Increase in velocimeter depth of focus through astigmatism

David J. Erskine
Lawrence Livermore National Laboratory, Livermore, California 94551

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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. 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. This note finds that the loss of signal can be prevented and that the useful depth can be greatly increased by attaching a cylindrical lens to the target lens. © *1995 American Institute of Physics.*

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 the relationships of important design parameters. Some of these relationships are derived by considering the vignetting of the beam by the diameters of the optical components. However, Ref. 4 does not discuss the vignetting that can occur from the hole in the mirror. That is the subject of this note.

Figure 1 shows the 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 semicollimates 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 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). This is called the *dead center* focus configuration. The impact by the projectile moves the target toward L_1. To avoid passing through the dead center in the experiment, the initial target position is set to the inside of the 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 the maximum power.

It was discovered that attaching a simple cylindrical lens to the front of the target lens eliminates the loss of signal at the dead center. Second, the judicious choice of cylindrical focal length can produce a light power relationship that is roughly uniform with target focus. These factors greatly ex-

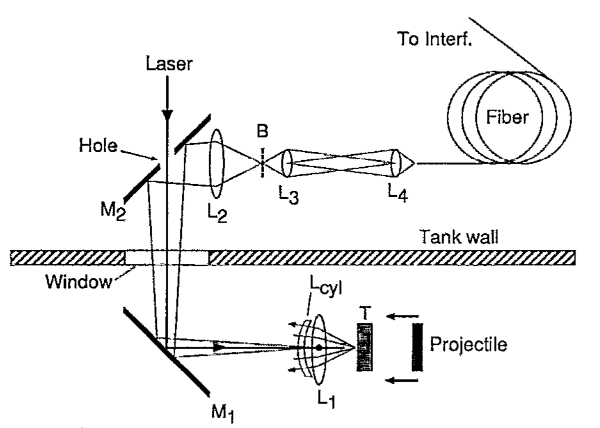

FIG. 1. Target interface optics. The target (T) contained in the tank is impacted by a projectile from a gas gun (Ref. 5). The target is illuminated by an argon ion laser and the reflected light returned to the interferometer via an optical fiber with a 600 μm core diameter. A 3 mm hole in mirror M_2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

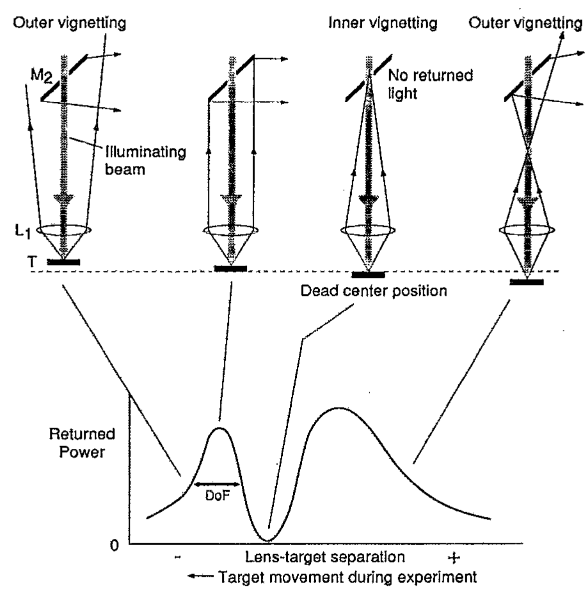

FIG. 2. Vignetting during target travel, without a cylindrical lens. The mirror (M_2) with a hole collects light reflected from target (T), illuminated by the laser beam passing through the hole. The plot of the returned power vs target lens focus is only suggestive. As the target moves toward lens (L_1), 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 the dead center, reducing the useful depth of focus. The range reduction is greater than a factor of 2 because the returned power falls off more slowly on the outside of the dead center.

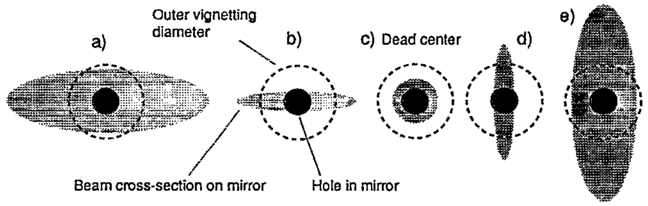

FIG. 3. The returning beam cross section on mirror M_2 when a cylindrical lens L_{cyl} is used, for several target lens focus positions. The dark circle is the hole in the mirror. The dashed circle is the effective aperture beyond which diameter vignetting occurs. Thus, only the portion of returned light falling on the annulus between these two circles will enter the interferometer. Without L_{cyl} (this case is not shown), the beam cross section at the dead center is smaller than the hole. With L_{cyl}, the average cross-section diameter is never less than the hole diameter, preventing a total loss of signal at the dead center. The judicious choice of a 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.

tend the DOF. The reason for this 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 the dead center is smaller than the hole, causing a 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 the dead center.

Figure 4 is a measurement of the returned power vs target lens focus, achieved by twisting the camera lens (L_1) focusing ring. The target was semipolished stainless steel, which was the witness plate for an equation of state experiment that was 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.

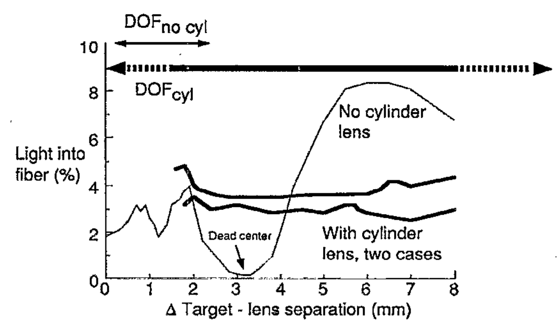

FIG. 4. Measured returned light power vs target lens focus position, for the case where this is no cylinder lens L_{cyl} (thin curve), and two cases with L_{cyl} (bold curves). The horizontal axis is the increase in camera lens (L_1) distance from the target (by twisting its focusing ring). The power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

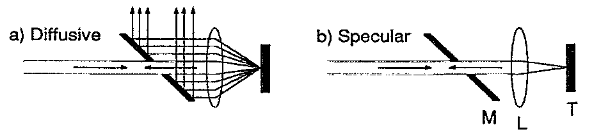

FIG. 5. Hole vignetting when mirror (M_2) is close to the lens (L_1) of target (T). (a) For a diffusively scattering target the vignetting is not substantial and is roughly independent of target position. (b) For a specularly reflective target oriented normal to the illuminating beam the vignetting is 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.

No drop in power was observed at the previous dead center position. Second, 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 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 of ≈ 2 mm. Since the power drops to 50% of the local maximum at the 0 mm mark, the DOF would be 2 mm. With L_{cyl}, the data of Fig. 4 indicate that the DOF is beyond 6 mm, and is quite likely as great as 10–12 mm. The average power is lower in the L_{cyl} case, but only by a factor of 2. The lack of fluctuation in the power is more important for good recording than its absolute value.

We note that the mirrors with holes 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. 5(a)]. In our arrangement, where the mirror with a hole is outside of a tank, a system of relay lenses could be used to image the target lens closer to the mirror.

However, we prefer to use specularly reflective targets to increase the returned light power. Consequently, a short distance between the mirror with a hole and the 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. 5(b)]. The insertion of a cylindrical lens would not significantly help in this case. Thus, weprefer to use a larger target–mirror separation and a cylindrical lens to lessen hole vignetting.

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