OPTIMIZATION OF A VISAR FOR MEASURING FLYER-PLATE VELOCITIES

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ABSTRACT: The laser, target, and cavity of a VISAR (velocity interferometer) have been connected with fibers, and then the collection efficiency has been maximized for 1-mm of target travel.

INTRODUCTION

VISAR (Velocity Interferometer System for Any Reflector^{1,2,3}) is commonly used for measuring flyer-plate velocities up to 6 km/s. Flyer plates can travel as much as 1 mm, which is large compared to usual depth-of-focus requirements for VISARs. Flyer plates are explosively driven, or driven by some other very energetic means; as such, they must be tested in a chamber, which will contain the explosion. Routing the laser beam to the chamber and the signal beam to the VISAR can be done safely and easily in multi-mode optical fibers.

We have optimized a fiber-coupled VISAR system for measuring flyer-plate velocities (Fig. 1). This system gives constant signal levels over the full travel of the flyer plate. Furthermore, the signal-collection efficiency is maximized, which allows use of a moderately sized laser. We also have optimized the VISAR cavity so it does not limit the system efficiency while giving a velocity sensitivity of about 1 km/s per fringe.

BACKGROUND

Two recent theoretical papers inspired this work. One proposes using faster lenses to collect more of the signal scattered off the target so lower powered lasers could be used⁴. This requires a small linear correction in the velocity calculation. The second paper optimizes the design of a fiber-coupled VISAR system so it can be used with targets that travel long distances⁵. This design gives a constant signal level over the travel, while maximizing the collected signal. The design generally requires that the distances between lenses, detectors, etc. be minimized.

THE SYSTEM DESIGN

We designed a prototype system specifically for measuring the velocity of large flyer plates. A velocity sensitivity of $VPF = 1$

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km/s was needed, and the depth of focus had to be $DOF = 1 \text{ mm}$. We also wanted to use the smallest possible argon-ion laser, so maximizing the signal collection efficiency over the depth of focus was important.

The logic driving the design: Figure 2 is a sketch of the light beams in the region of the target; Figure 3 shows the associated optics. As drawn, the collection lens collects a constant amount of the back-scattered laser light over the whole depth of focus. The two fiber ends are both imaged at the center of the travel. As shown in the figure, the laser spot diameter increases as the target moves inside or outside of focus. The collecting volume does the opposite.

It is fairly clear from Fig. 2 that smaller values for the laser parameters, d_{lr} and na_{lr} would keep the laser spot size smaller, which allows a longer DOF , or a faster collecting lens to be used. It is also apparent that larger values of d_{sig} and na_{sig} accomplish the same thing. More precisely, we can say that the Lagrange invariant of the laser fiber, $\mathcal{L}_{lr} \equiv 1/(2d_{lr}na_{lr})$, should be minimized, and the Lagrange invariant (a.k.a. optical invariant or entendu) of the signal fiber, $\mathcal{L}_{sig} \equiv 1/(2d_{sig}na_{sig})$, should be maximized⁵.

There is a theorem in optics that says that in a cascaded optical system, the Lagrange invariant of succeeding components cannot be larger than those preceding. If it is, the beam will be vignetted (This is derived from the theorem of conservation of energy). Thus, the Lagrange invariant of the signal collection system must meet the condition $\mathcal{L}_{coll. \text{ lens}} \leq \mathcal{L}_{sig} \leq \mathcal{L}_{cavity}$.

Design sequence: There were some fairly firm requirements in the region of the interferometer, so that subsystem had to be designed first. Its Lagrange invariant, $\mathcal{L}_{cavity}$, was then calculated, and using the inequality described in the previous paragraph, a signal fiber could be chosen. The laser fiber also needed to be chosen before the target-coupling optics could be designed.

The cavity optics and signal fiber: The VISAR cavity region is sketched in Fig. 4. The unequal-leg Michelson interferometer had to give a velocity sensitivity of $VPF = 1 \text{ km/s}$. Secondarily, its Lagrange invariant, $\mathcal{L}_{cavity} = L_{r-d}/(d_r d_d)$ needed to be minimized so the signal collection efficiency could be maximized.

The velocity sensitivity suggested that the unequal-leg Michelson interferometer should be made in the form of a delay-bar^{1,3}, with an optical path length difference of $OPD \approx 77 \text{ mm}$. A photomultiplier tube was the obvious detector choice, because they are very fast, they amplify the signal, and have a large sensitive area ($d_{del} = 10 \text{ mm}$). For convenience, the relay lens was chosen to be the same size. Therefore, the minimum length between the relay lens and the detector is about⁵ $L_{r-d} \approx 200 \text{ mm}$, and the Lagrange invariant is $\mathcal{L}_{cavity} = 2 \text{ mm}^{-1}$, so that of the fiber must be less: $\mathcal{L}_{sig} \leq 2/\text{mm}$. We had a fiber on hand that would meet this criteria $d_{sig} = 200 \text{ }\mu\text{m}$ and $na_{sig} =$

0.37.

The laser fiber: The laser fiber should have the largest Lagrange invariant possible. Nothing constrains the numerical aperture except availability, so choosing the lowest generally available value makes sense: e.g., $na_{lr}=0.11$. The laser fiber must be able to carry an adequate amount of laser power without damage or thermal run-away; this dictates the minimum acceptable diameter, d_{lr} . We used a small multimode fiber with $d_{lr} = 50 \mu m$.

Coupling to the target: For this design, the distance from the target to the collection lens is the only free variable in the target region. Once this length was chosen (the so called back-off distance), the depth of focus and fiber parameters defined the other focal lengths and lens spacings⁵. The parameters are shown in Fig. 3, with the signal collection cone being $F/3.4$.

EXPERIMENTAL RESULTS

We ran two different tests to prove out this concept: In one, the target was purposely placed outside the depth of focus so it would fly through the full focal region and hence, we could measure it. The depth of focus over which the signal was constant was $DOF \approx 1.1 mm$.

The data from the second test is presented here. In this test we placed the slapper at the center of the allowable travel so the starting position would be known. The difference voltages from the photomultipliers² are shown in Figs. 5a and 5b. Remember that there is a phase difference of a quarter of a wave between the "S" and "P" polarizations¹; as such, the voltages in Figs. 5a and 5b are proportional to the sine and the cosine of the phase. If these voltages are plotted against each other (Fig. 5c), the phase can be read out directly³ as angle. In Fig. 5c the radius of the figure remains constant within the DOF . This definitely increases the accuracy of the phase angle measurement, which increases the accuracy of the calculated velocity. Figure 6 shows the reduced data; the velocity and displacement. Equating times between Figs. 5a & 5b and Fig. 6 shows that the signal was constant for a travel of about 0.5 mm, just as expected.

The future: These "proof-of-principle" experiments were done with fibers and lenses available in our laboratory. The results seem to validate the theory.

If one wanted a more efficient system, a larger signal fiber and faster lenses would be needed. For example, a fiber with $d_{sig} = 400 \mu m$ and $na_{sig} = .625$ matches the Lagrange invariant of the VISAR cavity. This would allow a faster, $F/1.14$, collection lens to be used for the 1-mm depth of focus. Using these components would increase the signal collection efficiency eight-fold.

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- ⁵ Sweatt, *Rev Sci Instrum*, 63(5): to be pub. (1992)

FIGURES

- Fig. 1. Fiber-coupled VISAR system.
- Fig. 2. Close-up of beams in target region.
- Fig. 3. Target coupling optics.
- Fig. 4. Subsystem containing VISAR cavity.
- Fig. 5. Raw VISAR data; signals plotted vs. time in 5a & 5b, and plotted vs. each other in 5c.
- Fig. 6. Reduced data, including velocity and displacement.

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DAT:SWEATT.D02
~~19-MAR-82~~
10:06:49

Leg 1
VPF = 1.0000

Figs 5a & 5b

Fig 5c

TIME, NS

dat:SWEATT.V02

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Fig 6

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