etalon constant?**



PDV vs. VISAR

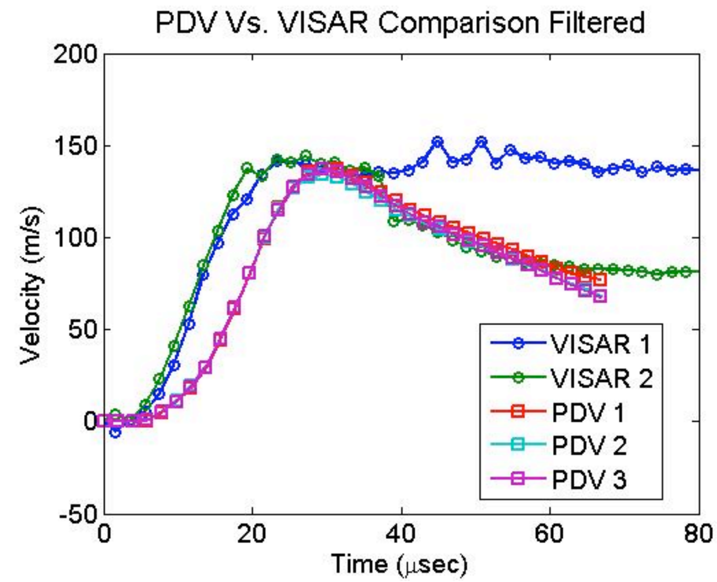
- **PDV has been validated with other experiments**
- **Correction factor ~1.65**
- **Calculate acceleration using central difference**
- **Noise will swamp acceleration**

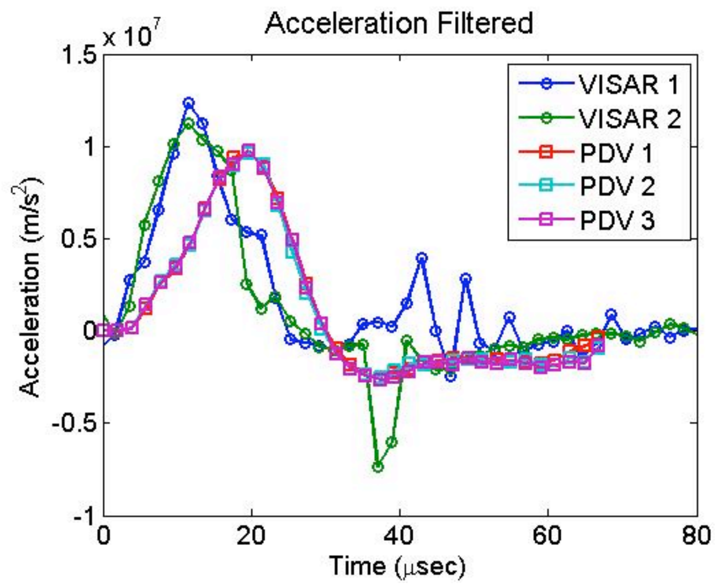




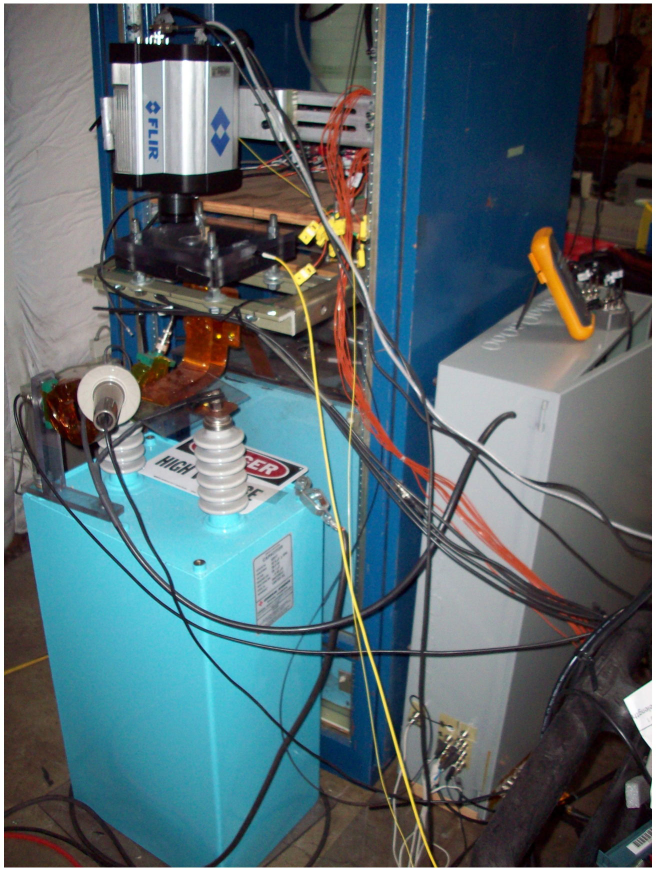
PDV vs. VISAR

- **Use FFT to filter VISAR help a little**
- **Still not a good as the PDV**
  - **Commercial components**
  - **Heterodyning!**



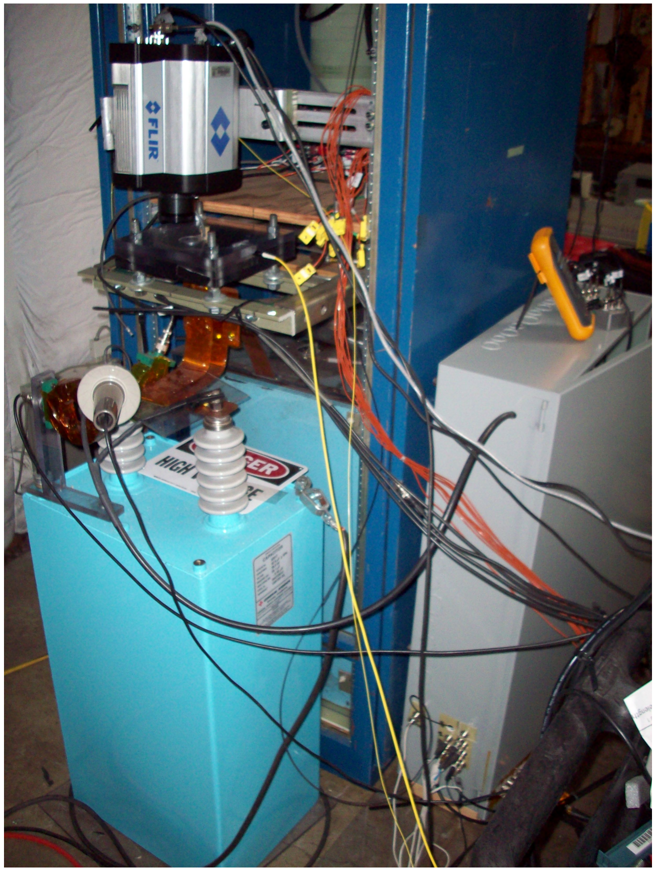


Conclusion



- Expanding ring experiment is for measuring material strength
- PDV provides a very precise, accurate, and reliable velocity measurements

Conclusion



Questions