2990
9/30
RFP-965

RECEIVED BY DTIC SEP 29 1967

MASTER

caps
EVALUATION OF THE OPTOMECHANISMS
LASER INTERFEROMETER SYSTEM

THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401
U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(29-1)-1106

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
leg

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, 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 product, 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 any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

Printed in the United States of America

Available from

Clearinghouse for Federal Scientific and Technical Information

National Bureau of Standards, U. S. Department of Commerce

Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

7 September 1967

RFP-965
UC-37 INSTRUMENTS
TID-4500

CESTI PRICES

H.C. \$ 3.00; MN .65

EVALUATION OF THE OPTOMECHANISMS LASER INTERFEROMETER SYSTEM

L. W. Utley

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401
U. S. ATOMIC ENERGY COMMISSION
CONTRACT AT(29-1)-1106

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

peg

CONTENTS

Abstract.....	1
Introduction.....	1
Description.....	1
Principles of Operation.....	2
Evaluation.....	3
Application.....	3
Potential Application.....	4
Conclusion.....	5
Bibliography.....	5

Evaluation of the OPTOmechanisms Laser Interferometer System

L. W. Utley

Abstract. A laser length-measuring interferometer system was purchased from OPTOmechanisms, Inc., and evaluated. The system was used to calibrate the longitudinal lead screw of a No. 4 Moore Products Company Measuring Machine and to calibrate the linearity adjustment of a Sheffield Corporation Measuring Machine. Both performances proved the Interferometer system to be extremely accurate.

INTRODUCTION

The use of optical interferometers for precise linear measurement of distance was first developed by Albert Michelson. However, until the advent of the laser the optical interferometer remained strictly a laboratory tool. This intense and highly coherent source of light, in combination with the development of sensitive photo detectors and modular logic computer circuitry, has made possible the design of a practical, rugged system capable of measuring large distances to microinch accuracy.

Three companies presently market laser interferometer systems: Airborne Instruments Laboratory,¹ DoAll Company,² and OPTOmechanisms, Inc.³ The results of competitive bidding identified OPTOmechanisms as the low bidder and therefore that system was purchased.

DESCRIPTION

The OPTOmechanisms Laser Interferometer system is an electro-optical instrument that measures distances with extreme accuracy by utilizing a coherent, monochromatic light of a known wavelength, as emitted by a gas laser. The system contains an analog computer, which continuously updates the wavelength for environmental conditions, and a digital computer which converts the fringe count

to a comprehensible numerical display of the distance measured. No mastering or calibration of the system is required.

The OPTOmechanisms Laser Interferometer system is shown in Figure 1, set up on a Moore No. 4 Measuring Machine. The OPTOmechanisms system consists of six basic components: a Sensor, a Reflector, a Fringe Counter, an Inch or Micron Computer, an Environmental Correction Computer, and a Laser Power Supply.

The Sensor contains a Spectra-Physics Inc.,⁴ Model 119 Single-mode helium-neon Gas Laser, which provides a coherent beam of light having a wavelength in vacuum of $6329.9147\text{\AA}$ (plus or minus $0.0003\text{\AA}$).⁵ Single-mode defines this laser as emitting only one frequency, and coherent beam of light means that all points in the wave-front receive light that is in phase. The sensor also contains the interferometer optics, photomultipliers, preamplifiers, and associated electronic circuitry.

The Reflector is a tetrahedral prism (sometimes called a corner cube) mounted in a holding fixture. It is fabricated with a beam accuracy of two seconds of an arc. (The return beam is parallel to the incident beam within this accuracy.) Since this instrument uses a folded-beam design each fringe represents one-quarter wavelength or approximately six-millionths of an inch.

The Fringe Counter displays 1-, 2-, or 4-counts per fringe. The Inch or Micron Computer consists of a multiplying digital computer, a multiplication factor input, and the inch (or metric) display.

The Environmental Correction Computer provides continuous correction factors for changes in part temperature, barometric pressure, and ambient air temperature. The correction due to humidity is put into the system manually by use of a potentiometer.

⁴ Spectra Physics, Inc., 1255 Terra Bella Avenue, Mountain View, California.

⁵ K. D. Mielinz, K. F. Nefflen, K. E. Gilliland, R. B. Stephens, National Bureau of Standards, R. B. Zipin, and Sheffield Corporation. "Measurement of the 633-nm Wavelength in Helium-Neon Lasers." *Applied Physics Letters*, Vol. 7, No. 10. November 1965.

¹ Airborne Instruments Laboratory, Division Cutler Hammer, Inc., Comac Road, Deer Park, L. I. N. Y.

² DoAll Company, 254 North Laurel, Des Plaines, Illinois.

³ OPTOmechanisms, Inc., 40 Skyline Drive, Plainview, L. I. N. Y.

The precise measurement of length with optical interferometry is a method known and accepted in industry and Government. There is extensive literature, part of which is listed in the Bibliography, describing the development of the utilization of lasers and optical interferometry for measuring length. Therefore, the operating principles will be only summarized in the following section.

PRINCIPLES OF OPERATION

The use of light for measurement depends upon the phenomenon of interference. As used in the OPTOmechanisms Interferometer, the beam of light from the laser is divided by a beam splitter into two parts

which travel optical paths of unequal length before being recombined. One part travels to a fixed front surface mirror, and the other part travels to the movable reflector (corner cube). The reflected beams are recombined at the beam splitter, and the resultant output beam is directed to photomultiplier tubes. If the light-waves of the two reflected beams are of the same phase when the beams are recombined, they reinforce each other and produce a light of higher intensity. If the corner cube is then moved one-eighth of a wavelength of light, throwing the light-waves of the two beams out of phase, they cancel (interfere with) each other and result in a light of lower intensity. Consequently, if the corner cube is moved a greater distance, the output beam varies from bright

FIGURE 1. OPTOmechanisms Laser Interferometer System: (a) Sensor, (b) Reflector, (c) Fringe Counter, (d) Inch or Micron Computer, (e) Environmental Correction Computer, and (f) Laser Power Supply.

12164-9

to dark and back to bright every one-quarter wavelength of displacement.

The photodetectors (photomultipliers) sense the intensity of the change in light; in effect, the photodetectors count the fringes — as the reflector moves. The electrical signals from the photodetectors are reshaped and converted into a displayed digital fringe count, which is a direct measurement of the distance the reflector (corner cube) moves.

Because the two photocells receive interference light-signals that are 90 degrees out of phase with each other, the system can determine which direction the corner cube has been displaced. This bidirectional ability coupled with fast counting capability makes vibration of the corner cube, relative to the beam splitter, fully countable.

EVALUATION

The interferometer system was required to meet certain Rocky Flats accuracy specifications. At maximum sensitivity (4-counts per fringe) an accuracy of 10-microinches per foot or about 1 ppm was specified. Each of the four factors for environmental correction mentioned above was found to be accurate to about 0.1 ppm. The equipment also had to have a repeatability of ± 10 microinches and a maximum travel velocity of at least one-inch per second. The system was set up on a lathe whose carriage had a travel of about 88 inches. Several times the carriage was traversed the full 88 inches and returned to the zero point within ± 5 microinches (according to the OPTOmechanisms interferometer system). The zero point was established with a very accurate electronic indicator. This repeatability was achieved at a maximum carriage speed of approximately 1.3-inches per second. Both repeatability and velocity requirements were, therefore, exceeded.

An error was found in the computation equation for index of refraction changes due to atmospheric variations. Operation of the system at an elevation of 6000 feet was specified; however, the equation programmed in the correction computer contained constants for sea level conditions. The major discrepancy was that the wavelength correction-coefficient due to ambient air-temperature change, was itself dependent upon barometric pressure. The discrepancy was corrected by making appropriate

adjustments in potentiometer settings in the correction computer.

The OPTOmechanisms Correction Computer presented another problem. The air-temperature thermistor of the equipment, (a resistor whose resistance varies linearly with temperature) was found to be self-heating. The voltage on the thermistor generated an internal current which caused an error of two to three degrees Fahrenheit. This was eventually corrected by the manufacturer of the air-temperature thermistor.

A third serious problem that arose during evaluation of the Interferometer system was radio frequency interference (noise) caused by switching an inductive load on and off. This noise caused spurious fringe counts. The noise level sensitivity was reduced in three ways. First, a copper screen was placed around the preamplifier circuit of the OPTOmechanisms Sensor. Second, the Interferometer system was connected to a regulated power source, whereas the noise producing equipment, being used for evaluation, was connected to an unregulated power source. Third, the on-off switch-box on the machine used for evaluation was grounded. No further trouble was encountered.

APPLICATION

The first application of the OPTOmechanisms Interferometer system involved a No. 4 Moore Measuring Machine. (See Figure 1.) It was decided to calibrate the errors in the longitudinal lead screw. Since a calibration of the lead screw was made initially with an inch-bar, the calibration with the OPTOmechanisms system served as a check on the inch-bar data. Using the Latin Square statistical method for comparing measurements of similar items (a technique developed by the Bureau of Standards),⁶ we calibrated the first 9 inches of the longitudinal lead screw of the Moore Machine with the OPTOmechanisms system. The average deviation of the 1-inch through 9-inch displacements of the longitudinal slide agreed with the inch-bar calibration within 2.6 microinches. This compared favorably with the repeatability of the Moore Machine of 5 microinches. The use of this Interferometer system in combination with the Latin Square technique gives a simple and accurate method for the calibration of lead screws.

⁶ Latin and Youden Squares, *National Bureau of Standards Technical News Bulletin*, Volume 34, Number 5, Pages 69-71.

The Interferometer system was also used to check out and calibrate two Sheffield Corporation Capacitance Bridge-type Long Range Transducers. These Transducers were the measuring heads on an automatic prototype machine gage recently delivered to Rocky Flats. This calibration served as the acceptance test for these new measuring heads. The linearity of the heads was adjusted to agree with the OPTOmechanisms readings. Figure 2 shows the arrangement of the test equipment.

POTENTIAL APPLICATION

Potential application of this instrument must be considered in view of its unique capabilities. Extreme linearity and the absence of the need for calibration make it valuable for measuring precision machine slide motion or positioning slides to a predetermined point. The lead screw therefore becomes only the slide actuation means, and its inevitable errors are of no consequence.

FIGURE 2. OPTOmechanisms System Calibrating the Sheffield Long Range Transducer: (a) Interferometer, (b) Drive Mechanism, (c) Corner Cube Reflector, and (d) Long Range Transducer.

11903-6

The digital nature of the measurement readout in combination with the features mentioned, make this laser interferometer system well-suited as the feedback element in numerical control systems for automatic machining and gaging.

Digital-to-analog comparator equipment is available to use in conjunction with the interferometer system. Direct comparison of actual inspection measurements with programmed nominal data may be accomplished with this equipment. The error difference is available for print-out. The comparator can also compare programmed-position with fringe count determination of position and generate an analog error signal for servo actuation.

The OPTOmechanisms Interferometer is also capable of "on-the-fly" measurement. For example, an angular position transducer can be attached to the end of a lead screw, whereas an interferometer measures linear travel. Using the signals from the angular-transducer, to pulse the interferometer readout, instantaneous position readings while in motion may be obtained and compared to the angular position. Differences from perfect linearity may then be printed out.

CONCLUSION

1. Evaluation of the OPTOmechanisms Laser Interferometer system proved the instrument to have both accuracy and precision within Rocky Flats specifications.
2. Attributes of long range, linearity, high accuracy, environmental compensation and no-need for calibration give this instrument unique capability in the area of precision measurement.
3. Auxiliary equipment is available to use in conjunction with the interferometer system. This equipment extends the use of the system to a

variety of automatic measurement and control applications.

4. This system is suitable for permanent installation on a machine tool and for any of the purposes mentioned in the discussion on potential application.

BIBLIOGRAPHY

Peck, Edson R., and Obetz, S. Wendell, "Wavelength or Length Measurement by Reversible Fringe Counting," *Journal of the Optical Society of America*, Vol. 43, No. 6, June, 1953, 505-509.

Murty, M. V. R. K., "Modification of Michelson Interferometer Using One Cube-Corner Prism," *Journal of the Optical Society of America*, Vol. 50, No. 1, January, 1960, 83-84.

Foster, J. D., and Gilson, J. D., "A Fringe-Counting Laser Interferometer For Industrial Length Measurements," SCTM 154-63-81, Sandia Corporation, Livermore Laboratory, September, 1963.

Corey, H. S., Lay, C. M., Schede, R. W., Sladky, R. E., "Length-Measuring Laser Interferometer," Y-1466, Union Carbide Corporation, Y-12 Plant, Oak Ridge, Tennessee, September, 1964.

Chitayat, Anwar K., "Automatic Measuring Interferometers for the Determination of Length and Angle," 64-PROD-23, and American Society of Mechanical Engineers publication, presented at ASTME April 1964 Meeting.

Foster, J. D., "Fringe Counting Laser Interferometers for Industrial Length Measurement," SCL-DC-65-92, Sandia Corporation, Livermore Laboratory, September, 1965.