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INCREASE IN VELOCIMETER DEPTH OF FOCUS THROUGH ASTIGMATISM

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Frequently, velocimeter targets are illuminated by a laser beam passing through a hole in a mirror. This mirror is responsible for diverting returning light from a target lens to a velocity interferometer system for any reflector (VISAR). This mirror is often a significant distance from the target lens. Consequently, at certain target focus positions the returning light is strongly vignetted by the hole, causing a loss of signal. We find that we can prevent loss of signal and greatly increase the useful depth of focus by attaching a cylindrical lens to the target lens.

INTRODUCTION

The motion of targets impacted by projectiles is frequently measured by a velocity interferometer system for any reflector (VISAR)[1-4]. The targets are located in a tank to contain debris and are optically interrogated remotely, keeping expensive optics outside the tank. Quite often the target is illuminated by a laser passing through a hole in a mirror, with the reflected light from the target returning nearly along the same path. The light not passing through the hole is diverted to the interferometer where the velocity is determined from the Doppler shift of light. Reference [4] gives an excellent review of several VISAR designs and relationships of important design parameters. Some of these relationships are derived by considering the vignetting of the beam by the diameters of optical components. However, the reference does not discuss the vignetting that can occur from the hole in the mirror. That is the subject of this report.

METHOD

Figure 1 shows our arrangement of optics coupling light to and from the target. A f/1.8 50 mm focal length camera lens (L_1) focuses the laser illumination and semi-collimates the reflected light. Mirror M_2 separates returning light from the incoming laser beam by a small hole which allows the laser beam to pass. Because of the significant distance between the L_1 and M_2, for certain focus positions the returning light is imaged into the hole, eliminating or greatly reducing the signal reaching the interferometer (Fig. 2). We call this focus configuration *dead center*.

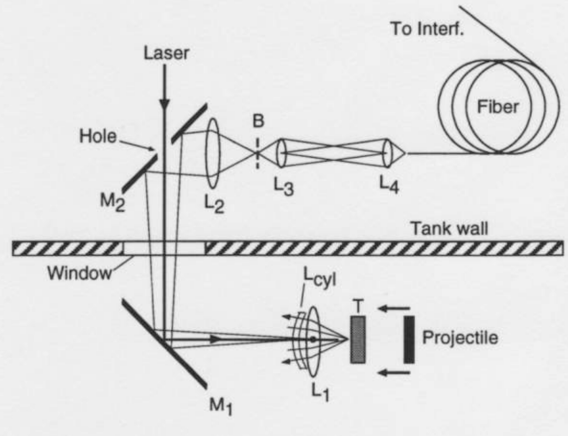

Figure 1. Target interface optics. Target (T) contained in tank is impacted by projectile from a gas gun[5]. Target is illuminated by an argon ion laser and the reflected light returned to the interferometer via optical fiber, 600 µm core diameter. A 3 mm hole in mirror M_2 separates laser and reflected light beams. L_1, L_2: f/1.8 50 mm focal length camera lenses; M_1 mirror; L_3, L_4: 10x microscope objectives. Telescope formed by L_2 and L_3 images aperture of L_1 to aperture of L_4 through intermediate image B. L_4 images aperture of L_3 onto fiber diameter. L_3-L_4 separation 22 cm. L_1-M_2 separation 110 cm. M_2-L_2 separation 8 cm. Cylindrical lens L_{cyl} (focal length -66 cm) is glued to front of L_1 to ameliorate vignetting by hole in mirror.

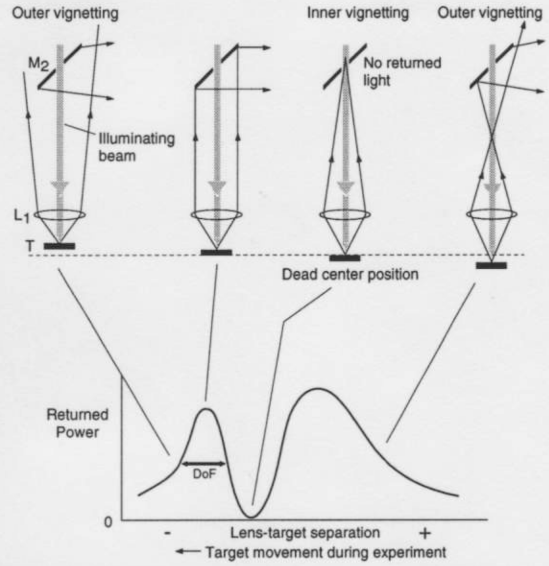

Figure 2. Vignetting during target travel, without cylindrical lens. Mirror (M_2) with hole collects light reflected from target (T), illuminated by laser beam passing through hole. Plot of returned power vs. target lens focus is suggestive only. As target moves toward lens (L_1), there is a position (dead center) where returned light is imaged into the hole and little is reflected by the mirror. To avoid this during the impact experiment, the initial separation must be set to the inside of dead center, reducing the useful depth of focus (DoF). The range reduction is greater than a factor of two because the returned power falls off more slowly on the outside of dead center.

Since impact by the projectile moves the target toward L_1, to avoid passing through dead center in the experiment the initial target position is set to the inside of dead center. However, this greatly reduces the depth of focus (DoF), defined as the range of travel where the returned power is at least 50% of maximum.

We discovered that attaching a simple cylindrical lens to the front of the target lens eliminates the loss of signal at dead center. Secondly, judicious choice of cylindrical focal length can produce a roughly uniform returned light power relationship with target focus. The combination of these two greatly extends the depth of focus. The reason is illustrated in Fig. 3, which diagrams the cross-section of the beam where it intersects M_2, when a cylindrical lens (L_{cyl}) is used. Only light in an annulus outside the hole and inside some effective vignetting diameter will pass on to the interferometer. Without L_{cyl}, the beam diameter at dead center is smaller than the hole, causing complete loss of signal. With L_{cyl}, the beam cross-section is generally elliptical, except for the dead center position where it is circular with a diameter exceeding the hole. Since the average diameter never falls below the hole diameter, the signal is not completely lost at dead center.

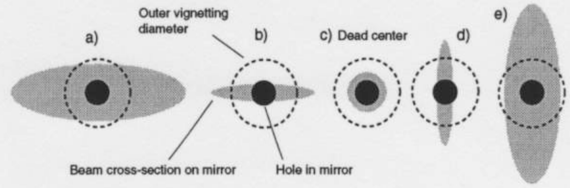

Figure 3. Returning beam cross-section on mirror M_2 when a cylindrical lens L_{cyl} is used, for several target lens focus positions. Dark circle is hole in mirror. Dashed circle is effective aperture beyond which diameter vignetting occurs. Thus, only the portion of returned light falling on the annulus between these two circles will enter interferometer. Without L_{cyl} (this case not shown), the beam cross-section at dead center is smaller than hole. With L_{cyl}, the average cross-section diameter is never less than the hole diameter, preventing loss of signal at dead center. Judicious choice of cylinder focal length can produce an intersection between the annulus and the beam cross-section which is approximately independent of target focus, creating uniform returned power.

Figure 4 is a measurement of the returned power versus target lens focus, achieved by twisting the camera lens (L_1) focusing ring. The target was semi-polished stainless steel, which was the witness plate for an equation of state experiment to be performed. Without L_{cyl}, the light drops to zero at one position. After gluing the cylindrical lens to the front of the camera lens we repeated the measurement. No drop in power was observed at the previous dead center position. Secondly, for a -66 cm cylindrical focal length found empirically, the power was roughly uniform for the entire range of focus accessible by twisting the focusing ring. Apparently, the cross-section of the beam overlapping with the accepting annulus of M_2 was roughly constant. Such a uniformity had never been achieved with our target optics without L_{cyl}.

In VISAR experiments the velocity is determined by counting fringe shifts from an interferometer output. If there is a break in the data, these shifts become ambiguous to an integer number of fringes. To avoid such a break, the target position must start inside the dead center position, since it will be pushed toward the lens by the impact. In Fig. 4 this would correspond to a position ≈2 mm. Since the power drops by to 50% of local maximum at the 0 mm mark, the depth of focus would be 2 mm. With L_{cyl}, the data of Fig. 4 indicate the depth of focus is beyond 6 mm, and quite likely as great as 10 to 12 mm. The average power is lower in the L_{cyl} case, but only by a factor of two. The lack of fluctuation in the power is more important for good recording than its absolute value.

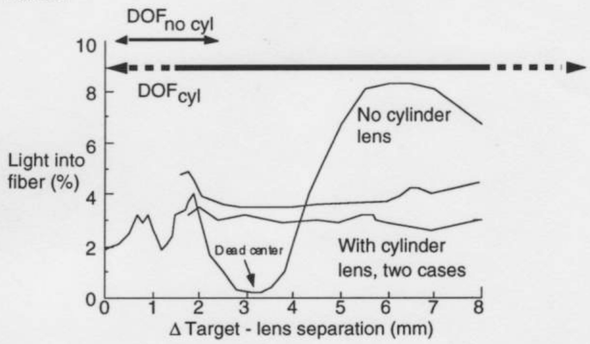

Figure 4. Measured returned light power versus target lens focus position, for the case of no cylinder lens L_{cyl} (thin curve), and two cases with L_{cyl} (bold curves). The horizontal axis is the increase in camera lens (L_1) distance from target (by twisting its focusing ring). Power out of interferometer fiber was divided by power entering tank window. Target was semi-polished stainless steel. When L_{cyl} was glued to camera lens front, it restricted focusing ring movement to >1.7 mm. Fluctuations in signal for <2 mm are caused by growing image of surface scratches as lens approaches ∞:1 conjugate ratio. Double arrowed bars indicate practical depth of focus ranges (DoF) for the cylinder and non-cylinder cases. Dashed portions are estimated. $DoF_{no\ cyl}$ must be on inside of dead center to avoid loss of signal as target moves toward lens after impact.

We note that the holed mirrors discussed in Ref. [4] are positioned much closer to the target lens than in our configuration. This reduces the focus dependence of hole vignetting for a diffusively scattering target (Fig. 5a). In our arrangement, where the holed mirror is outside of a tank, a system of relay lenses could be used to image the target lens closer to the holed mirror.

However, we prefer to use specularly reflective targets to increase the returned light power. Consequently, a short distance between the holed mirror and target lens is a disadvantage because for specular targets normal to the beam, the beam returns along the same path and is strongly vignetted by the hole (Fig. 5b). Insertion of a cylindrical lens would not significantly help in this case. Thus, we prefer to use a larger target-mirror separation and the use of a cylindrical lens to lessen hole vignetting.

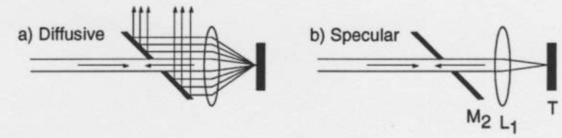

Figure 5. Hole vignetting when mirror (M_2) is close to lens (L_1) of target (T). a) For a diffusively scattering target the vignetting is not substantial and is roughly independent of target position. b) For a specularly reflective target oriented normal to the illuminating beam the vignetting is complete when the target is at the focal point of the lens. An astigmatic lens would not significantly reduce hole vignetting when the mirror is close to the lens.

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