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LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

LASER DISC COMPUTER SIMULATION

John B. Sonderman

Ann T. Glassman

May 14, 1974

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LASER DISC COMPUTER SIMULATION

John Sonderman

Ann Glassman

May 6, 1974

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Introduction:

The Optics Group has been making evaluations of an eight disc laser amplifier. (Datum 1). One of the tests consisted of a wavefront distortion test of the entire assembly using a Mach Zehnder interferometer. Later it was decided to use a computer program to model this same experiment. The POLYPAGOS lens evaluation program was chosen. The objective was to analytically determine the wavefront distortion of a laser beam passing through a series of eight discs with specified surface figures, and compare the data with experimental results.

The system consisted of eight elliptical laser discs of Owens-Illinois ED-2 glass (NRL type). The discs had an effective aperture of 6.8 cm and a thickness of 1.99 cm. They were mounted at Brewster's angle (57.2°) and all tests and the computer analysis were done with the discs in this configuration (see Fig. 1). In the computer study, each disc surface was assumed to be first flat, then convex with a specified spherical radius. Three different spherical curvatures were examined; in each case all of the discs were assumed identical; all with the same convex radii. The spherical figure refers to the long axis of the disc ellipse and was calculated for a disc of 15.5 cm across the long axis at .63 microns wavelength. The three cases were:

<u>Spherical Figure (at $\lambda = 6328\text{\AA}$)</u>	<u>Curvature (1/r)</u>
$\lambda/4$	$\pm 5.26 \times 10^{-7}/\text{cm}$
$\lambda/10$	$\pm 2.09 \times 10^{-7}/\text{cm}$
$\lambda/20$	$\pm 1.04 \times 10^{-7}/\text{cm}$

See Fig. 2. The program was run for a 1.06μ wavelength beam both with collimated light and with a 2.5 milliradians half angle divergence.

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In each case two additional surfaces were added at the end of the disc array: a perfect refracting surface which was $f/4$ to give a spherical wave and a reference focal surface.

It was determined (from the experimental results) that the system was astigmatic. That means that the image of a point is spread in a direction along the axis. See Fig. 3 for example. Two sections of the cone of rays diverging from P and refracted by the lens are shown shaded. After refraction, all rays from P pass through a horizontal line, the primary image, and later through a vertical line, the secondary image. The cross section of the entire refracted beam is elliptical, the ellipse degenerating to a straight line at the primary and secondary images, and to a circle, the circle of least confusion, at some point between them.

In order to best sample this astigmatic system, the reference focal surface mentioned above was placed at two positions, corresponding to the primary image and the circle of least confusion in Fig. 3.

The point spread function or impulse response of an optical system is an analytical description of the light amplitude distribution in the image of a point object formed by that optical system. In our example, it is equivalent to the far field pattern or the Fraunhofer diffraction pattern. The detailed distribution of light in the image of an extended object can be calculated from a knowledge of the distribution in the image of a point.

The point spread function in the focal plane of our "perfect" $f/4$ lens is obtained by a two-dimensional Fourier transform of the calculated pupil function $F(i,j)$ where

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$$F(i,j) \equiv B(i,j) \cdot \exp [-k W(i,j)]$$

$$k = 2\pi/\lambda.$$

$W(i,j)$ is the computed aberration function and $B(i,j)$ is the amplitude function which is either 0 or 1 for our assumed uniform spherical wave.

Parallel light through flat glass discs would give a perfect Airy disc as a point image where the first dark ring would have a radius of about 5 microns. Fig. 4 shows the effect of the disc curvature on the central maximum of the diffraction pattern at the two image planes. The patterns are contours of equal intensity of the central maximum of the Airy disc.

Figure 5 illustrates the graphical output of POLYPAGOS for the flat glass discs in diverging light. Here the spot diagram (geometrically traced ray intersections in the focal plane) is rotationally symmetrical at the circle of least confusion. The contour diagram which includes the effects of diffraction begins to show the slight cross shape. Comparing Figs. 4, 5 and 6 shows that in diverging light the $\lambda/20$ surfaces actually improve the diffraction pattern. This effect is even more clearly illustrated in Fig. 7. Here the optical path differences from a perfectly spherical wavefront are plotted for the four glass surface figures in both parallel and diverging light. Again the $\lambda/20$ figured surface produces the minimum astigmatism in diverging light. The experimentally obtained curve is in good agreement with the observed surface flatness, but of course the surfaces were not true spheres.

The POLYPAGOS program computes the encircled energy inside any specified circle in the output beam. The encircled energy within the first and second

rings of the theoretical Airy pattern was computed and plotted. The theoretical energy distribution was plotted on the same graph for comparison (see Graph #5). Note that by the second dark ring the computed energy is close to the theoretically expected value for a diffraction pattern due to an aperture the size of the discs.

Experimental

The experimental phase of the evaluation of the eight disc laser amplifier consisted of two parts. First each of the discs had its wavefront distortion and the flatness of its faces determined. Secondly the entire system of eight discs was tested for wavefront distortion.

Each disc was placed in a Fizeau interferometer to obtain wavefront distortion interferograms at Brewster's angle. A Fizeau interferometer was used rather than a Twyman-Green interferometer in order to obtain the sharpened fringes formed by the multiple reflections set up in the Fizeau cavity between the reference and the sample.

For the flatness measurement, the discs were silvered in our coating facility to enhance the interference fringes. The fringes were again formed, this time of each surface separately in the Fizeau interferometer. See Table I.

The discs were of good quality, all of the single pass wavefront distortion $\lambda/8$ or better where $\lambda = 6328\overset{\circ}{\text{A}}$ (He-Ne). The surface flatness was almost as good with more than half the surfaces $\lambda/8$.

The discs were also looked at in a Davidson interferometer (a type of Fizeau) where it was determined they were saddle shaped.

The laser amplifier system with eight discs was tested as a complete unit in a 6-inch aperture Mach-Zehnder interferometer. The test, for wave-front distortion, was run with first a collimated He-Ne laser beam and secondly a beam of 2.5 milliradians half-angle divergence. See Fig.

As a collimated beam of light traverses a collection of perfectly plane plates it is refracted. The end result is only a lateral shift in position for the beam; it is still collimated, assuming the internal quality of the glass is perfect. If that same collimated beam traverses a collection of non-plane plates, for instance, spherical surfaced plates, it will emerge either diverging or converging, i.e., no longer collimated. The spherical surfaces have had a lensing effect. If the surfaces are aspherical they will have a similar but non-symmetric effect to spherical surfaces.

The Mach-Zehnder interferometer compares a collimated beam which has traversed in this particular case eight laser discs (16 surfaces) with a plane reference beam, thus forming interference fringes. The presence of these fringes denotes deviations from a plane wave in the active beam due to traversal of the eight laser discs. This experiment was repeated with a beam of 2.5 mr divergence. In this case the reference beam is spherical.

The interferograms of the laser disc amplifier inside the Mach-Zehnder were photographed and measured. The system when tested with a collimated beam had $2\frac{1}{2}$ fringes (see Fig. 10a) while with the diverging beam only $1\frac{1}{2}$ fringes were present, see Fig. 10b. The diverging beam has partially compensated for the lensing properties of the laser discs, i.e., in the case of the diverging input beam, the output beam was more nearly a plane wave.

It was determined (by examining the interferograms) that the major aberration of this particular system was astigmatism. Note on Fig. 10a, that the fringes on top curve outward as do the fringes on the bottom, i.e., away from each other, indicating astigmatism. The down curving fringes at the edges of Fig. 11 also indicate this. Figure 12 shows the relationship between the fringes on the interferograms for diverging light through the system as produced by the Mach Zehnder interferometer and the optical path difference between the output beam and a reference spherical beam.

The results of the computer simulation and the experimental evaluation have been described separately. It is useful now to compare them. The starting assumptions and conditions in each case must be kept in mind. In the computer case, the plates were assumed to have known identical surfaces that were flat to $\lambda/4$, $\lambda/10$ or $\lambda/20$ where $\lambda = 1.06\mu$. This was not the case in the actual experimental set up; the surfaces were of different degrees of flatness and the glass itself, though of good quality, was not perfect. In the experimental case, He-Ne 6328 $\text{\AA}$ wavelength was used.

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Fig. 1 Eight Disc System as Calculated

FIG. 1 / 5702 / 86

Fig. 2 NRL Laser Disc

Fig. 3 Astigmatism

Fig. 4 Collimated Light Point Spread Function Contour Diagram

Fig. 5 Data for Flat Discs in Diverging Light

Fig. 6 Diverging Light Point Spread Function Contour Diagrams

Fig. 7 Astigmatism Produced by 8 NRL Discs Wave Aberration at a Line Focus

Fig. 8 Encircled Energy

Fig. 9 Mach-Zehnder Interferometer

a. Mach-Zehnder Interferometer-Single Pass Wavefront Distortion
8 Elliptical discs Collimated beams

b. Mach-Zehnder Interferometer-Single Pass Wavefront Distortion
8 Elliptical discs 2.5 milliradian diverging beam

Mach-Zehnder Interferometer
Single Pass Wavefront Distortion
8 elliptical discs
2.5 milliradian diverging beam

Fig. 11

Fig. 12 Analysis of interferograms

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External:

Mr. Philip Mace
University of California
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, NM 87544

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