

# VISAR ‘cross-hairs’: Simultaneous perpendicular line-imaging VISAR

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**Abstract.** Often the velocity measured at the rear surface of a dynamic compression target varies spatially, caused for instance by the tilt/curvature of a gas gun flyer, asymmetries in the magnetic field on a pulsed power driven experiment, or meso-scale heterogeneous targets. One way to monitor this in an experiment is to employ multiple point velocimetry techniques, but even with multiplexing this can become expensive in terms of hardware, in particular high speed sensors and scope channels. We report on the initial development of a multi-axis line-imaging VISAR system, which will record the spatial velocity along two orthogonal directions. Cylindrical optics are used to project a set of cross-hairs onto the target, maximising the use of input laser light; we then describe the image relay, interferometer configuration and alignment. This ‘quasi’ two dimensional system will become one of the principal diagnostics on the MACH (Mega Ampere Compression and Hydrodynamics) facility at Imperial College London, where the multi-axis measurement will help optimise strip-line design to achieve uniform ramp compression of targets.

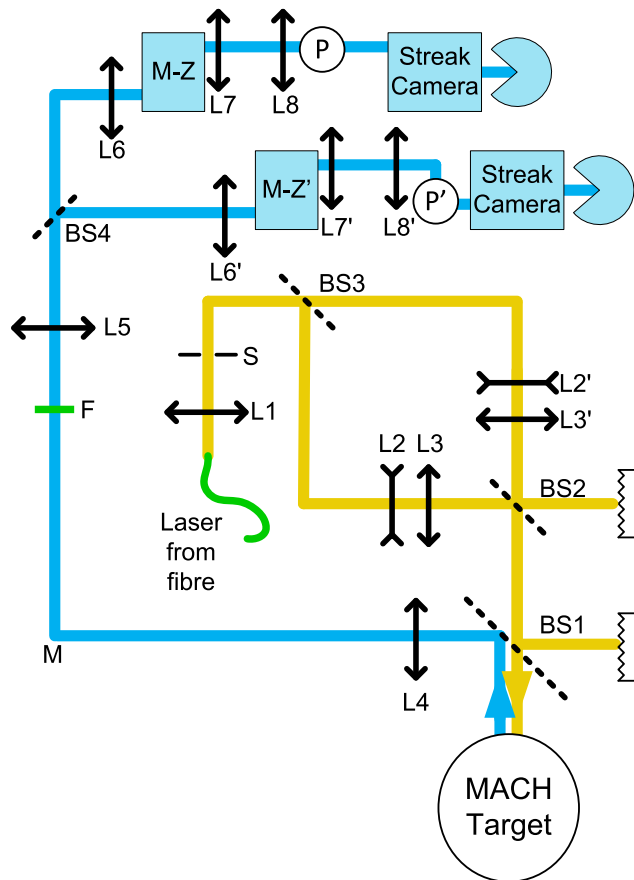
## 1. Introduction

We discuss the implementation and initial application of a spatially resolved velocity diagnostic, extending on ORVIS [1] and line-VISAR [2, 3] systems, as based on the original single point diagnostic by Barker [4]. Suitable for samples of varying diameters (5-20mm) this ‘quasi’ two dimensional diagnostic, is continuous in both temporal and spatial domains.

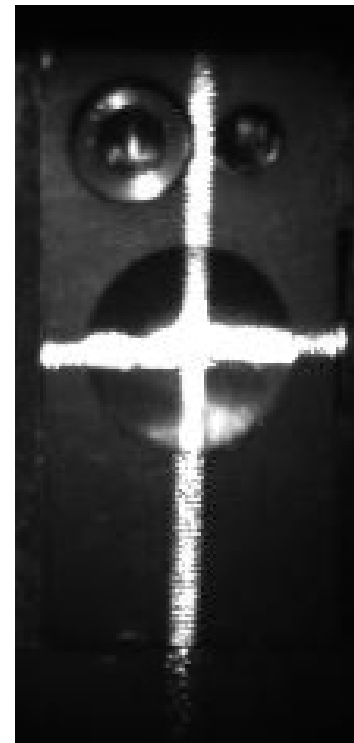
Isentropic Compression Experiments (ICE) such as those performed on the MACH (Mega Ampere Compression and Hydrodynamics) generator or Veloce [5] drive a stress wave through a sample in a strip-line configuration. The stress wave is created from the Lorentz force, generated by the self interacting current density and magnetic field,  $\mathbf{F} = \mathbf{J} \times \mathbf{B}$ .

The distribution of stress across the target has therefore a direct relation to the current density in the strip-line and the magnetic field, which is again linked to the current density. In the interest of creating a planar wave to conduct one-dimensional experiments similar to that which can be achieved in a plate-impact experiment, the strip-line design must be iteratively adjusted to produce the best results. While similar work has been completed on Veloce [5], experimental validation on individual generators is essential due to the complexity of current flow in three dimensional pulsed power experiments.





**Figure 1.** Layout of the X-VISAR diagnostic, excluding coupling of the laser to the fibre. The orange and blue lines refer to line-formation and image relay optics respectively.



**Figure 2.** Two lines form a cross-hair on the MACH target and recessed sample. This picture is taken through the image relay optics before the interferometer.

## 2. Implementation

X-VISAR is a set of cross-hairs illuminating the target, which is imaged to separate interferometers which apply orthogonal fringe combs to resolve perpendicular spatial information. Figure 1 describes the optical layout to the X-VISAR system, with the laser collimated into the fibre away from MACH. The probe laser is a Coherent Verdi V6, a 6W CW 532 nm DPSS laser which is coupled to a 100  $\mu\text{m}$ , 0.22NA multi-mode fibre for light transport to the line-formation optics. Before this fibre is a mechanical beam shutter, set to 500 ms duration.

The laser light from the fibre is collimated by L1 (150 mm), and spatially filtering it through S, a 20 mm square aperture, which serves to partially flatten the beam intensity profile at the cross-hairs. It is then split at a beam-splitter (BS3) and focussed through orthogonally mounted 30 mm cylindrical optics, a pair of -400 mm (L2) and +300 mm (L3) lenses. These are recombined at BS2 (where 1/2 the light is dumped), creating cross-hairs, and directed towards the target through the primary 3" beam splitter (BS1) to the target (figures 2 and 3). A periscope (not shown) turns the beam downwards into the target chamber, through a visible AR coated window. All optics in the system are 2" diameter unless otherwise stated, to increase the returned light.

The rear surface of the target is not a mirror finish, so predominantly specularly reflected light is collected at the first 500 mm achromat lens, L4 (positioned at  $\sim 900$  mm). The relay

then comprises of two 750 mm achromatic lenses (L5 and L6) to transfer the image to the interferometers (M-Z and M-Z') with a magnification of approximately 1.6 at the output beam splitter.

After the final lens it is possible to spatially filter out the unwanted line image, to improve contrast in the fringe comb and remove the region of double intensity at the centre of the cross-hair. A 1" diameter 1 nm FWHM laser line filter (F) is placed in the image relay (out of the image plane) to stop unwanted broadband light emission from the firing process propagating to the streak cameras.

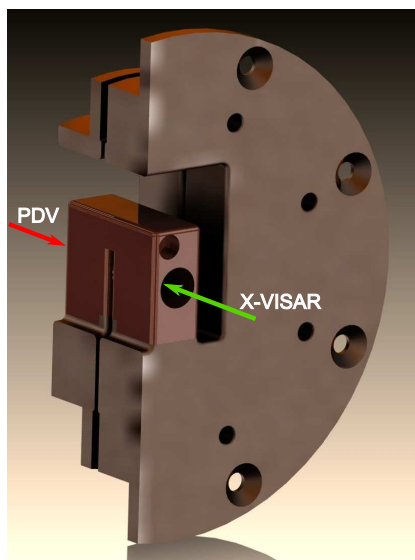
There is a clear aperture through a 2" diameter 200 mm etalon for a 7 mm diameter sample, with the angle between the paths in the interferometer as  $9.5^\circ$ . The interferometer, comprising of two 1" beam splitters, two 1" mirrors, a 150 mm linear translation stage (LTS) and etalon (suspended separate from LTS) is mounted on a removable breadboard for added stability and convenience.

The output beam splitters on the Mach-Zehnder interferometers are tilted to produce the fringe spacing and orientation required [3], in orthogonal directions prior to image rotation.

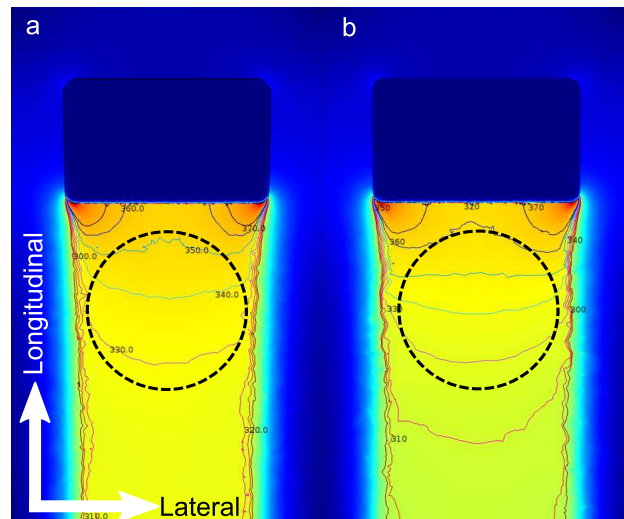
The image is then relayed to the streak camera by lenses L7 and L8 and enlarged as appropriate depending on the sample diameter and desired region of interest. At the periscope P' the image is rotated and directed into the streak camera, without the need for dove prisms, as opposed to the periscope P, where the image is not rotated.

A web-cam is used for live monitoring of the second interferometer output, through a 1% beam sampler. However a Thorlabs CMOS USB camera and flipped mirrors (between L7 and L8) is used for fringe spacing and contrast adjustments, image relay focusing, and precise locating of white light fringes. We are using two Kentech Streak cameras which have a nominal sweep time range of 10 ns – 3 ms, with the rear phosphor screen imaged by Digital SLR cameras.

Three 5 mW alignment lasers are used for replicating the probe beam, initial interferometer alignment, and a counter-propagating laser. The laser for interferometer alignment has a



**Figure 3.** A cutaway diagram of the MACH strip-line target mounted in its holder. The sample of  $\sim 1$  mm thick and recessed from the back surface.



**Figure 4.** Comsol modelling of magnetic field intensity (Tesla) with a 1% tapered (a) and untapered target. It is clear to see the region of larger uniform intensity in (a), where there are less contour lines. The dashed lines show sample location in this design.

removable beam expander, which aids in checking for clear apertures when laying down optics for the Mach-Zehnder interferometer. The counter-propagating beam (inserted between BS4 and L6) ensures the image relay optics (L4 and L5) are aligned correctly. It is also used to align M and BS1 such that the laser spot is co-centred with the cross-hairs at the target, and the small specular reflection propagates through BS1 and aligns with an iris near L1.

The entire experiment runs from one trigger, with <10 ns jitter between trigger unit and current arrival at the strip-line.

A quasi white light (WL) source is required to align the interferometer into a Mach-Zehnder configuration, by locating WL fringes the two paths of the interferometer are known to be equal in length [3]. WL was created from a white LED tile array, which acts as the reticle and line filters centred about 532 nm (1 nm and 10 nm FWHM) used to narrow the spectrum. A 300 mm camera lens was used to project an image through to the interferometer, which can be focussed to any point, usually the output beam-splitter. The location of the WL fringe point varied across a range of  $\sim 100 \mu\text{m}$  over many days, possibly due to temperature changes ( $\sim 5^\circ\text{C}$ ) and the linear translation stage requiring re-homing periodically. It cannot be considered ‘set and forget’ and demonstrates a need for monitoring and periodic re-alignment.

### 3. Preliminary applications of X-VISAR

By projecting a line of laser light as opposed to illuminating the entire region of interest it is intuitive that the light is used to a greater efficiency. Without the use of polarising optics, to form a cross-hair on the target, composed of two lines both incident normal to the target,  $1/2$  the laser light must be dumped. Compared to a traditional velocity diagnostic there is a further reduction of approximately  $1/2$  when the image is spatially filtered for each interferometer. Despite this reduction in light by a  $1/4$ , it is still viable alternative provided,

$$\frac{w}{r} < \frac{\pi}{8}, \quad (1)$$

where  $w$  is the width of the line/region of interest and  $r$  is the radius of the target. For MACH  $r \sim 3 \text{ mm}$ , so  $w < 1.2 \text{ mm}$ .

#### 3.1. Strip-line design

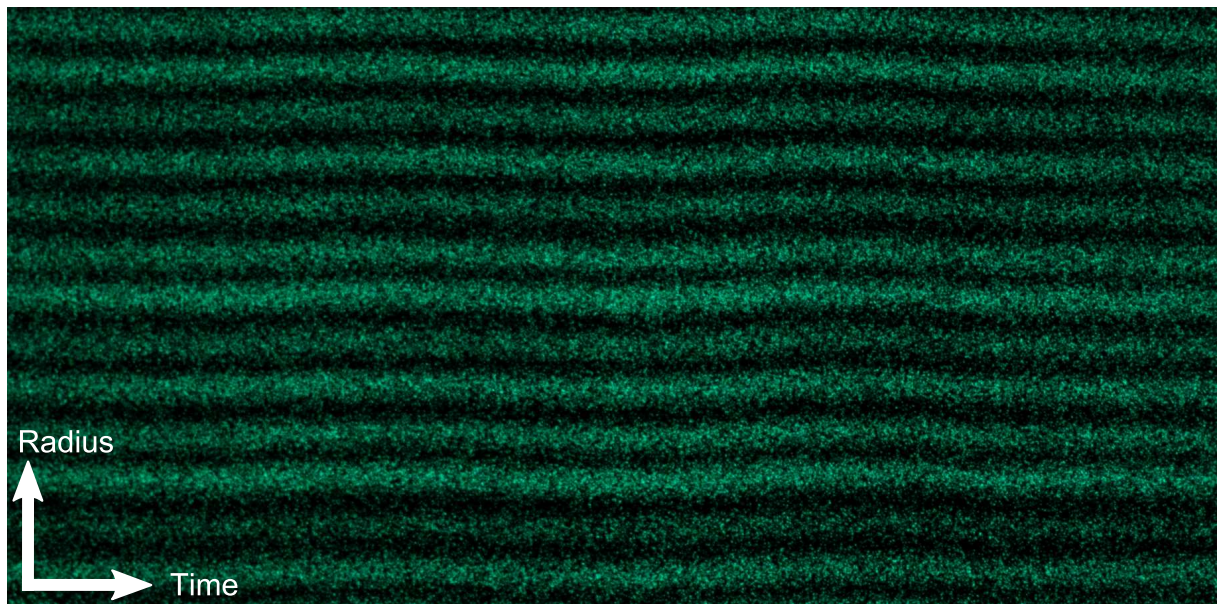
Simple and quick models of magnetic field intensity can be performed in Comsol, a finite element analysis software capable of simulating magnetic field densities (figure 4). In these models 65 kV was placed across a strip-line model created in SolidWorks. An iterative process of modelling and experimental validation is the basis of the target optimisation process for MACH. For instance by tapering the target [5], a larger region of uniform magnetic field strength is created (figure 4a), which is desired for stress wave flatness.

#### 3.2. Initial experiments

Initial experiments were performed on MACH at 60 kV charge voltage (significantly below the 80 kV design specification) on 2 mm thick copper samples. In these experiments, simultaneous VISAR and single point PDV were fielded. The PDV measurement is made using an up-shifted ‘3<sup>rd</sup> generation’ system, from a single collimating probe held off 5 mm away from the sample in a rapid prototyped target holder, aligned with the centre of the target.

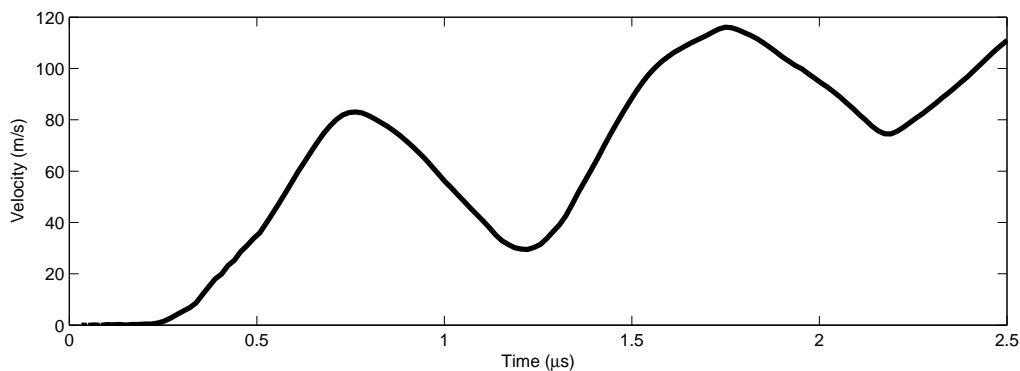
One channel of line-imaging VISAR is shown in figure 5 and a point Photon Doppler Velocimetry (PDV) probe from the opposite surface of the same load, shown in figure 6.

In figure 5 only half of the fringe comb has been imaged to the streak camera, corresponding to a radius across the target. This will provide higher spatial resolution for an experiment if the target has been characterised to be laterally symmetric. With a nominal streak setting of  $10 \mu\text{s}$  it can be seen that there is a change of phase or ‘fringe shift’ corresponding to increases in



**Figure 5.** Streaked fringes pre-analysis: the bottom of the image corresponds to the centre of the target, with the respective increase in radius and time labelled. The spatial resolution should reveal any radial velocity distributions resulting from the MACH drive.

velocity at two points (the velocity per fringe is approximately  $250 \text{ ms}^{-1}$ ), in rough agreement with the PDV data.



**Figure 6.** PDV trace from the opposing target. The oscillating wave structure is due to current ringing in the MACH generator.

The MACH current pulse used in these experiments was a decreasing sinusoid, taking  $\sim 555 \text{ ns}$  to reach current peak, with a total period to return through zero of approximately  $1.1 \mu\text{s}$ . At zero current the Lorentz force is at a minimum, increasing as the current increases negative. The ringing in the current pulse can be seen to match periodicity with the rear-surface velocity, which has a rise time of  $\sim 540 \text{ ns}$  and a full period of  $\sim 1 \mu\text{s}$ .

#### 4. Conclusion

An X-VISAR diagnostic on the MACH facility will be used to validate and help interrogate the optimum strip-line target design. The principal benefits being continuous temporal and spatial

recording unlike a two-dimensional imaging velocimeter [6] or multi point PDV [7] respectively. It makes better use of the available light which is safer, cheaper and reduces issues with laser speckle. MACH has the potential for a high rep rate operation, the X-VISAR only requiring three mirror re-alignments per shot, that can be completed under vacuum.

### Acknowledgements

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