UCRL- 85281
PREPRINT

CONF-810613--9

MASTER

REFLECTION/TRANSMISSION PHASE-SHIFT
INTERFEROMETER AND VIEWING OPTICS*

J. A. Monjes
B. W. Weinstein
D. L. Willenborg

This paper was prepared for submittal to
Conference on Laser and Electro Optics
Washington, D. C.
June 10-12, 1981
and Applied Optics, March 1, 1981

June 15, 1981

Lawrence
Livermore
Laboratory

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISCLAIMER

REFLECTION/TRANSMISSION PHASE SHIFT
INTERFEROMETER AND VIEWING OPTICS*

J. A. Monjes, B. W. Weinstein and D. L. Willenborg

LAWRENCE LIVERMORE NATIONAL LABORATORY
P. O. Box 5508
Livermore, CA 94550

ABSTRACT

The interferometer and viewing optics that are the main optical components of an Automated Surface Mapping system (ASM) used to characterize the surface topography and the wall thickness uniformity of opaque and transparent spherical shells is described.

To characterize surface finish or wall thickness of spherical shells with an accuracy of 10 nm and a resolution of 1 μ m the differential phase shift between two beams of orthogonal polarizations is measured, before and after the probe beam has interacted with the test object.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

INTRODUCTION

Transparent and opaque spherical shells used in laser fusion targets¹ must be characterized for wall thickness uniformity and surface quality with a spatial resolution of 1 μ m and 10 nm accuracy. To meet these requirements an interferometer capable of working in transmission as well as in reflection mode has been designed and fabricated and it is undergoing final evaluation tests at the present time.

This dual purpose interferometer is the main optical component of the Automated Surface Mapping system (ASM)² designed at LLNL. The ASM is an opto-electronic instrument capable of automatically measuring and recording surface quality and wall thickness of laser fusion targets in less than 5 minutes in an efficient and reliable manner.

The main subsystems of the ASM shown in Figure 1 are: Phase shift generator; Interferometer and Viewing Optics; Spherical Target Rotator;³ Phase Shift Detector and Measuring Device; Controlling Computer, Data Acquisition/Display and Associated Electronics.

The subject of this paper is restricted to the interferometer and viewing optics subsystem shown in Fig. 2. In this figure we can see the central location of the

test object (laser target in this case) with the two arms of the interferometer making a quadrangle around the target and the measuring beam focused on both sides of the test object. This configuration automatically compensates for thermal variations in the horizontal plane and small displacements ($\approx 2 \mu\text{m}$) of the target along the interferometer's axis.

The initial positioning of the target with respect to the measuring beam is facilitated by an optical system which looks at the focus of the measuring beam along two orthogonal directions. Two reticles are imaged and aligned for coincidence with this focus, so that when the target is placed in the focus of the measuring beam it will be imaged simultaneously on the center of both reticles.

OPERATIONAL PRINCIPLES

The Phase Shift or Heterodyne Interferometer provides very accurate measurement of optical path differences (OPD) by detecting the differential phase shift of two orthogonal polarizations of slightly different frequencies.⁴ The single frequency plane polarized output of a laser is split into two branches. The two branches are frequency shifted

relative to one another by 100 kHz, and the polarization of one branch is rotated by 90° as shown in Fig. 3.

A small fraction of the recombined beam is directed toward a phase shift reference detector, while the larger fractional intensity is directed toward the interferometer (Fig. 4) where each polarization is propagated along separated optical paths. One path constitutes the measuring branch the other is the reference branch, the test object is introduced in the measuring branch. At the interferometer's output the two beams are recombined and directed toward the measurement phase detector, the phase difference between the reference and measurement detector (Fig. 1) is a direct representation in real time of the OPD introduced by the test object.

BASIC INSTRUMENT DESCRIPTION

Figure 3 Phase Shift Generator and Fig. 4 Phase Shift Interferometer Optical Path are used for the purpose of this basic description.

Figure 2 is a schematic representation of the Phase Shift Generator⁴ where we can see how the output of the laser is split in two components of equal intensity and

directed toward the Bragg cells (acousto-optic modulator) where the single frequency of the laser f_0 is shifted to a new value $f_n = f_0 + f_1$ for one component and to $f_m = f_0 + f_2$ for the other component.

The relative frequency shift between the two components is $\Delta f = f_n - f_m = 100 \text{ kHz} \pm 100 \text{ Hz}$. The " f_n " frequency is directed to a $\lambda/2$ retardation plate where the original TE polarization is rotated 90° to TM polarization, the other beam of frequency $= f_m$ keeps its original TE polarization and is directed toward the output beam combiner where the two beams are colinearly integrated in a single output beam. The resultant rotating elliptical polarization constantly changes state at a rate of 100 kHz. A beam splitter directs 10% of the intensity toward the reference phase shift detector and 90% toward a spatial filter with an adjustable beam expansion ratio. After the spatial filter the beam is directed to the interferometer.

The rotation of the polarization ellipse⁵ maximum and minimum intensities axes is generated by the differential frequency Δf between the two orthogonal polarizations, thus intensity variations can be detected by placing a 45° polarizer in front of a photo detector. This detector will respond to the intensity variations induced by the variable

transmittance of the polarizer for different orientations of the ellipse of polarization.

The beam diameter is kept smaller while the frequency shifts are introduced in order to minimize aberrations. However the beam has to be expanded and a plane wave, diffraction limited beam, must be propagated toward the measuring objective of the interferometer if the desired spatial resolution is to be achieved.⁶

The interferometer (Fig. 4) takes the output beam from the spatial filter and splits it into two orthogonal polarization components of slightly different frequency, one component is directed along the measuring arm and constitutes the probe beam, the other directed along the reference arm is the reference beam. Irregularities on the opaque target's surface or wall thickness variations in transparent targets will locally delay the wave front of the measuring beam.

For opaque targets the wave front is retro reflected by the target's surface, for transparent targets the wave front is back reflected by a flip in double-sided mirror placed behind the target, the beam retraces its path producing the effect of a double pass interferometer.

The probe beam is recombined with the reference beam at

the interferometer's output. The resulting elliptical polarization will have a differential phase shift with respect to the original input polarization, this differential phase shift provides an easy and accurate way of measuring the localized surface irregularities or wall thickness variations of the test object.

Small areas of $1\text{ }\mu\text{m}$ diameter on the target's surface are sequentially presented to the measuring beam, until the entire surface is explored. This is done by a microsphere manipulator with the capability of rotating the target about two orthogonal axes without displacement.³

The primary advantage of the interferometer arrangement shown in Fig. 4 is that it is insensitive to changes in position of the target sphere. Small translations of the test object along the beam axis cause no change in path for the probe beam. In an ordinary interferometer, where the probe beam is simply focused on one point on the sphere, any motion of the sphere along the beam axis has the same effect as a defect on the surface. Because our interest lies in defect amplitudes of 10 nm, we would need a manipulator able to maintain the sphere position to 10-nm accuracy. (Such a manipulator would be extremely expensive.) With the ASM interferometer, the manipulator is required to maintain the

sphere position only within 1 μm .

INTERFEROMETER DESIGN CONSIDERATIONS

The interferometer as shown in Fig. 4 receives a diffraction limited beam directly from the spatial filter. By changing lenses the spatial filter provides for a variable expansion ratio from 3:1 to 8:1, the 8:1 ratio is used to achieve the maximum spatial resolution.

At the polarizing input beam splitter the TE component is reflected at 90° generating the reference beam. The TM component transmitted by the beam splitter is the probe beam that is transformed to circular polarization by the $\lambda/4$ wave plate, this beam is focused on the target's surface by a strain free objective of $\text{NA} = 0.4$ to achieve the diffraction limited resolution of $\sim 1 \mu\text{m}$. The system provides for interchangeable objectives such that when used with the proper beam diameter it will achieve the designated resolution.

Since the size of the probe beam focal spot determines the number of scans and therefore the length of time required to explore the entire target there is a trade off between resolution and characterization time.

Since all reflections on the target or mirror are at normal incidence (see insert in Fig. 4) there are no changes in the circular polarization (except sense of rotation) therefore after the second pass through the $\lambda/4$ plate the beam becomes TE and it is reflected by the input polarized beam splitter following its path through the penta prisms and beam combiner toward the back side of the reflective target (or back side of the double sided mirror for transparent targets).

The beam cross section on the rear surface of the target is between 10^3 to 10^4 times larger than the measuring spot, therefore localized irregularities on the rear surface are averaged over a large area introducing only a negligible error relative to the measurement on the front surface.

In Fig. 4 we see that the probe beam reaches the back surface of the reflective target or mirror in a state of circular polarization. After reflection it is transformed to TM by the $\lambda/4$ plate and directed, collinearly with the TE polarized reference beam, toward the measuring detector.

The reference beam has a constant TE polarization along its entire optical path, this path has been folded 3 times in order to equalize the length of measuring and reference branches. This is not a coherence limited requirement but

it is done in order to cancel phase shifts generated by the unequal thermal expansion effect that will result if the total optical path of both branches are not the same within an error of less than 1 μ m.

TARGET LOADING OPTICS

To measure the surface irregularities of a spherical target in the ASM system, we must place the target between the target rotator tips in accurate coincidence with the optical axis of the measuring branch of the interferometer. To accomplish this, a target-viewing and alignment instrument (shown schematically in Fig. 5) has been designed and integrated into the ASM system.

To precisely locate the target in the interferometer, we view the target simultaneously along two orthogonal axes. One viewing arm is coincident with the interferometer axis and uses the interferometer rear focusing objective as an imaging objective. The other arm uses an identical objective placed at 90° to the interferometer axis. As Fig. 5 shows, the image formed by each of these two objectives is projected onto an alignment reticle.

The two targets and reticle images are combined in a

central beam splitter so that both images can be seen in the same field of view. The beam-splitter output is directed to both an eyepiece and a TV camera.

Once the reticles have been aligned on the interferometer axis, they serve as a reference for positioning the target on the rotator tips. The target is centered on each reference reticle as it is viewed either on the eye piece or TV screen.

This system has been tested in an optical bench setup, and the measured resolution limit is 1.5 μ m. Figure 6 shows the two orthogonal views of a target centered on the reticles as observed in the experimental set up.

MECHANICAL CONSTRUCTION

The main objective of the mechanical design is to achieve maximum thermal and dynamic stability of the entire interferometer. To this end the optical path is enclosed in aluminum tubes and all the components are mounted on an Invar plate as shown in Fig. 7. The entire unit is enclosed in a plastic bell jar with filtered and controlled atmosphere. The two penta prisms provide coarse and fine adjustment of the O.P.L. without changing the direction or

position of the probe beam. The three microscope objectives are focused on the target with a resolution of 12 nm by inch-worm drivers controlled from a remote console.

The target position and final centering on the common focal plane of the three objectives can be viewed through the eye piece located on the right side of Fig. 7 or on the TV monitor connected to the camera on the bottom of the same figure.

Fig. 8 shows an elevation view of the interferometer. The target rotator system is centrally located and independently mounted on the surface of the air suspended optical table. To ensure that vibrations originated in the drive system of the ball rotator are not transmitted to the optical system the interferometer Invar base plate is mounted on three damped kinematic mounts. Also shown in this figure is the plastic bell jar mounted on the Invar base plate, and a floating seal under the Invar plate surrounding the driving stages completes the protective envelope.

SUMMARY

On the basis of the partial tests already performed on

each of the major components and on the experience gained in our previous mapping system "TOPO II" (Ref. 3) it is expected that the integrated ASM system will map spherical surfaces with an accuracy of 10 nm, a spatial resolution of approximately 1 μ m, and a positional repeatability on the spherical surface of 0.1 μ m to 0.5 μ m. The data will be displayed and recorded in a Mercator projection as shown on Fig. 9. In this figure only a small sector of the target surface is displayed and the respective scales for each axis are shown. A future improvement will be to display the same data on a three dimension spherical representation.

ACKNOWLEDGEMENTS

The authors wish to thank Verne Richmond for his dedication and mechanical design of all the related hardware. Also we want to express our gratitude to the target group management for its encouragement and support.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government thereof, and shall not be used for advertising or product endorsement purposes.

REFERENCES

1. Laser Program Annual Report - 1979 Vol. 2 p. 4-30.
2. Laser Program Annual Report - 1979 Vol. 2 pp. 4-42 to 4-49.
3. Monjes, Weinstein, Willenborg and Richmond, Microsphere Rotator, UCRL-83375.
4. Massie, Nelson & Holly, Heterodyne Interferometry, Applied Optics, 1 June 1979, p. 1797, Vol. 18 No. 11.
5. Azzam & Bashara, Ellipsometry and Polarized Light, North Holland, 1977.
6. Bergner, Gelbke and Menliss, Photomicrography, The Focal Press, London, N.Y. 1966.

FIGURES

- Fig. 1. Automated Surface Mapping System
- Fig. 2. Reflection/Transmission Interferometer and Viewing Optics
- Fig. 3. Phase Shift Generator
- Fig. 4. Reflection/Transmission Interferometer Optical Path
- Fig. 5. Target Loading Optics
- Fig. 6. Orthogonal View of Target on Reticles
- Fig. 7. Interferometer and Loading Optics Plan View
- Fig. 8. Interferometer and Ball Rotator Elevation View
- Fig. 9. TOPO II Map of Thickness Variations Versus Angular Position

AUTOMATED SURFACE MAPPING SYSTEM

Fig 1

REFLECTION/TRANSMISSION INTERFEROMETER AND VIEWING OPTICS

Fig 2

PHASE SHIFT GENERATOR AND SPATIAL FILTER

REFLECTION/TRANSMISSION INTERFEROMETER OPTICAL PATH

Light source

Spectra Physics HeNe Laser 124A-15 mw $\lambda = 0.633 \mu\text{m}$

Long mode spacing $\Delta f = \frac{c}{2d} = 214 \times 10^6 \text{ Hz}$ - d = oscillator length = 0.70 m

Coherence length $L_c = \frac{c}{\Delta f} = 1.4 \text{ m}$ - contable $\Delta L_a = \frac{L_c}{100} = 0.014 \text{ m}$

$$\Delta L_a = 1.4 \text{ cm}$$

Fig 4

TARGET LOADING OPTICS

10 01-0680-1827

Fig 5

Fig 6

INTERFEROMETER AND LOADING OPTICS PLAN VIEW

10-01-0581-1190

Fig 7

INTERFEROMETER AND BALL ROTATOR ELEVATION VIEW

10-01-0581-1191

Fig 8

TOPO II MAP OF THICKNESS VARIATIONS VERSUS ANGULAR POSITION

10-90-0279-0270

Fig 9