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USE OF THE SMARTT INTERFEROMETER AS AN ALIGNMENT TOOL FOR INFRARED LASER SYSTEMS*

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Abstract

The ability to minimize the pointing and focusing errors at the focal plane is crucial in many applications involving infrared laser systems. This is particularly the case for systems involving multiple beams reaching the focal plane, as in the case of the LASL CO_2 laser fusion systems. For example, the LASL Helios CO_2 Laser Fusion System has eight 34-cm diameter beams each with an f number of approximately 2.4 coming to focus, the last element being an off-aperture parabola with a focal length of approximately 77.3 cm. The design tolerance for pointing accuracy is $\pm$ 25 microns and for focusing accuracy is $\pm$ 50 microns for the Helios system. The Smartt Interferometer shows promise of not only evaluating the optical quality of the beam, but it can be used to align the beam to the tolerance levels stated above. This paper describes the procedure, as well as experimental results obtained, which show that pointing accuracies of $\pm$12.5 microns and focusing accuracies of $\pm$25 microns are obtained at the focus of a CO_2 laser beam in a setup which duplicates the target region of the Helios CO_2 Laser Fusion System. The backlash in the x-y-z stage micrometer used in the experiment is estimated to be 10 microns, though precautions were taken to move in the same direction throughout an experimental run.

Introduction

The necessity to be at the proper focal plane is essential for both imaging (where the contrast and hence modulation transfer function properties come into play) and focusing (where the Strehl ratio, encircled energy and irradiance distributions play a key role) applications for optical devices creating a real focus at the image plane. This becomes even more necessary when multiple beam systems are involved. In complex systems like the CO_2 laser fusion systems, it would be very helpful, if in addition to locating the proper target plane, the optical properties of the beam can also be determined at the same time at that plane. Interferometry using the Smartt interferometer[1] appears to provide a scheme for achieving both of these objectives stated above. The experimental setup, the alignment and the evaluation procedures, as well as the results obtained using this method are described in the paper.

The Infrared Smartt Interferometer

The Smartt interferometer is a common path interferometer, conceived and developed by R. N. Smartt and disclosed jointly with J. Strong.[1,2] The infrared version is schematically shown in Figure 1. Collimated light from an infrared laser is brought to focus by the lens under test, and the Smartt plate which is at the focus creates a reference wave in addition to the beam under test. The vidicon lens reimages the pupil (which contains the resulting interference pattern) onto a pyroelectric vidicon, yielding a video signal that is displayed on a video monitor. The Smartt plate is mounted on x-y-z stage so that tilt and defocus can be easily introduced. Basically, it is a two-beam interferometer in which the reference beam is generated by the diffraction from a small pinhole in the Smartt plate (Figure 1) at the focus of the beam under test. The plate, ideally does not introduce any aberrations of its own, and by some kind of coating or doping of the silicon, (which has been the material for the plate for the two kinds of Smartt plates produced so far), the transmission of the test beam is adjusted for maximum fringe contrast. The two beams interfare and yield fringes of constant optical path difference, similar to those obtained with a Twyman-Green interferometer.

The infrared Smartt interferometer was first described by J. C. Wyant et al.[3,4,5] These papers give an excellent description of the various theoretical and practical aspects of building and using a Smartt Interferometer. The Smartt plate described by them used a thin silicon wafer with a gold, semi-transparent 200 A-thick gold coating with a transmittance of .002, and the pinhole diameter was 65 microns.

The Smartt plate used in the Los Alamos experiments has a 40 microns diameter hole in a 13 microns thick silicon wafer. The process for getting the plate uses a current limiting electroetch based on a technique described by Meeks[6] and developed by R. Hammond and A. Gibbs of the Los Alamos Scientific Laboratory. We hope to describe this technique in a

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future paper in greater detail. Figure 2 shows a photograph of the infrared Smartt interferometer used at Los Alamos.

Use of the Smartt Interferometer as an Alignment Tool

Figure 3 shows the laboratory setup schematically. The chopped beam from a Sylvania 941 laser is cleaned by a spatial filter and expanded to fill the aperture of the collimating mirror. The collimated beam is brought to focus by a turning flat off-aperture focusing parabola combination. The Smartt plate is at the focus and is capable of three orthogonal displacements in the x, y and z directions as it is mounted on an x-y-z stage. The pyroelectric vidicon lens images the pupil (which contains the Smartt interferogram) onto the vidicon and the resultant video signal is displayed in real time on the monitor and the video cassette recorder is used to record the results for later analysis. It should be pointed out that the turning flat and the focusing parabola used in this experiment are identical to the corresponding elements in the Helios CO_2 Laser Fusion System and the laboratory setup duplicates the target chamber geometry of one of the eight beams in the Helios CO_2 Laser Fusion System. Figure 4 shows a photograph of the actual laboratory setup.

For beams with very little aberrations, the Smartt interferometer produces circular dark and white fringes in and out of focus, and straight line fringes when the interferometer is in the focal plane but with tilt introduced in the x or y directions. Consequently, it is tempting to try to locate the position of the null fringes to locate focus. The problem of locating the proper focus is equivalent to determining the location of a point in space and hence the error in locating it along z axis can be considered a focus error and along the x and y axes as the pointing error. However, in practice, it is very difficult to pinpoint the location of the null fringe along the z axis (as the appearance in the monitor does not change very much over a range of $\pm$ 150 microns along the z axis) and this difficulty complicates the problem of the pointing also.

There is an interesting solution to this dilemma, which appears to result in a situation where the accuracy is limited only by the inaccuracies in the x-y-z stage (like backlash, etc.). The location of the focal plane is accomplished in the following way: as shown in Figure 5, if we introduce a tilt in the y direction nearly vertical fringes are obtained and if we now move the Smartt plate in the $\pm$ z direction, circular fringes of opposite curvatures are obtained. Thus the location of the focal plane can be obtained iteratively. In practice, in real time, (as the Smartt plate is moved along the z axis), it was easy to detect the change in curvature to within $\pm$ 15 microns. Having located the focal plane thus, a deliberate tilt is introduced in the $\mp$ y direction. (The same argument applies to a tilt in the - y direction.) As shown in Figure 6, the shape of the straight line fringes is in opposite directions across the focal plane.** In real time, it was easy to get to the proper pointing to within $\pm$ 12.5 microns. Figure 7 shows the appearance of the fringe pattern when a deliberate tilt is introduced in the x direction. Figures 8-10 show the actual fringes obtained in the laboratory. It should be pointed out that when the experiment is actually done in the laboratory, when all the motions are taking place in a dynamic fashion, the changes in curvature and the changes in shape of the fringes are observed with greater sensitivity than when the static photograph is taken.

Thus, with good beams, this technique appears to easily meet the focusing alignments for large laser systems. We deliberately introduced aberrations in the beam (roughly 2 wavelengths peak-to-valley, consisting of astigmatism, coma and spherical aberrations) and verified that the above technique for alignment worked well. The additional complexity introduced with aberrated beams (especially with large aberrations), has to do with the fact that the choice of the proper plane depends on both the types of aberrations in the beam and what the optimum criteria for the focal plane is (this depends on the application). It is in this regard that this technique appears to have definite advantages over indirect techniques like the autocollimating technique commonly referred to as the Hartmann method,[7] where it is not possible to quantify the types of aberrations or predict quantities like the Strehl ratio, encircled energy, etc. The automatic feature of this technique is that an interferogram is obtained and this can be reduced to provide the parameters of interest, using techniques described in other articles by J. Loomis[8] and V. K. Viswanathan et al.[9] In this connection, it is worth pointing out that Koliopolous[4,5] has shown that when the diameter of the Smartt pinholes is less than half of the Airy disc diameter produced by an unaberrated beam, the reference beam in the Smartt interferometer contributes negligible aberrations of its own.

** Here a deliberate tilt was introduced in the y direction and the Smartt plate was moved in the $\pm$ x direction.

In Figures 5 through 7, reading from top to bottom, the motion starts in the positive direction, goes through focus and on to the negative direction along the z, x, and y axes respectively.

In Figure 8, the successive differences in displacement are 2.5 microns and in Figures 9 and 10, the successive diffraction in displacement are 12.5 microns. The tile value for all these figures is 100 microns.

Experimental Comparisons Between Hartmann Scheme and Smartt Interferometer Alignment Technique

We tried both methods with a good beam in an identical laboratory setup described previously. We found that we could locate the focus to ± 15 microns and the pointing to ± 12.5 microns for the Smartt technique. The corresponding numbers we obtained for the Hartmann technique were: ± 150 microns for focus and 25 microns for pointing. In the Helios CO_2 Laser System, I. Liberman and R. F. Benjamin[10] obtained an average pointing error of 34 microns.

Conclusions

1. The alignment technique described above using the infrared Smartt interferometer shows promise of meeting the focusing and pointing accuracies needed in large laser systems like the CO_2 laser fusion systems.
2. The technique shows promise of easy application to situations where there is a need to point and focus different beams (in multiple beam laser systems), at different locations in space.
3. The method has definite advantages over indirect techniques in that the optical properties of the beam can be obtained at the focal plane in question.

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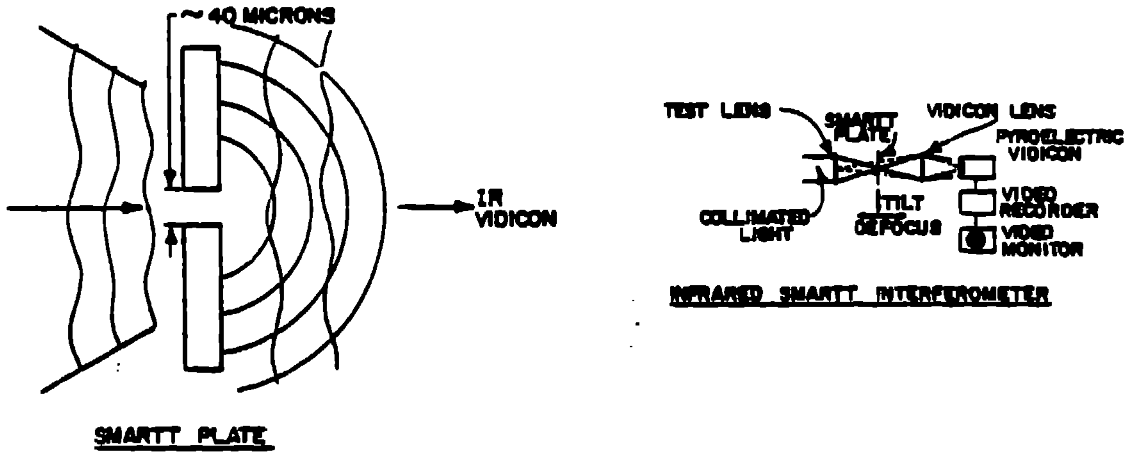


Figure 1

Figure 2

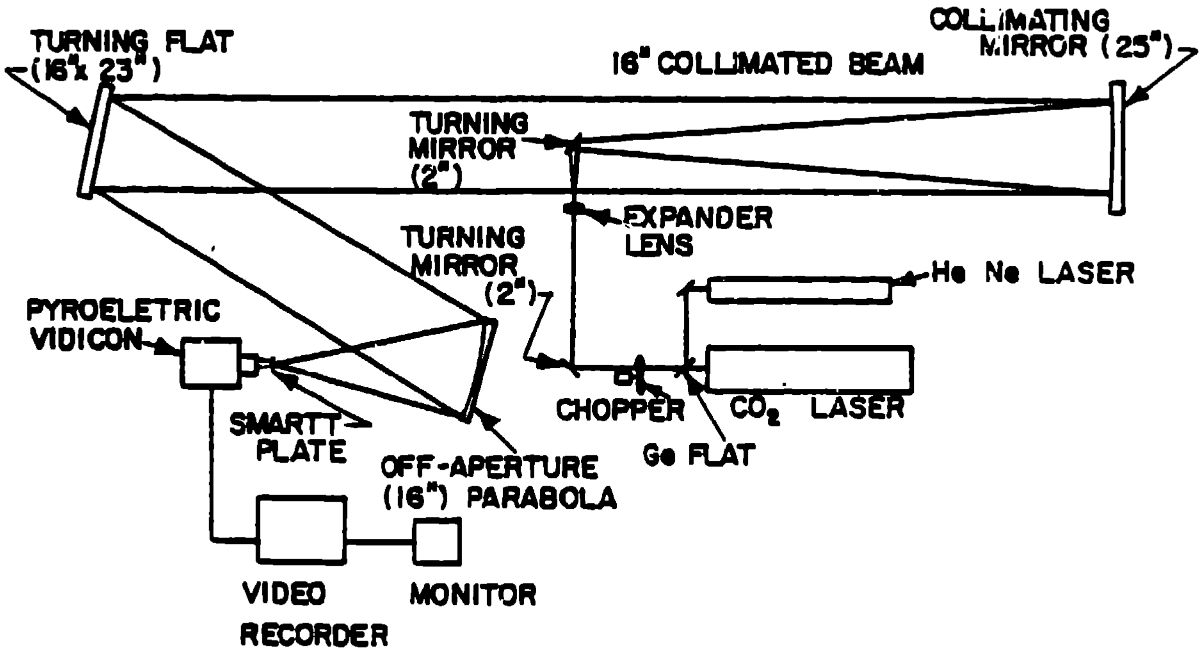
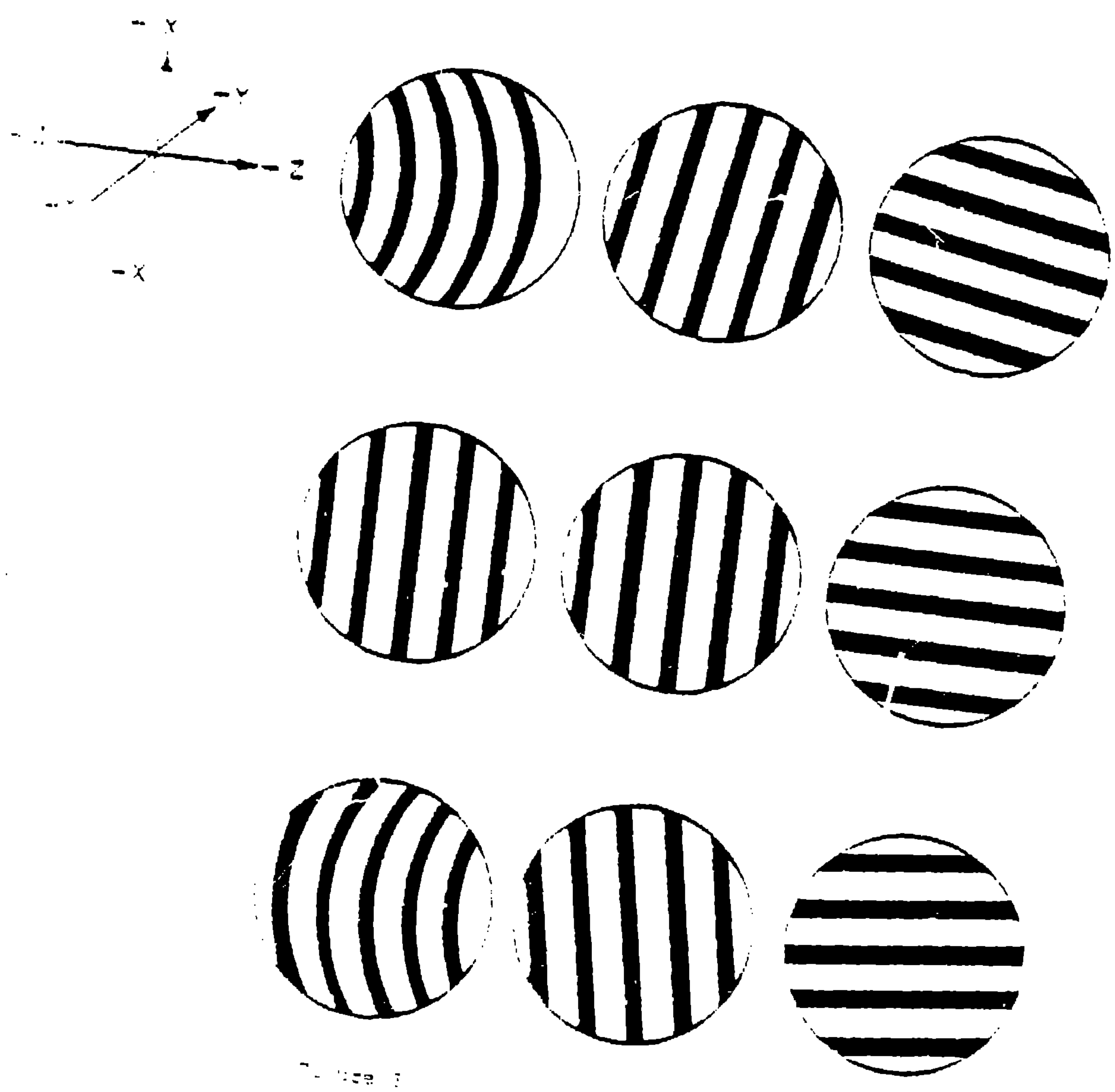


Figure 3

Figure 4



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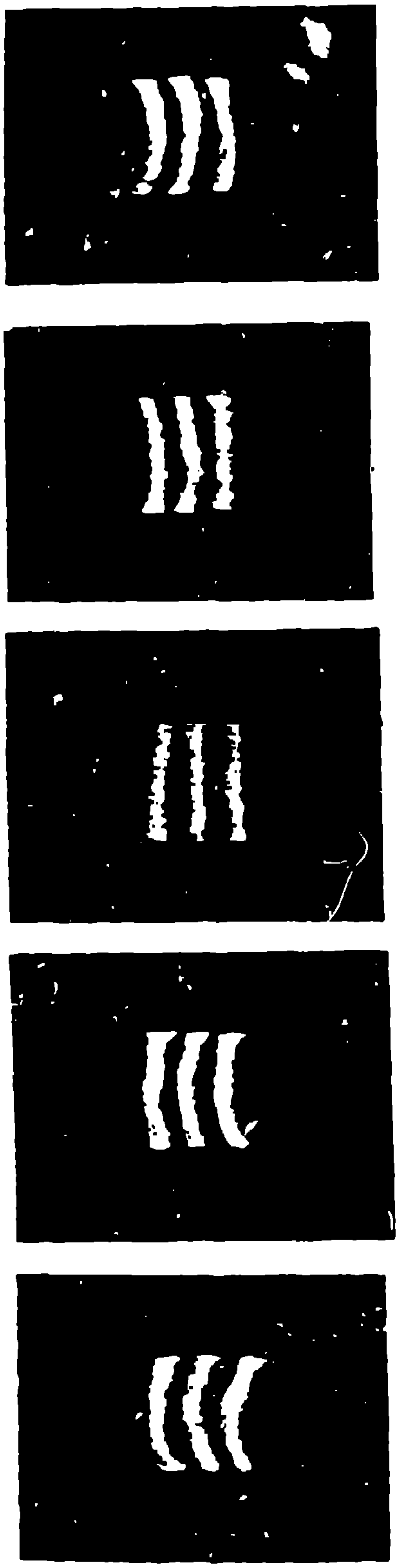

Figure 4

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