

HiRadMat Beryllium Thermal-Shock Test

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PASI 2nd Annual Meeting

RAL, UK

April 5, 2013

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CERN's HiRadMat Facility

- Provides high-intensity pulsed beam where material samples can be tested ($4.9e13$ ppp)
- Short pulse lengths suited for thermal shock tests ($7.2 \mu\text{s}$)

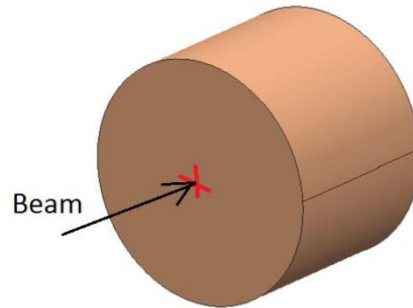
Objectives

- Collaboration with RAL HPTG
- Fracture Beryllium with one or multiple beam pulses
- Experimentally deduce the onset of plastic deformation
- Benchmark numerical simulations currently based on scarce literature data
- Potential post irradiation analysis



Conceptual test design

Fall 2014?



- Thick/thin Be specimens
- Incident beam at different radial locations
- One or multiple beam pulses per specimen

- Measurements
 - Radial vibrations - Laser Doppler Vibrometer (LDV)
 - Image fracture – High speed camera



HRMT-14 experiment



Radial Velocity Measurements



- Radial measurements performed with a Laser Doppler Vibrometer equipped with :
 - Targeting laser (green).
 - Infrared laser for measurements
 - Long range lens
 - In line video camera with reticle overlay

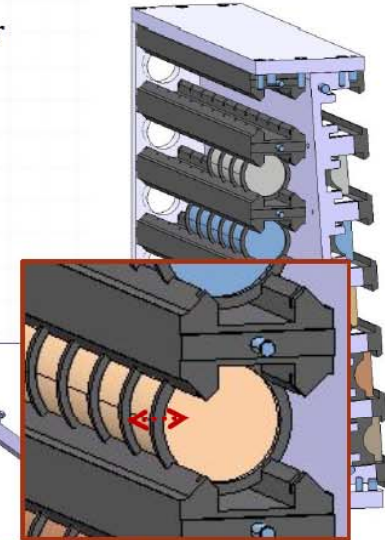
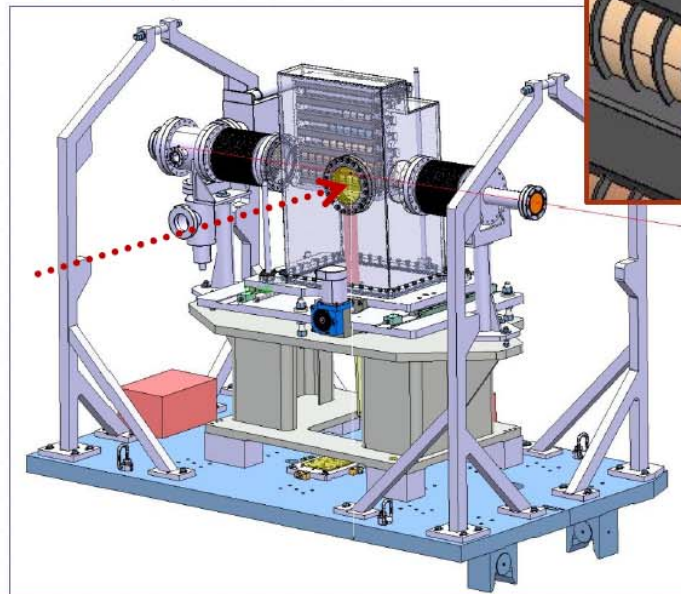
Polytec

RSV-150 Remote Sensing Vibrometer

Special Application Vibrometers

Customized system developed in collaboration with Polytec® for this application!

RSV-150	Remote Sensing Vibrometer
Video output	CVBS signal, 1 V p-p/75 Ω, BNC, PAL standard
Settings	LCD display and soft keys, software remote control via USB (with supplied control application Microdrive Panel)
Signal level	LED bar indicator and RS232 voltage output, indicates the return signal strength
Operating temperature	45 °C ... 440 °C (41 °F ... 104 °F)
Size	235 mm x 320 mm x 150 mm (3U, half rack/42 HP)
Weight	6 kg
Power supply	100 ... 240 VAC (±10%, 50/60 Hz)/(12 - 24 V DC, optional)
Protection class	IP-20
PC interface	USB 1.1, system remote control



13 November 2012

A. Bertarelli, M. Guinchard - EN-MME

29

Bertarelli, A and Guinchard, M., 'An overview of HiRadMat experiment on collimator materials', CERN Engineering Department Technical Meeting (ENTM), 13 Nov 2012.



HRMT-14 experiment

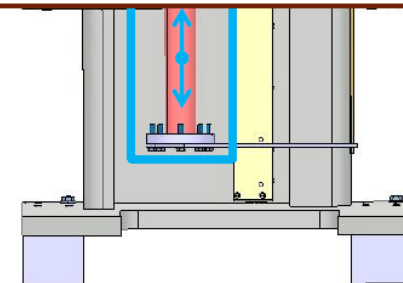
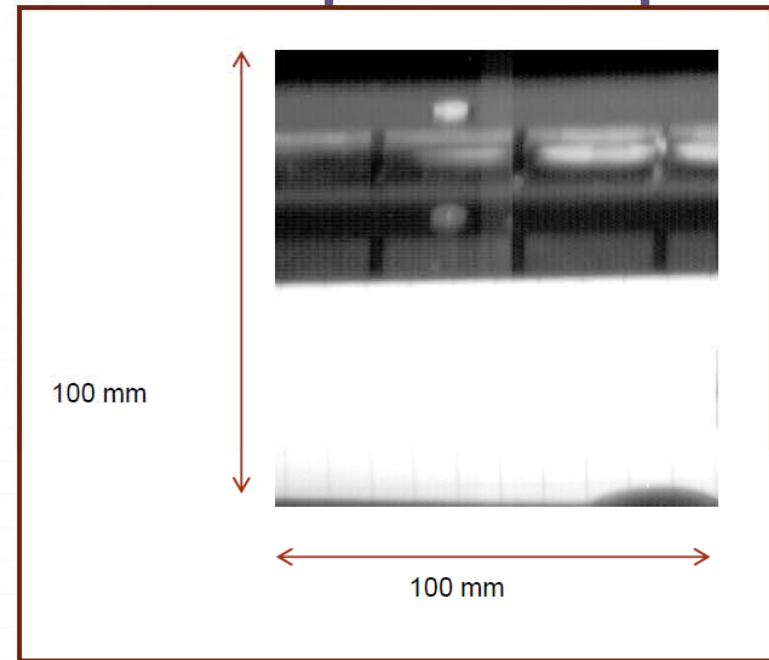


High Speed Camera



High Speed Camera Specifications:

- Distance: ~42 m,
- Optical Circuit: 3 mirrors + 1 window,
- Lens: Nikkor 1000 mm,
- Resolution: 224x224 px,
- Observable area at 42 m: ~100x100 mm,
- Pixel Dimensions: 1 px ~ 0.45x0.45 mm,
- Frame rate: 20000 fps,
- Shutter time: 5 μ s.



Courtesy : HiRadMat Team

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31

Bertarelli, A and Guinchard, M., 'An overview of HiRadMat experiment on collimator materials', CERN Engineering Department Technical Meeting (ENTM), 13 Nov 2012.



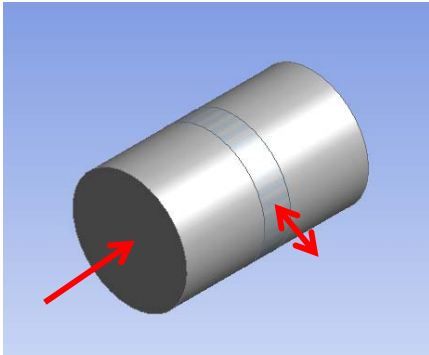
ANSYS numerical simulations

HiRadMat maximum intensity beam parameters:

- Beam energy: 440 GeV
- Bunch intensity: $1.7e11$ protons
- Number of bunches: 288
- Maximum pulse intensity: $4.9e13$ protons
- Pulse length: $7.2 \mu\text{s}$
- $\sigma_{\text{rms}} = 1 \text{ mm}$

- Scaled MARS energy deposition up to 10 times to obtain peak temperatures close to melting ($\sim 1100 \text{ }^\circ\text{C}$)

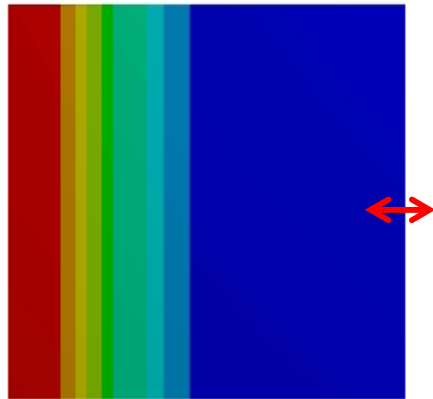
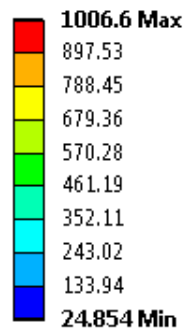




- Radial displacements resulting from 1 beam pulse
- Radius: 5 mm
- Elastic and bilinear kinematic plastic material model

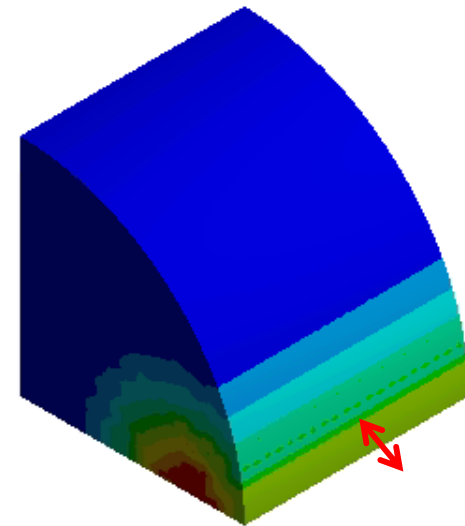
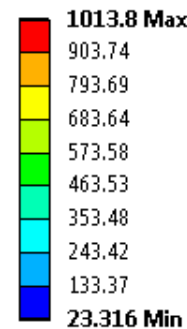
- Axisymmetric model
- Incident beam at $r/R = 0$

B: Transient Thermal
 Temperature
 Type: Temperature
 Unit: °C
 Time: 2.e-005
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- 3D model
- Incident beam at $r/R = 0.5$ & 0.75

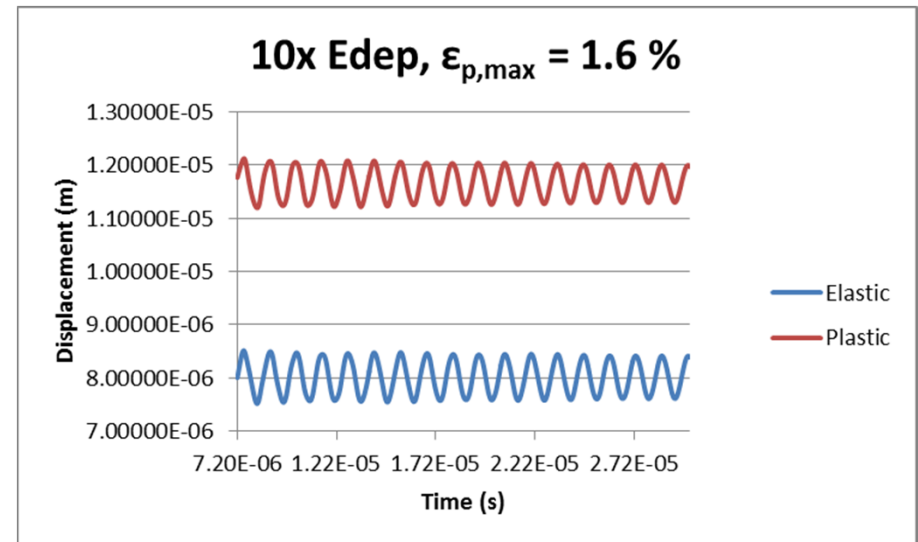
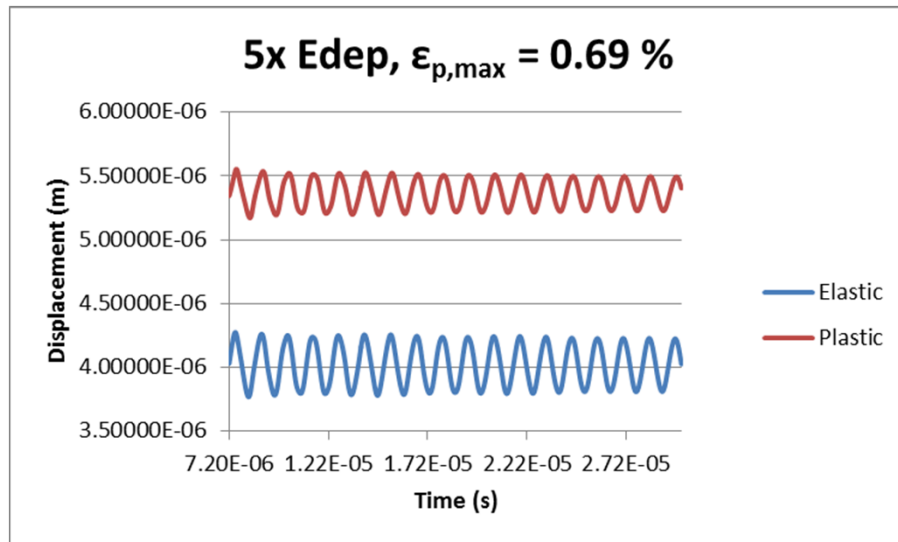
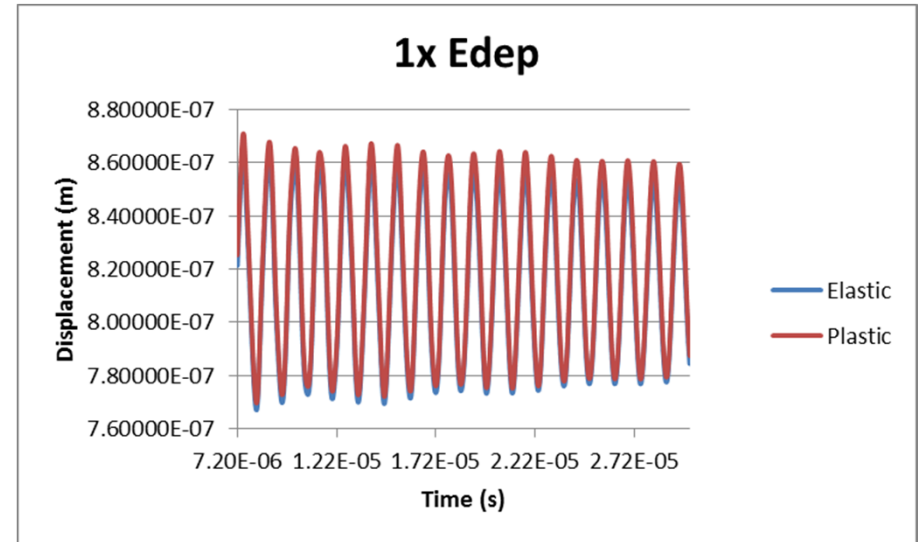
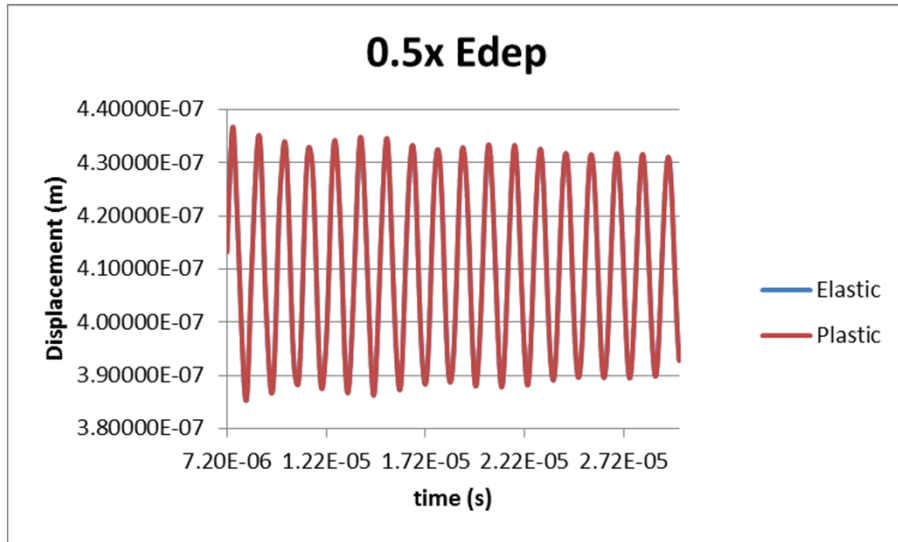
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- Radial displacements at window edge



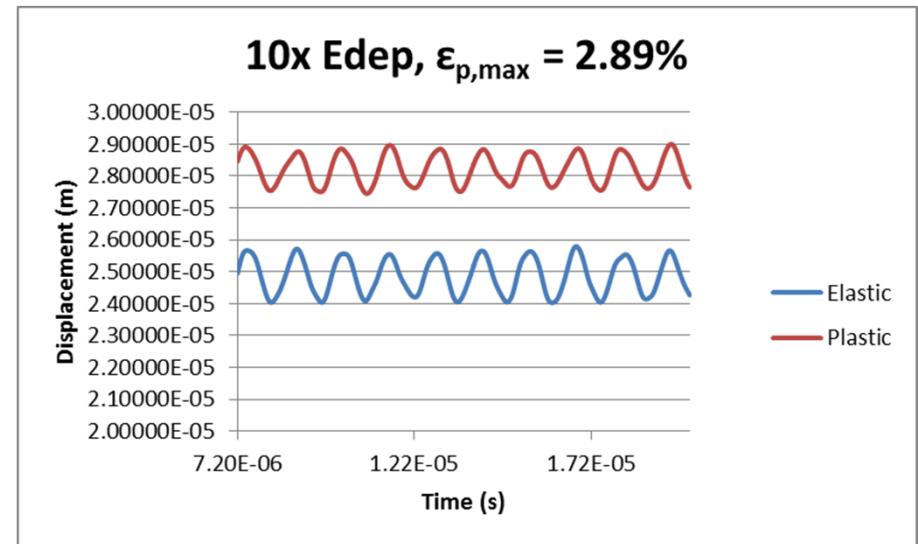
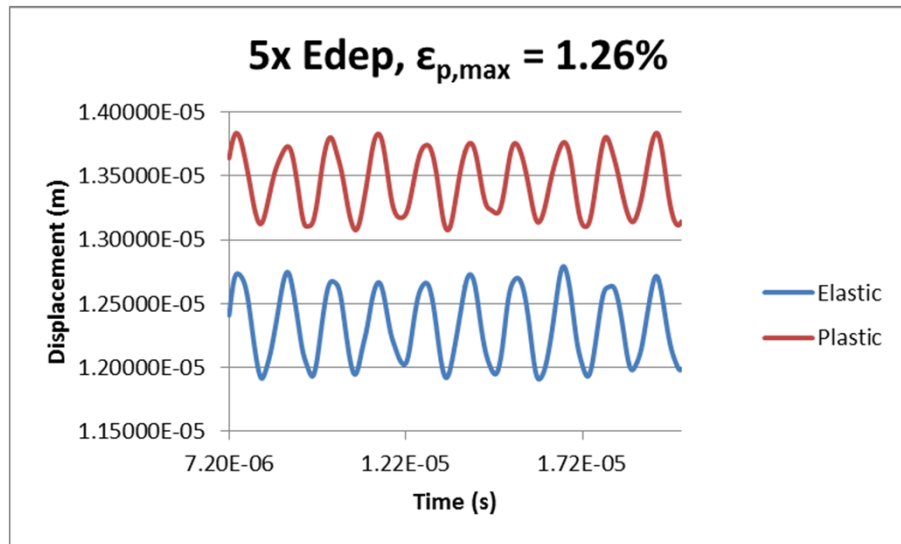
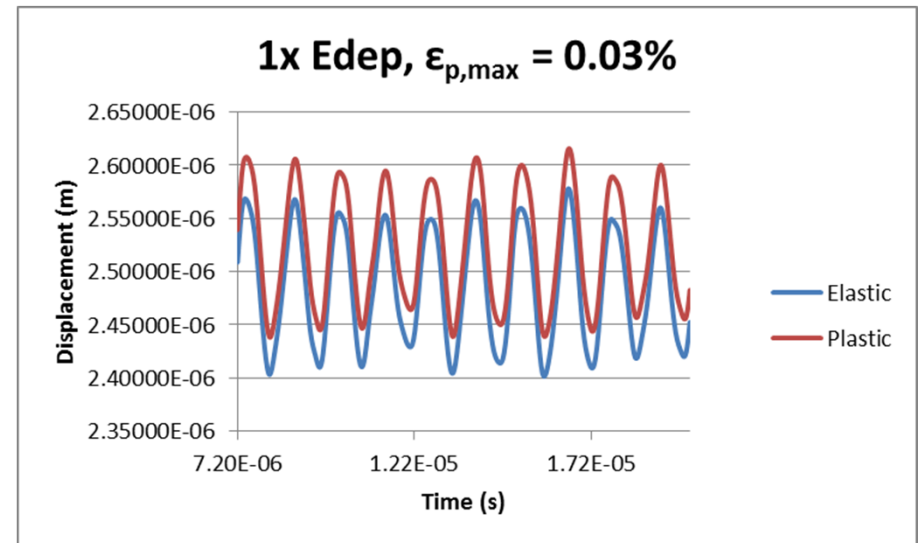
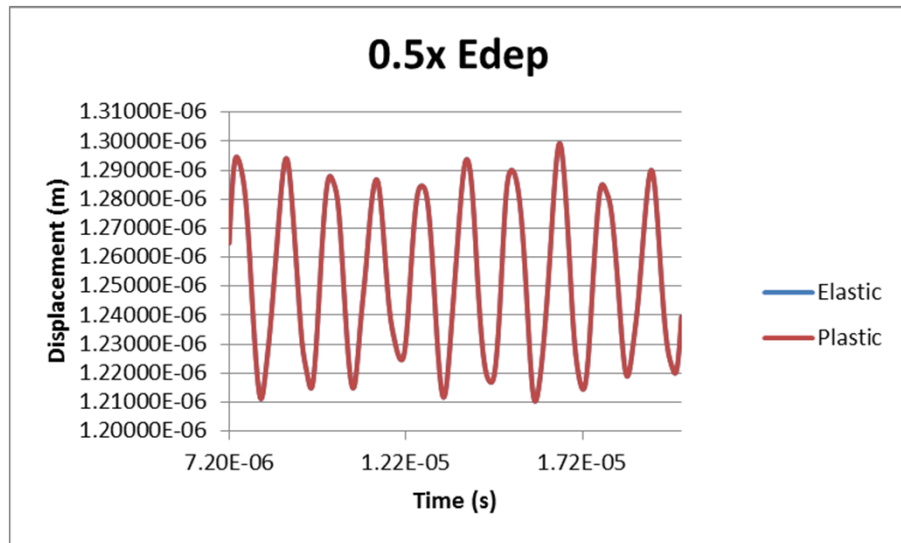
Displacements - beam at $r/R = 0$



- Frequency ~ 0.75 MHz



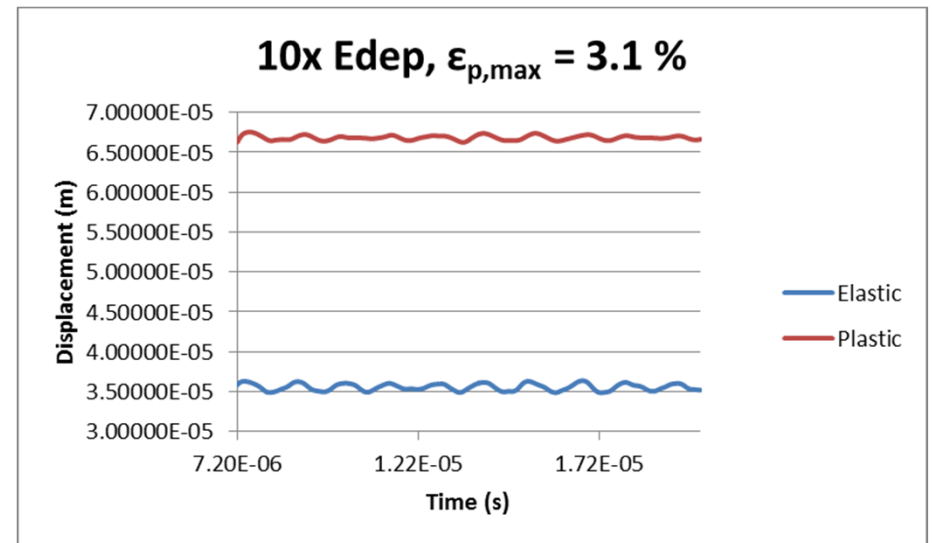
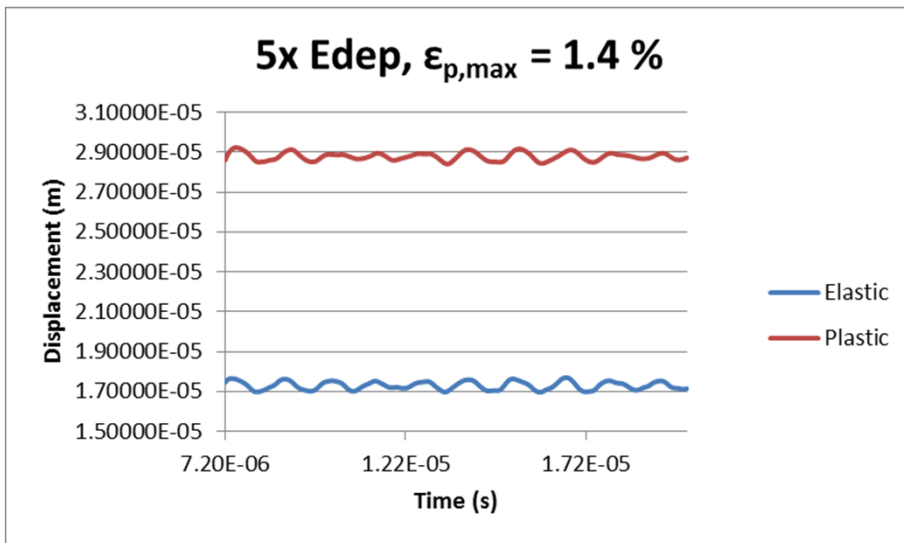
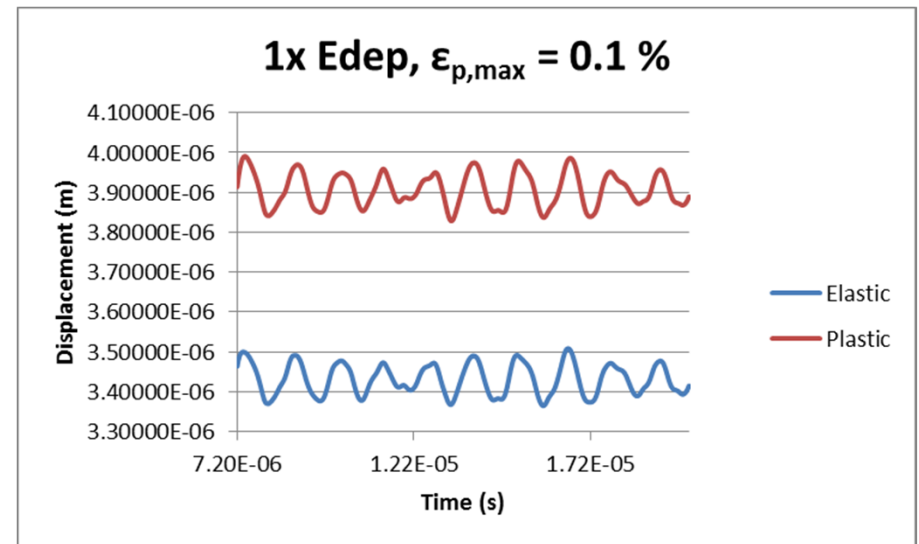
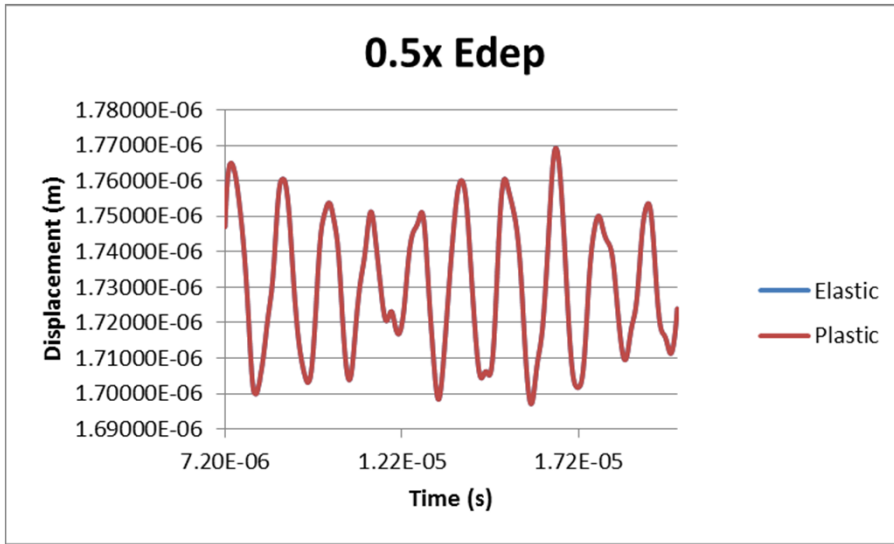
Displacements - beam at $r/R = 0.5$



- Maximum plastic strain at window edge



Displacements - beam at $r/R = 0.75$

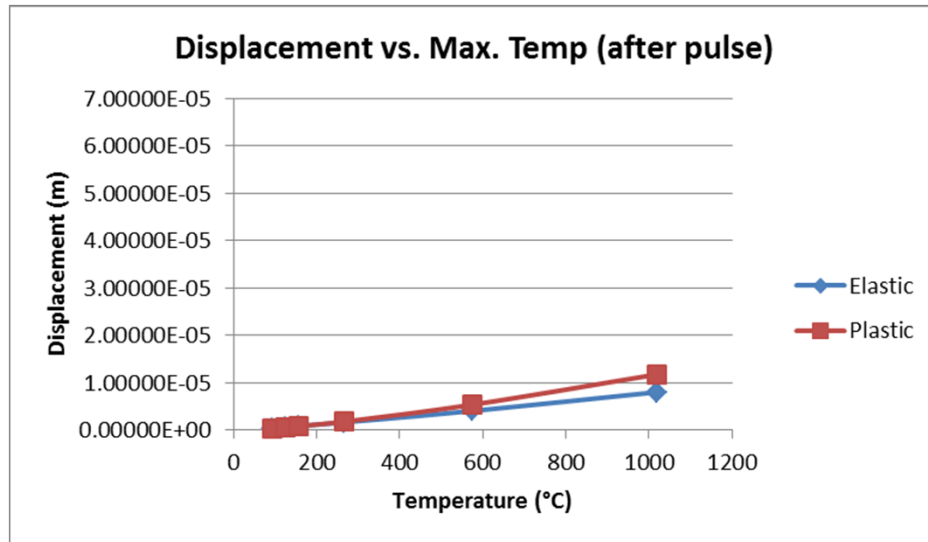


- Maximum plastic strain at window edge

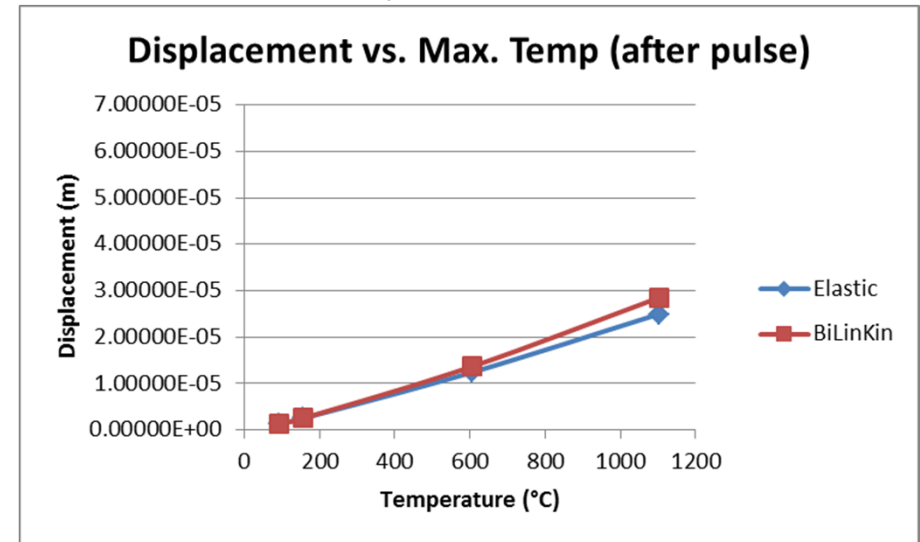


Maximum displacement as a function of Edep (Tmax)

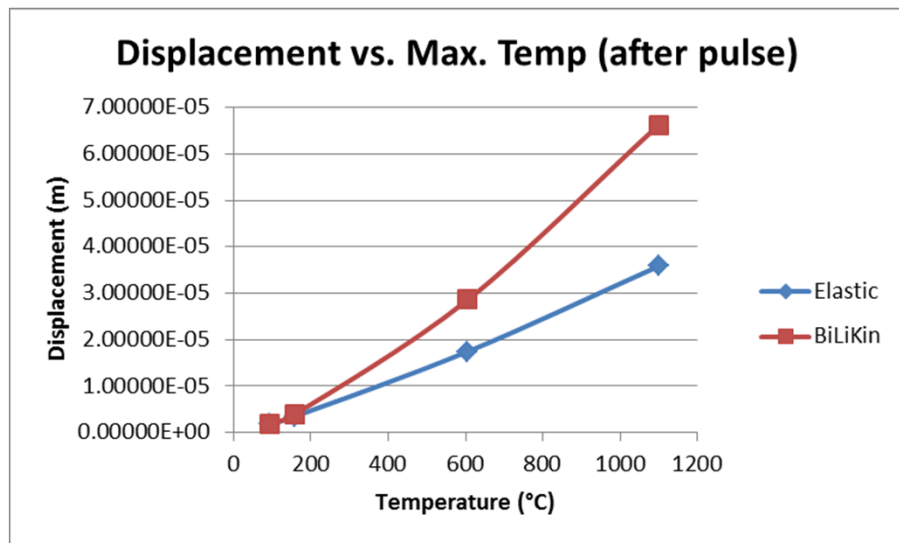
$r/R = 0$



$r/R = 0.5$



$r/R = 0.75$



- Incident beam at $r/R = 0.75$ shows largest deviation in displacement for elastic and plastic behavior ($\sim 30 \mu\text{m}$)



Ability to crack/fracture Be?

$r/R = 0.5, 10x \text{ Edep}, \text{ Edge } T = 120 \text{ }^\circ\text{C}$

C: Transient Structural

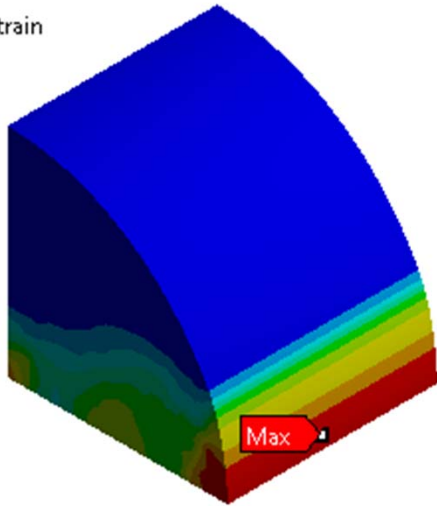
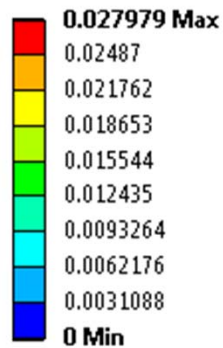
Equivalent Plastic Strain

Type: Equivalent Plastic Strain

Unit: m/m

Time: 2.e-005

4/2/2013 8:34 AM



C: Transient Structural

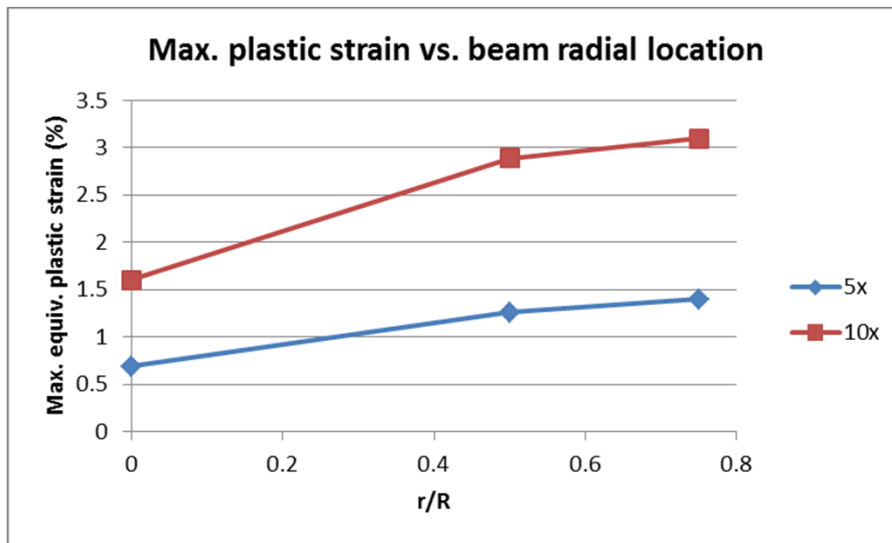
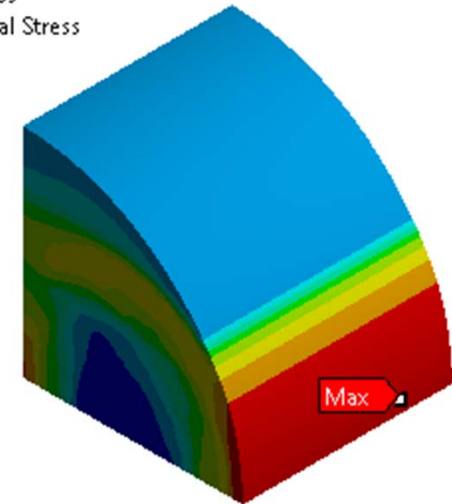
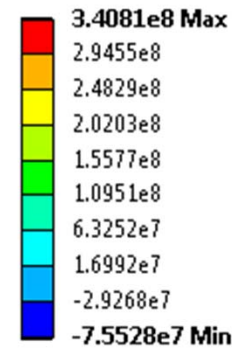
Maximum Principal Stress

Type: Maximum Principal Stress

Unit: Pa

Time: 7.421036107e-006

4/2/2013 8:33 AM



- Large enough tensile stress at window edge may initiate cracks
- 3.1% plastic strain at RT may lead to fracture
- Dependent on temperature



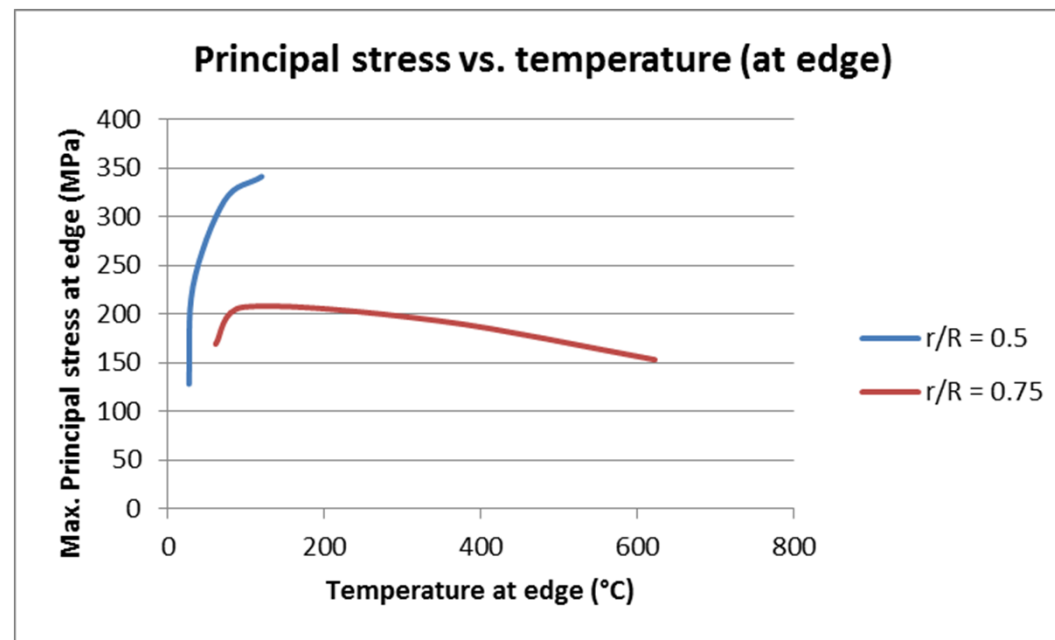
BUT...

Temperature of Be at max. equiv. plastic strain of 3.1% ~ 622 °C

$\epsilon_{\text{fracture}} \sim 20\%$ at 600 °C

- Possibility of melting before any cracking occurs
 - Failure due to fatigue need to be investigated

Maximum principal stress at edge

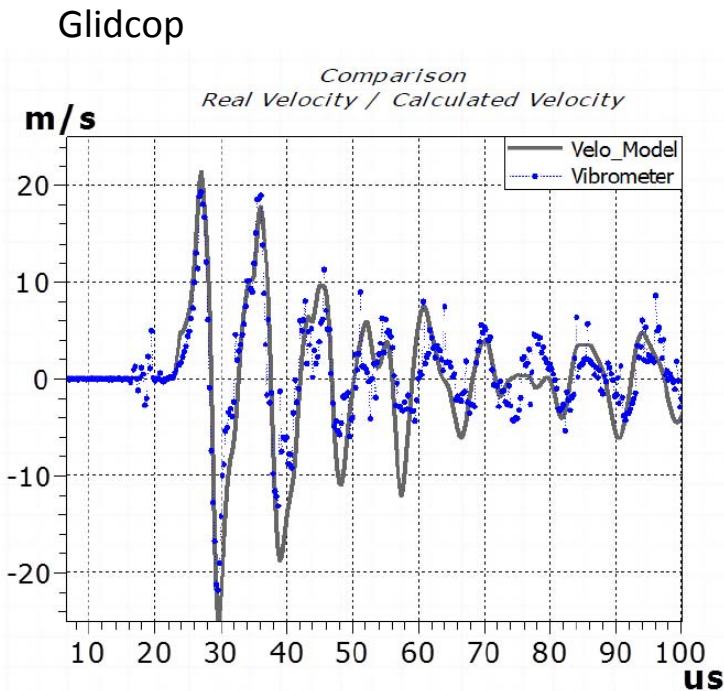


Further work

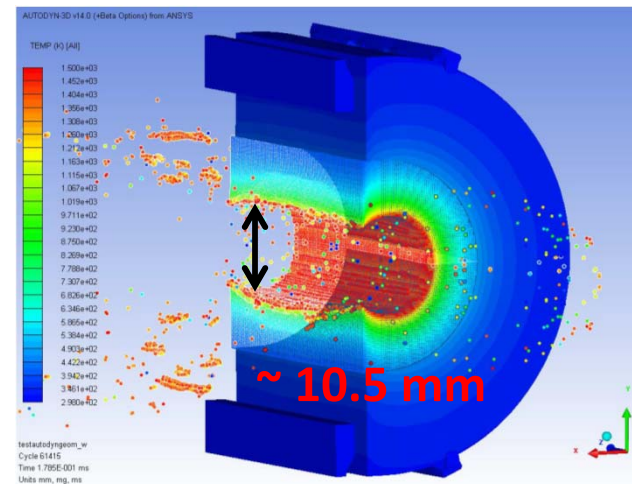
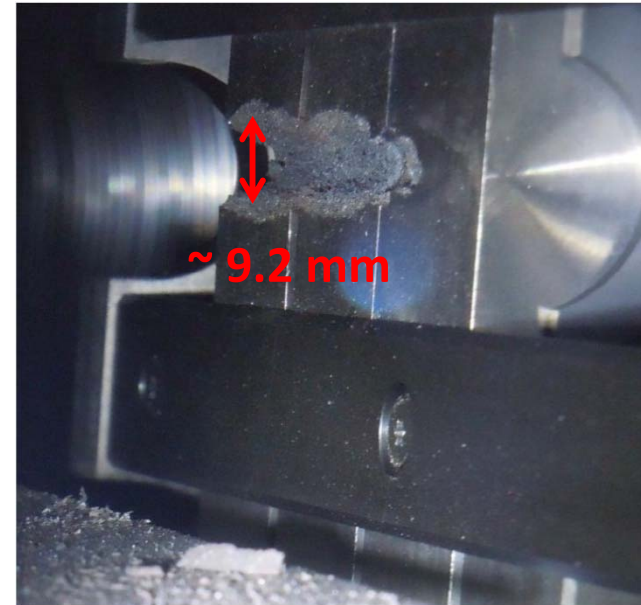
- More numerical simulations
 - Optimize specimen size and incident beam location
 - Multiple beam pulses
 - Other specimen geometries to induce larger plastic strain
- Be material properties
 - Strain rate dependency
 - Plasticity model for $T > 600 \text{ }^\circ\text{C}$
- Damage/fracture model using LS-DYNA/Autodyn
- Pre-cracked zone at edge of specimens?
- Further analysis for thin window tests



Some results from HRMT-14



- LDV and high speed camera measurements fairly comparable with numerical simulations
- Goal: make similar comparisons for Beryllium



Inermet 180



Thank you

