TITLE: INTERFEROGRAM REDUCTION AND INTERPRETATION AS APPLIED TO THE OPTICAL ANALYSIS OF THE 10 KJ LASL LASER FUSION SYSTEM

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INTERFEROMETER REDUCTION AND INTERPRETATION AS APPLIED TO THE OPTICAL ANALYSIS OF THE 10 KJ LASL LASER FUSION SYSTEM*

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ABSTRACT

The LASL 10 kJ Eight-Beam CO₂ Laser Fusion System, currently under construction, has approximately one hundred optical elements per beam. The nominal system is diffraction limited and degradations in performance are primarily caused by imperfect components as well as alignment errors. Consequently, analysis and predictions for the system are very much dependent on the proper description of the imperfect components.

The approach taken at LASL has been to characterize the components interferometrically. Briefly, interferograms of the various components are made at the 633 nm He-Ne wavelength. These are digitized, after visual examination, at appropriate sampling points along the fringes. The interactive semi-automatic computer program¹ developed at LASL is used to verify and if necessary correct the digitization. The correct digitization data is next input to the computer program FRINGE 2² and this program is used to generate, among other data, Zernicke polynomial coefficients at 10.6 microns for the wave front. The 36 Zernicke coefficients characterize the O.P.D. (optical path difference) at each manufactured surface and these are accepted by the diffraction propagation computer program LOTS³ and the laser beam is thus propagated through the entire system and various parameters of interest such as Strehl ratio, intensity and encircled energy distributions are computed at stations of interest throughout the system.

* Work performed under the auspices of the U. S. Department of Energy.
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***Optical Sciences Center, University of Arizona
An example of this procedure using an actual interferogram of a manufactured component will be presented and the various limitations will be discussed.

Analysis of the total system, based on expected component quality, has shown that spatial filters are very effective in removing aberrations and that only components after the final spatial filter are crucial to achieving near diffraction limited performance. Further analysis of these components has already shown the need to improve the optical quality of the large sixteen-inch diameter salt windows in the system.

The approach of interferometrically defining and characterizing the various manufactured optical components appears to be a powerful tool in the analysis and optimization of the optical parameters in the laser fusion system. Detailed results of the analysis for one complete leg of the Eight-Beam System will be presented.

References

1. CDFL - Computer Determined Fringe - developed by W. S. Hall of Los Alamos Scientific Laboratory.
2. FRINGE 2 is an interferometric analysis code developed at the University of Arizona.
3. LOTS is a diffraction Propagation code tailored to LASL Laser Fusion System developed by George Lawrence of the University of Arizona in conjunction with the Laser Division of LASL.
INTERFEROCMM REDUCTION AND INTERPRETATION AS APPLIED
TO THE OPTICAL ANALYSIS OF THE 10 KJ LASL LASER FUSION SYSTEM*

V. K. Viswanathan, W. S. Hall, I. Liberman,** G. Lawrence***
University of California
Los Alamos Scientific Laboratory
Los Alamos, NM 87545

The LASL 10 kJ Eight-Beam CO₂ Laser Fusion System, currently
nearing completion, has approximately one hundred optical elements
per beam. Figure 1 shows the layout of the system. Each of the
eight beams is expected to deliver 1.25 kJ within a nanosecond
pulse.

The nominal system is diffraction limited and the degradations
in performance are a consequence of imperfect components, alignment
errors, etc. Hence, the analysis and predictions as well as
attempts to optimize optical performance of the system are very much
dependent on the proper description of the imperfect components.

The approach taken at LASL has been to characterize the com-
ponents interferometrically. To describe the procedure briefly,
Fizeau or Twyman-Green type interferograms of the components are
made at 633 nm wavelength. These are digitized using one of two
methods (to be described later). Zernike polynomial coefficients at
10.6 microns are generated and used to characterize the O.P.D.
(optical path difference) at each manufactured surface. The wave
front is propagated through the entire system, taking diffraction and
O.P.D. modifications introduced at each component into account and

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various parameters of interest such as Strehl ratio, intensity and encircled energy distributions, amplitude and phase of the wave front are computed and displayed as desired.

The first method for digitizing the interferogram (either positive or negative) consists of processing the interferogram with a scanning display microdensitometer. The output is then "cleaned" and stored in a photostore file (which is a 512x512 matrix).

The computer program C.D.F.L.\textsuperscript{1} which uses merger criteria in the x and y directions (for points to be considered to lie on the same fringe) prints the fringe pattern with all minima as shown in Figure 2. Next, the pattern is refined further to that shown in Figure 3 and operator intervention removes the discontinuities and ensures the correct ordering of the fringes as shown in Figure 4. These fringes are automatically digitized by proper sampling. The reduction described here is that of a noisy and marginal interferogram. If one traces over the negative with a Leroy 'O' pen, the process actually works better and is considerably faster and very little operator intervention is necessary.

The second method is straightforward and consists of using a 4953 Graphics Tablet in conjunction with a Tektronix 4015 terminal; the sampled coordinates are directly stored in a file. Figure 5 shows a typical interferogram reduction using this method.

Actually, we had used a third method before we received the Graphics Tablet. This consisted of scotch-taping the interferogram film onto the face of the Tektronix terminal and then using the terminal cross hairs for the digitization process. Obviously, this is less accurate than using the tablet because of parallax errors, etc.
The first method is the most accurate and has the virtues of being compatible with automation as well as with several internal checks for possible errors. The second method is, however, easier to implement in practice (at least at LASL) and, as the original interferograms were taken at 0.633 microns and the results are desired at 10.6 microns, it is accurate enough and will not introduce errors in the representation of manufactured elements. It does suffer from the drawback that the operator has to make sure himself that no errors were introduced in sampling the points along the fringes.

The next stage consists of automatically transferring the data to the computer program FRINGE$^2$ and correctly orienting the element as well as ensuring the proper sign of the O.P.D. While we can access any of two versions of FRINGE available at LASL, and the program itself has a truly varied array of analysis outputs, the interest here is to fit the data to Zernike polynomials as closely as possible, and to get the Zernike coefficients at 10.6 microns as punched card output. Figure 6 shows a typical printed output. At present, a file ABR (which consists of the Zernike coefficients data for all the elements as they occur sequentially in the system) is created, but eventually we hope to make this process automatic.

The Diffraction Propagation Program LOTS$^3$ propagates the laser beam through the entire system, (using the Zernike polynomial coefficients to represent the manufactured surface); it allows for energy variations from saturating gain and loss intentionally placed in the optical path. Various parameters of interest such as Strehl ratio, intensity, encircled energy distributions, amplitude and phase are computed and displayed at stations of interest. Figure 7 shows the output at the target plane for one of the legs of the Eight Beam System.
Analysis of the total system, based on expected component quality, has shown that spatial filters of proper size are very effective in removing many troublesome aberrations and that only components after the final spatial filter are crucial to achieving near diffraction limited performance. Further analysis of these components has already shown the need to improve the optical quality of the large sixteen inch diameter salt windows in the system. Figure 8 shows the system performance in terms of Strehl ratio for one leg of the Eight Beam System based on compliance of mounted optical components, as well as the expected performance based on interferogram reduction of the actual manufactured components occurring after the final spatial filter in the system.

In conclusion, the approach of interferometrically defining and characterizing the various manufactured optical components appears to be a powerful tool in the analysis and optimization of the optical parameters in the laser fusion system. This technique could be used as an optical design, analysis, and assembly approach to these novel, and complex systems which appear to defy conventional approaches to optical systems design, optimization and analysis.

References
2. FRINGE - Generic name for an interferometric analysis program developed at the University of Arizona.
3. LOTS is a diffraction propagation code tailored to LASL Laser Fusion System developed by George Lawrence of the University of Arizona in conjunction with the Laser Division of LASL.
4. "Optical Analysis of the LASL 10 kJ CO₂ Laser Fusion System"

EIGHT BEAM SYSTEM OPTICAL SCHEMATIC

Figure 1
Figure 3
### Pupil Radius: 17.78 cm

<table>
<thead>
<tr>
<th>Diffraction Angle</th>
<th>7.5017</th>
<th>Arc Sec</th>
</tr>
</thead>
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<tr>
<td>1</td>
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<td>1396.477</td>
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<tr>
<td>2</td>
<td>756.455</td>
<td>1396.462</td>
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<tr>
<td>3</td>
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<td>20</td>
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</table>

**12 x Total Data Points**

**12 x Within Unit Aperture**

**Data Will Be Rotated**

Figure 5
WAVEFRONT DEVIATION IN UNITS OF WAVES
TILT AND OFFOCUS MEASURED FROM DIFFRACTION FOCUS
INTERFEROMETER USED A WAVELENGTH OF 0.633 MICRONS

<table>
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<tr>
<th>N</th>
<th>RM9</th>
<th>PHN</th>
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<td>5</td>
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</table>

FIRST ORDER (GAUSS) DESCRIPTION
MAGNITUDE | ANGLE | RPSIGNATION
WAVES | DEG | TILT
0.674 | 87.8 | TILT
0.128 | OFFOCUS

STREHL RATIO 0.902

THIRD ORDER (SEIDEL) ABBREVIATIONS
MAGNITUDE | ANGLE | RPSIGNATION
WAVES | DEG | TILT
0.778 | 85.9 | TILT
0.173 | OFFOCUS
0.247 | A1, A | ASTIGMATISM
0.110 | -61.2 | COMA
= 0.123 | 3RD ORDER SPHERICAL ABBERRATION

FOLLOWING THIRD ORDER TERMS WERE SUBTRACTED:
TILT FOCUS
RESIDUAL WAVEFRONT VARIATIONS FOR DATA
AV | RM9 | MAX | MIN | SPAN | STREHL
0.198 | 0.152 | 0.111 | -0.117 | 0.271 | 0.908

RESIDUAL WAVEFRONT VARIATIONS FOR POLYNOMIAL
AV | RM9 | MAX | MIN | SPAN | STREHL
0.898 | 0.841 | 0.111 | -0.127 | 0.271 | 0.948

ZERNIKE POLYNOMIAL COEFFICIENTS

Figure 6
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<th>ENERGY</th>
<th>1122.05722 JOULES</th>
</tr>
</thead>
<tbody>
<tr>
<td>STPEHL FATIO</td>
<td>.4740</td>
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</table>

**PROFILE OF INTENSITY** JOULES/50. CM.

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<th>1.15E+00</th>
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<th>1.11E+00</th>
<th>1.07E+00</th>
<th>1.13E+00</th>
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<td>8.57E+07</td>
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<td>4.64E+06</td>
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<td>2.54E+06</td>
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<td>1.62E+06</td>
<td>1.13E+06</td>
<td>3.98E+05</td>
<td>5.52E+05</td>
<td>1.44E+05</td>
<td>2.28E+05</td>
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<td>1.04E+05</td>
<td>2.85E+05</td>
<td>2.33E+05</td>
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<td>3.37E+04</td>
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<td>9.28E+04</td>
<td>2.04E+04</td>
<td>1.06E+03</td>
</tr>
</tbody>
</table>

**Focal Length is** 77.2600 CM
**Image 1 Unit** = .00060 CM
**Clear Aperture** = .02500 CM
**Station** 0

**Energy** = 1122.05722 JUOLES
**Peak Intensity** = 95142580.81496 JUOLES PEP 50. CM

**Profile of Intensity** JOULES/50. CM.

**Figure 7**

**Encircled Energy**

<table>
<thead>
<tr>
<th>RADIUS IN CENTIMETERS</th>
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<tbody>
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**Figure 7**
Figure 8