Conference: Spatial Velocimetry Workshop

Title: The application of Line VISAR to dynamic impact experiments using the AWE 70 mm bore gas gun

Date: 9th September 2013

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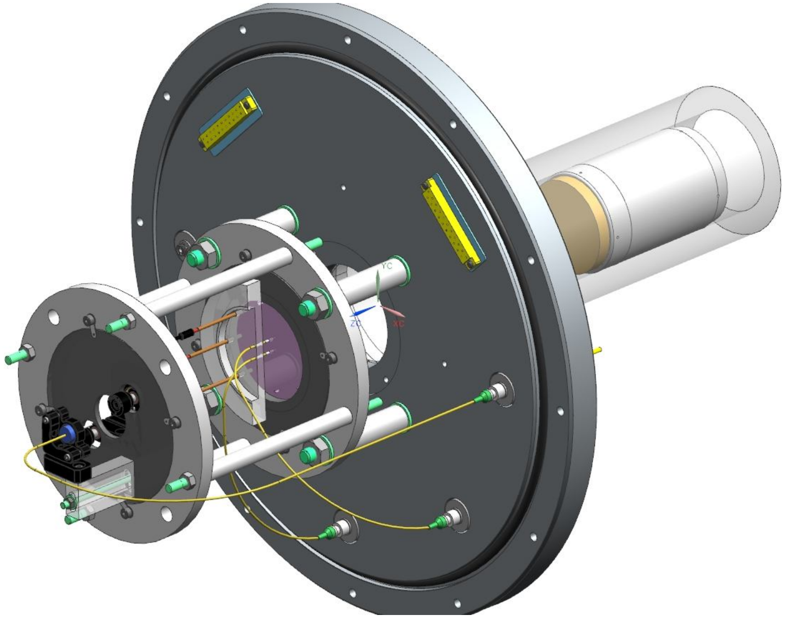


Overview

- What is Line VISAR
  - Why Line VISAR.

- Single stage helium gas gun at AWE.

- System layout
  - Front end optics & fast lens.
  - Design and function of the interferometer.
  - Balancing the interferometer.
  - Etalon selection and velocity sensitivity.
  - Streak camera.
  - Triggering and use of timing markers.

- Target preparation.

- Data examples.

What is Line Imaging VISAR

- An optical (non-contact) velocimetry diagnostic.
- Spatially resolved Velocity Interferometer System for Any Reflector (VISAR).
- A target free surface is illuminated by a high power laser beam, and imaged through an interferometer.
- Movement of the target surface leads to a Doppler shift of the reflected light.
- The fringe pattern generated by the interferometer changes because of this Doppler shift.
- The pattern is relayed to a streak camera which temporally resolves the fringe pattern.
- With knowledge of the interferometer delay, etalon material and laser wavelength the velocity time profile can be determined.

Why Line VISAR

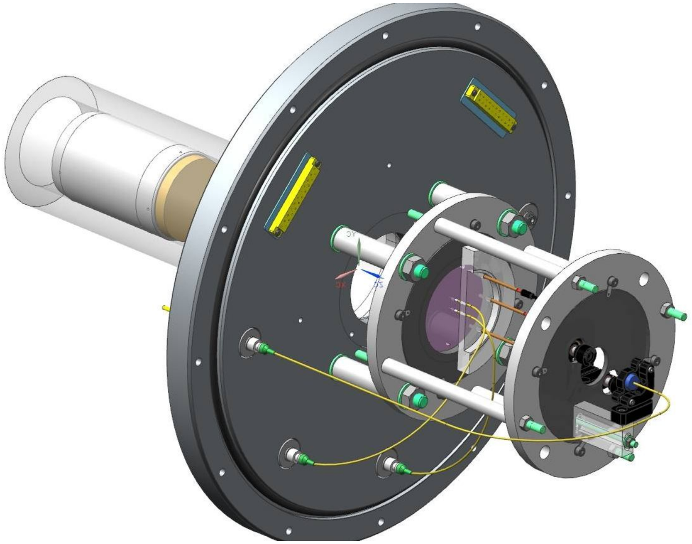
- It provides continuous spatial information.
- Can be used to measure material properties on the mesoscale <100 μm.
- This may help to better crystal structure, grain boundaries and dislocations.
- There are many properties that are of interest
  - Statistical velocity data.
  - Sound-speed artefacts.
  - Grain boundary interactions.
- Relatively few publications using spatial techniques.

Single stage helium gas gun at AWE.

- Single stage Helium gun with a 70 mm bore.
- Experiments modelled to ensure target behaviour is 1D for the duration.
- Several μs pressure pulse of bulk material.
- Velocity range 150-900 m s^{-1}.
- Targets lapped flat and parallel.
- Tilt typically <1 mrad.

Front End Optics & Fast Lens

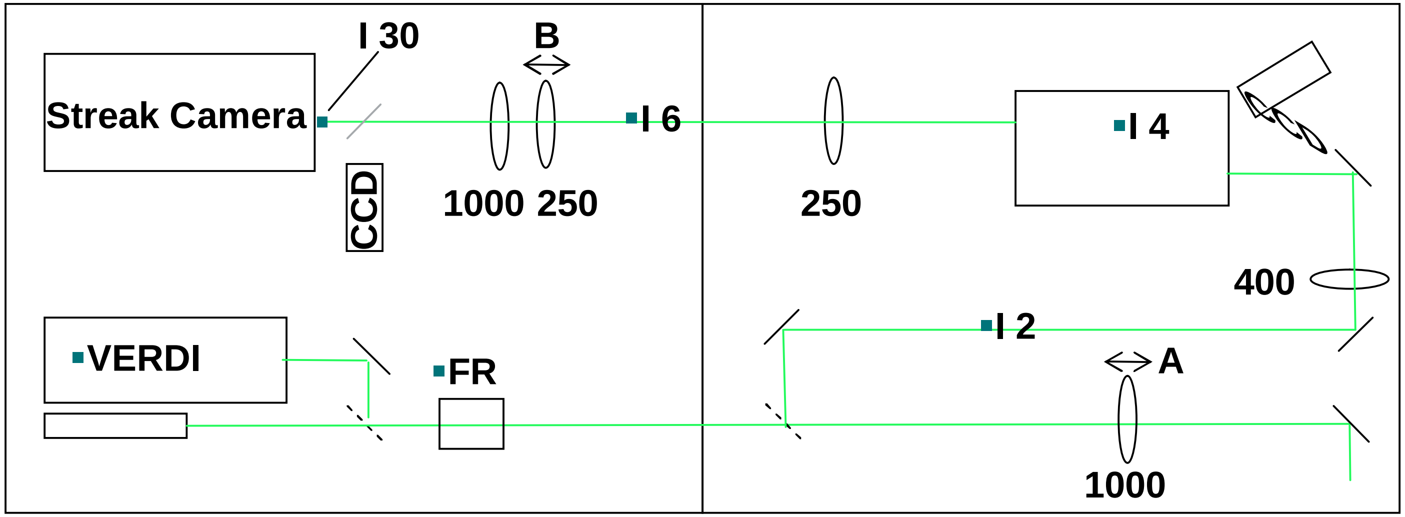
- Ø= 50.8 mm, f = 500 mm fast lens used to collimate the beam from the gun.
  - VPF Fast lens correction[1] for f#10 < 1.0006.
  - <50 μm features can be readily observed.
  - Depth of field is in the region of 1 mm.
- Spot size ~1 mm resolution may dictate large optics.
- Target contained within a widowed vacuum chamber.
- Our target / optical system is mechanically coupled to the gun.
  - Experimental data has been lost due to vibration problems.



1. P. M. Celliers et al Rev Sci Inst, Vol 75, 11, Nov 2004

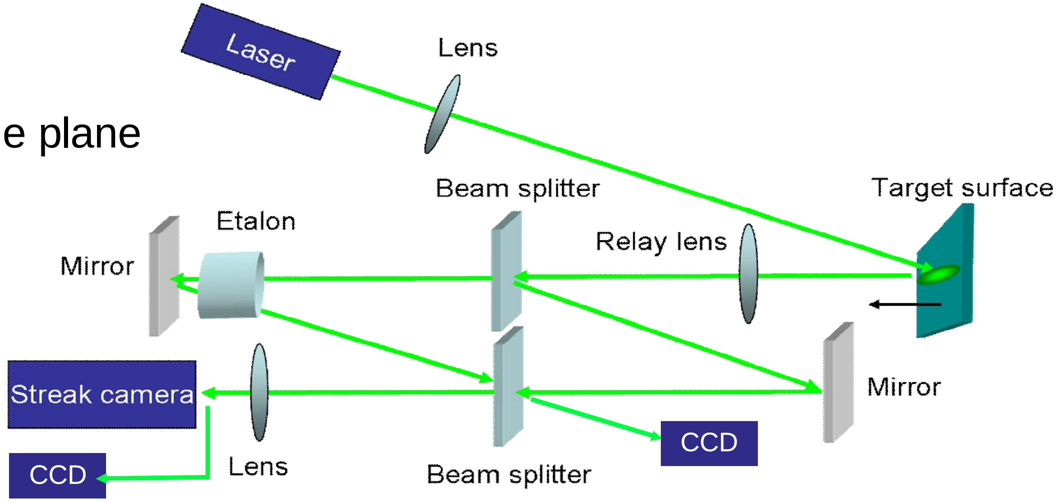
System Layout

- Image plane before interferometer allows insertion of cross hairs.
- Fine focus achieved with translation stage on bench (A).
- Collimation from target accommodates differing gun locations.
- System uses standard off the shelf parts.
- Magnification stage prior to streak camera easily changed by swapping lens (B).
- Magnification by 30.
- Higher resolutions achieved simply by changing first lens.



Design & Function of the Interferometer

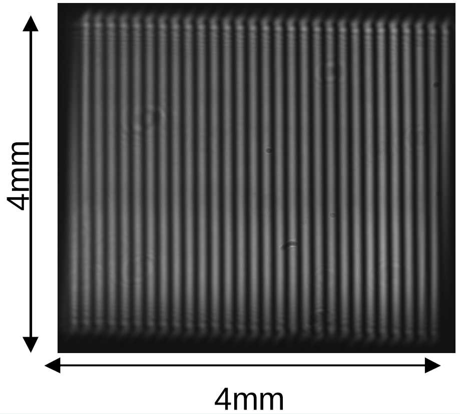
- Design based on that published by Celliers et al[1].
- Mach Zehnder configuration with a double pass through the etalon.
- The interferometer in divided into a reference and delay leg.
- The interference fringes are formed on the output beam splitter surface.
- Fringe spacing and orientation is adjusted by tilt of the exit beam splitter
- We use Ø = 25.4 mm diameter optics.
- Mirror gimbal mounts with piezo actuators.
- CCD’s are used to ensure images overlay.
- Cross hairs are placed in image plane before the interferometer.

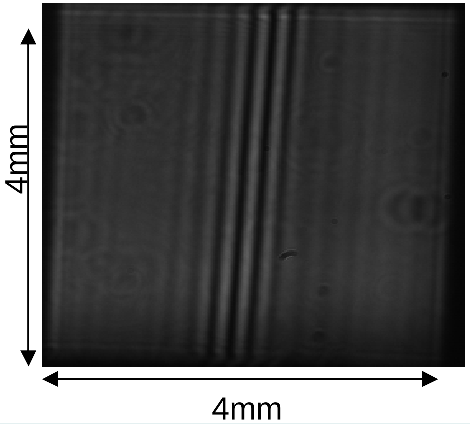


Balancing the Interferometer

- The delay and reference legs of the interferometer must be precisely balanced prior to installing the etalon.
- The balancing procedure (etalon removed)
  - Each path balanced to within 0.5 mm using a ruler or laser range finder.
  - An alignment laser (low power HeNe) is passed through the whole optical system.
  - Mirrors and beams splitters are adjusted used to achieve **collinear beams** in the near and far field.
  - Using an incoherent light source (green diode) adjust the position of the delay leg mirror until clear and central fringes are seen. Optimise the contrast iteratively continually checking the collinear alignment of the beams adjusting the delay leg mirror and exit beam splitter as required.
  - Confirm the orientation of the fringes matches those with the HeNe.
  - A translation speed of 3-5 μm s^{-1} allows fringes to be observed.

Green Light





White Light

Etalon Selection & VPF

- Ø= 50.8 mm UV Grade Fused Silica etalons are used to introduce sub nanosecond delays.
- The choice of etalon is varied to ensure the interferometer is most sensitive to changes in velocity near the desired velocity range.
- After the interferometer has been balanced the etalon is inserted and the delay leg mirror is translated
- Small adjustment of the interferometer may be required to ensure high fringe contrast
- The Velocity Per Fringe and required etalon translation distance can be calculated[2] by:

Parameter		Value	Units
Etalon Refractive Index	n	1.4607	
Translation Distance	d	0.0269	m
Time Delay	τ	0.4410	ns
Dispersion	δ	0.0318	
Wavelength	λ	532	Nm
Velocity Per Fringe	VPF	584.566	$m\ s^{-1}$
VPF Error	±	1.325	$m\ s^{-2}$

$$d = h\left(1 - \frac{\cos\theta_{\mathrm{h}}}{n\cos\left(\sin^{-1}\left(\frac{\sin\theta_{\mathrm{h}}}{n}\right)\right)}\right)$$

$$\tau = \frac{2h}{c\cdot\cos\left(\sin^{-1}\left(\frac{\sin\theta_{\mathrm{h}}}{n}\right)\right)}\left(n-\frac{1}{n}\right)$$

$$VPF = \frac{\lambda}{2\tau\left(1+\delta\right)}$$

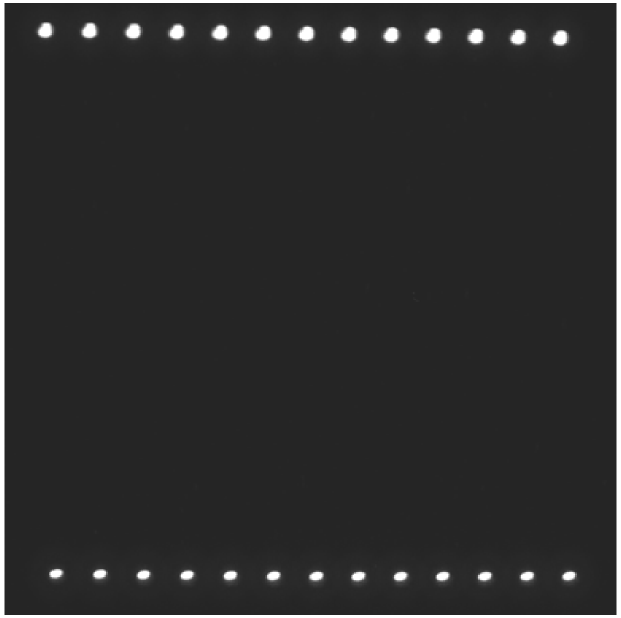
2. Bolme, C. A., & Ramos, K. J. (2013). *Rev Sci Inst, 84(8), 083903–083903. doi:10.1063/1.4817307*

Use of a Streak Camera to Record Fringe Shift

- A Streak camera is used to temporally resolve variations in light intensity across its input slit.
- We use Optronis SC-51 streak cameras fitted with Spectral Instruments SI 800 and SI 1000 CCD Detectors.
- We are typically looking at events over 1 µs timescales and to 2-4 µs sweep windows are used.
- The large sweep window allows for significant timing jitter but temporal resolution remains high.
- Using a narrower the slit width and shorter sweep window leads to high temporal resolution typically 50 µm.

Triggering & Use of Fiducial Timing Markers

- Fiducial timing markers used to precisely correlate captured events on steak camera, recording digitisers and other diagnostics such as PDV.
- The timing markers are used to calibrate the temporal axis however must be removed before applying Fourier based analysis routines.
- An example of a static sweep with timing markers in place is shown.
- In this case the markers are 50 ns wide with a period of 300 ns.
- The marker intensity is adjusted to match that of the static signal and is fibre pigtailed from the marker laser to the camera input slit.

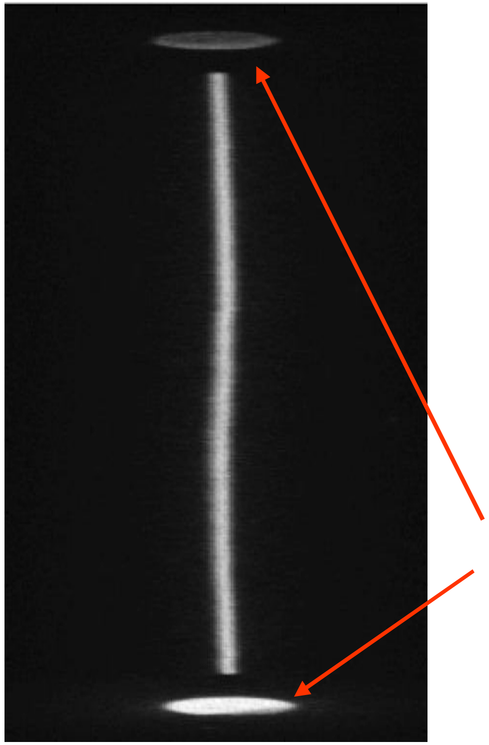


Timing markers and timing accuracy.

For example with our current sweep rate, system setup and corrections for cables.

Combined timing errors without distortion correction ~ ±7 ns.

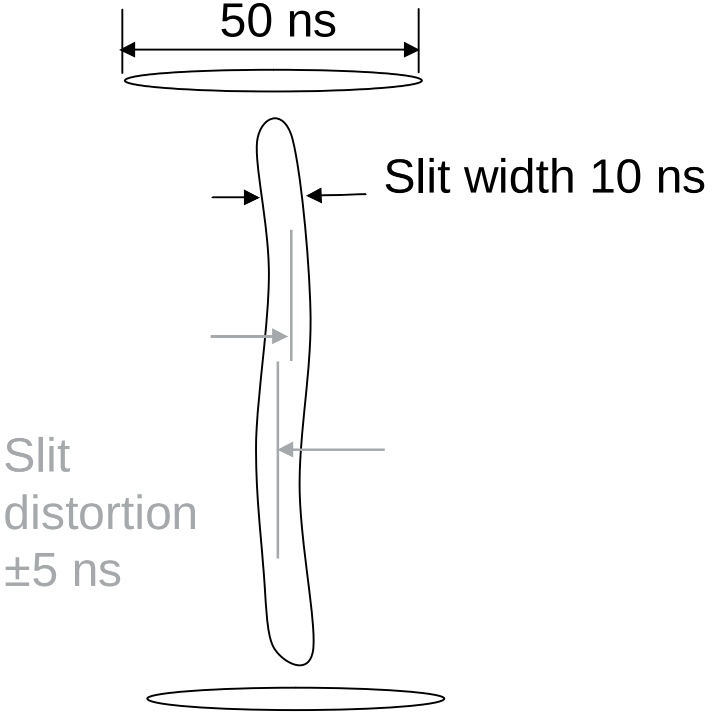
Expanded image of the 50 µm slit.



“This image was taken in focus mode. We need to dynamically calibrate the camera in sweep mode.”

Timing markers

“We can locate the centre of the markers to a sub pixel level <1 ns ”



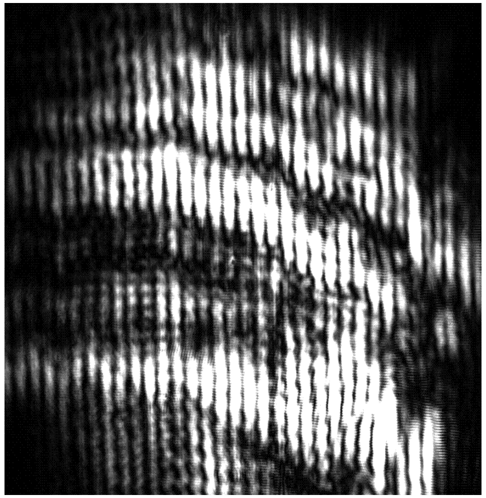
Target Preparation

- Using a diffuse surface finish
  - Removes sensitivity to target tilt.
  - May give less variable average surface reflectivity.
  - Will lead to laser speckle which destroys fringe contrast.

- The incident laser light may be delivered via multimode fibre
  - Much reduced speckle was not observed.
  - Collimation over large distance without significant loss is challenging.
  - Vibration of the fibre can aid alignment - the effect of this on the measured phase change is not clear.
  - Fibre transmission is preferable in many cases.

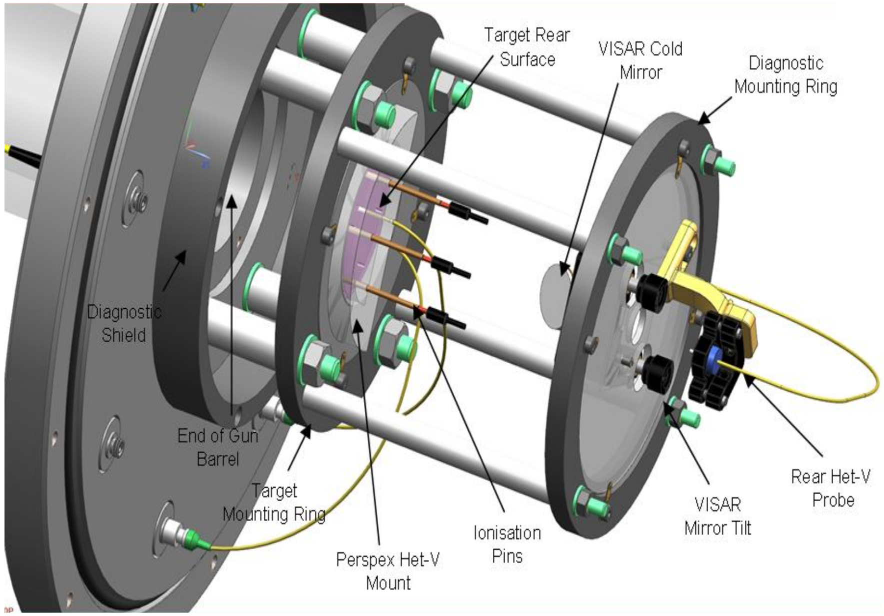
- Highly specula surface finishes give very little speckle
  - Tilt of the target surface can lead to data loss.
  - Surface reflectivity may change dramatically on breakout.

- Anvils may be used
  - Yet to be tested with our system.
  - VPF correction is required.



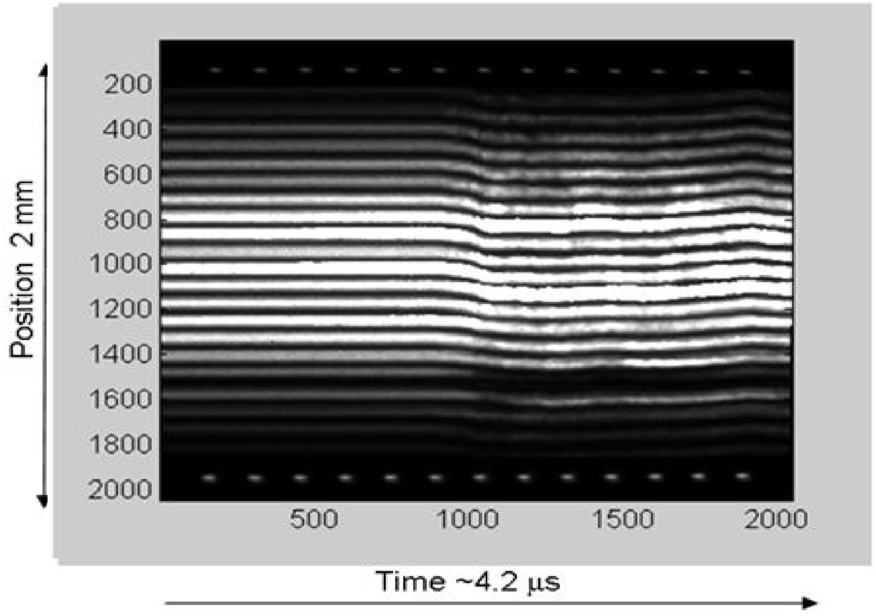
Experiments

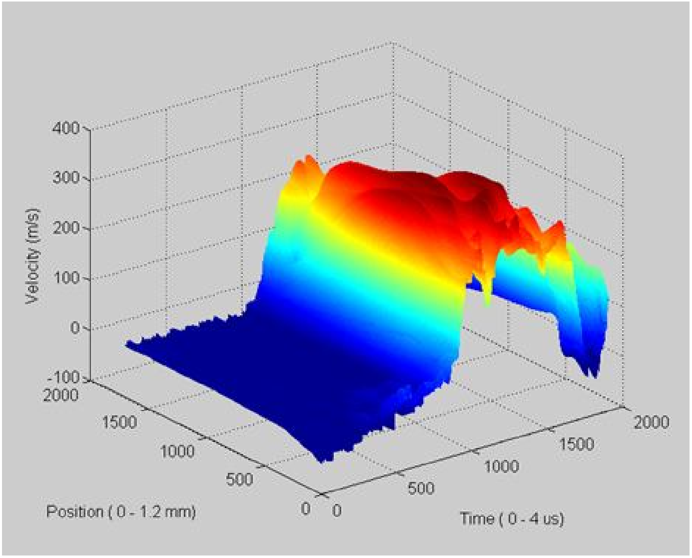
- Symmetric impacts on several materials
  - Aluminium -diffuse.
  - Iron -polished.
  - Tantalum -polished but surface defects
  - Copper -polished.
- Symmetry constrains particle velocity to that of the flyer.
- Use of a cold mirror allows PDV/HetV at 1550 nm on the same region of the target.
- Flyer velocity recorded using PDV/HetV.
- Ionisation pins are used for diagnostic triggering and tilt measurement.



Example Data

- Line VISAR used to spatially resolve the dynamic behaviour of tantalum impacted at 240 m s^{-1}.
- Symmetric impact of a 4.0 mm thick Ta Target by 4.0 mm thick Ta Flyer.



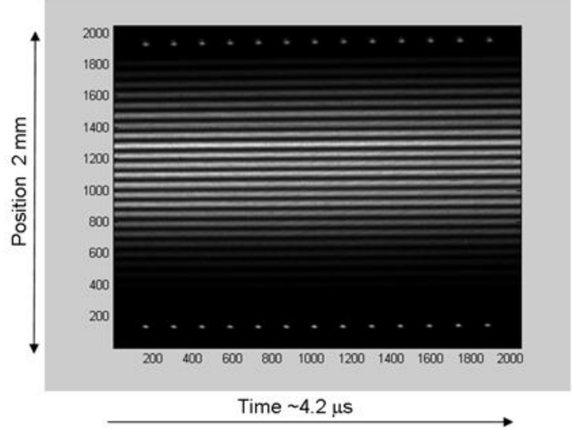


Example Data

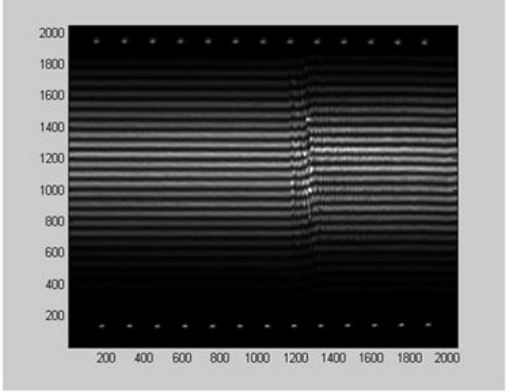
Symmetric impact Armco Iron 4 mm/ 4 mm at 356 m s^{-1}, VPF 600 m s^{-1}

Fringe size 63 µm

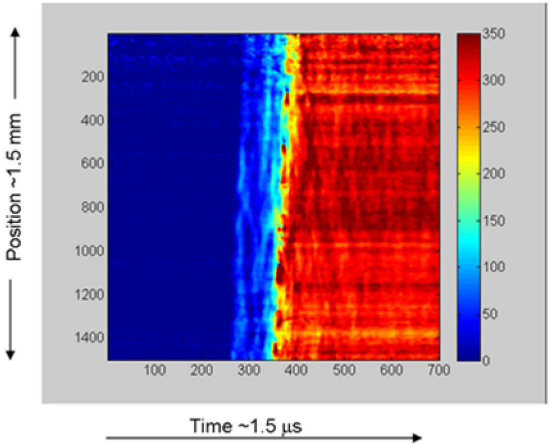
Static fringes



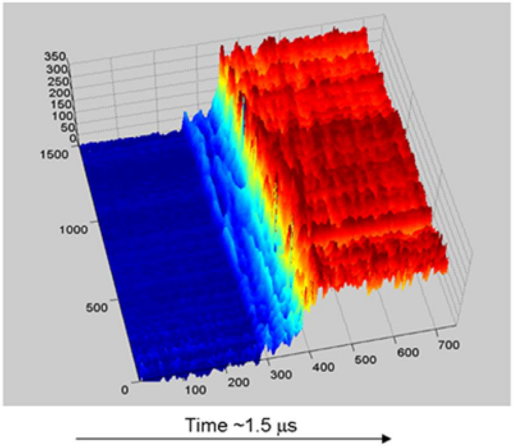
Dynamic fringes



Spatial velocity map ms^{-1}



3D velocity map ms^{-1}



Conclusions

- Line VISAR capability is being developed and has successfully been fielded on several metals.
- Flyer impact velocities are currently limited by gun vibration.
- Careful target preparation is necessary to avoid speckle.
- An optical resolution of better than 50 µm can be achieved with sensible depth of field.
- Careful analysis techniques and high fringe density is required to realise high resolution spatial velocity data.