Equation of state measurements using single Fabry-Perot velocimeter

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Abstract. Accurate measurement of projectile and free surface velocity of target is a crucial part of any high pressure physics experiments involving hyper velocity impact. Fabry Perot velocimeter (FPV) is a widely accepted technique for single surface velocity measurements. In the present work a possibility of using single FPV for two surface velocity measurements is experimentally explored. The laser light is launched in such a way that it illuminates both the surfaces under study and reflected light coming from the flyer as well as from the target is used to generate interference fringes. Therefore by recording fringe displacements due to Doppler shift in reflected light corresponding to movement of both the surfaces at different time instants, velocity profile of both target and projectile can be computed. This technique has been utilized for equation of state measurements of polyurethane based retro-reflective tape at 12 GPa and aluminum at 15 GPa. Measured peak particle velocities at the target-glass interface have been found in good agreement with the reported equation of state data.

1. Introduction
High pressure equations of state (EOS) studies by projectile impact often require the velocity measurement of minimum two surfaces. These measurements are commonly the velocity of projectile and particle velocity in target. Optical velocimeters [1, 2], which are based on measuring the Doppler shift in the light reflected from the moving surface are widely used for such measurements. One such technique viz. Fabry-Perot velocimeter (FPV) utilizes the property of Fabry-Perot interferometer that its fringe diameters are related to the wavelength of the incident light. Therefore by recording the time evolution of fringe diameters on a streak camera, velocity profile of the moving surface can be computed by knowing the equations of Fabry-Perot interferometer and Doppler shift. Since two streak cameras and two interferometers are required for measuring velocity of two surfaces, such measurements become complex and expensive. In the present work a possibility of using single FPV for two surface velocity measurements is demonstrated. The laser light is launched in such a way that it illuminates both the surfaces under study and reflected light coming from the flyer as well as from the target is used to generate interference fringes. In this arrangement, during the initial flyer movement, expanding fringes are expected to be seen in the streak record along with unchanged fringes produced by the fraction of light reflected from stationary target. After impact, these unchanged fringes would also show a jump according to the movement of target surface. Therefore by recording both fringe movements on same record, velocity profile of both the surfaces can be computed.
Here we report the experimental viability of this concept being investigated on an electrically exploding foil accelerator [3] (also known as electric gun) for EOS studies of polyurethane based retro-reflective tape and aluminum target.

2. Experimental Setup

To carry out high pressure impact experiments an 8 kJ portable electrically exploding foil accelerator has been utilized. The principle of electrically exploding foil accelerator (EEFA) is to use the energy initially stored in a fast capacitor bank to explode a thin metallic bridge foil sandwiched in between two dielectric sheets backed by a heavy tamper on one side and an appropriate size barrel on the other. Due to fast explosion, foil material expands and punches out a section of the dielectric sheet (flyer) positioned adjacent to it and drives it up in the barrel to suitably high velocities. The present system is capable in accelerating 10 mm diameter thin (~125-150 μm) dielectric or metal laminated dielectric flyers to a velocity of 2-4 km/s. The accelerated flyers made an impact to the target placed at the other side of the barrel covering only half the barrel area and leaving other half for the probing of flyer. Schematic of the experimental setup is shown in fig.1. The thin target sample is supported by a 1 mm thick glass plate to maintain its planarity till the time of impact. The experiments have been performed under symmetric impact condition by using the flyers made of 125 μm thick Kapton sheet with a layer of target material bonded over it.

![Figure 1. Schematic of experimental setup.](image_url)

A single frequency (532 nm) laser with beam diameter of 2.5 mm is launched partially over the target and partially over the flyer through a hole created in the mirror, which also direct the scattered light to a collimating lens (not shown in Fig.1). The collimated light is then used to generate the interference pattern using a Fabry-Perot etalon. The diameter of interference fringe produced by Fabry-Perot interferometer depends upon the wavelength of the incident light. Hence by considering the equation for relativistic Doppler shift and the equations of Fabry-Perot interferometer, velocity of moving projectile may be written in terms of the instantaneous diameter of Fabry-Perot fringes [4].

\[
v = \frac{c \lambda_1}{4d \mu} \left( i + D_{L,\text{f}} - D_{L,\text{i}} \right)
\]

Where \( \mu \) is the refractive index of the material present between the two mirrors of Fabry-Perot interferometer, which are separated by a distance ‘d’, and ‘i’ represents the total number of new fringes moved out from the center of the fringe pattern. \( D_{L,\text{f}} \) and \( D_{L,\text{i}} \) are the diameters of the innermost and next to innermost bright fringes produced by the Fabry-Perot interferometer when flyer/ target are
at rest. $D_{0\text{b}}$ is the instantaneous diameter of the innermost bright fringe while flyer/target are in motion. Hence if fringe diameters are known at different time instances velocity profile can be obtained by this relation. Time evolution of interference fringe diameters is recorded on a streak camera.

3. Experimental Results

Initial experiments have been carried out on a 30 µm thick retro-reflective tape, which is used because of its good reflective properties maintained even at the arrival of shock. The projectiles made of retro-reflective tape (30 µm) bonded over the Kapton sheet (125 µm) are accelerated in a barrel of length 2.0 mm. These projectiles impact on the target made of 30 µm thick retro-reflecting tape supported by 1 mm thick glass plate. Time evolution of fringe diameters with computed time resolved velocity profiles of both target and flyer are shown in Fig.2 (a). The initial part of the streak record shows the fringe movements according to flyer movement along with stationary fringes generated from the stationary target, at a later stage on impact these stationary fringes also show a jump corresponding to

![Figure 2. Streak record of FPV (top) and inferred velocity profiles (bottom) for (a) retro-reflective tape at 12 GPa (b) aluminum at 15 GPa. (t₁= Time at which flyer movement starts, t₂= Time at which target-glass boundary moves.)](image-url)
the movement of tape-glass interface. The analysis of obtained streak record shows a flyer velocity of 3.1 km/s and tape-glass interface peak velocity of 1.6 km/s. As retro-reflective tape is mostly made of polyurethane with a thin reflecting metal layer, the EOS of polyurethane as reported in reference-[5] is used for the theoretical prediction of interface velocity. On comparison measured peak interface velocity has been found to be 30% higher than this theoretical prediction which might be due to the presence of thin metallic layer embedded in the tape.

The results of experiments carried out in a similar way on 30 µm thick aluminum target are shown in Fig.2 (b). In these experiments though the major portion of the laser spot is focussed on target but due to loss in reflectivity on shock arrival the fringe intensities are low. The analysis of obtained streak record shows a flyer velocity of 2.3 km/s and aluminum-glass interface peak velocity of 1.2 km/s, which has been found to be matching well with the reported EOS data within experimental accuracies of 8%, which is higher in present case due to finite absolute error (±0.2 km/s) involved with the present FPV measurements, but at higher pressures or at higher velocities contribution of this error will become less significant.

4. Conclusions
In the present work experimental feasibility of using single FPV for two surface velocity measurements has been successfully demonstrated on retro-reflective tape and aluminum targets at 12 GPa and 15 GPa respectively. Single streak records showing the details of flyer and target velocity profiles have been obtained by illuminating the Fabry-Perot interferometer by laser light reflected from flyer and target both. In these experiments complete velocity profiles of both surfaces have been recorded by operating streak camera at slower speeds, but with some prior information about flyer velocity, streak camera may be operated at faster speeds to record only final flyer velocity and complete target velocity profile to achieve finer temporal details.

5. References
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