HOLOGRAPHIC LENSES IN SPECKLE METROLOGY AND SOLAR CONCENTRATION

BY

HIRA LAL YADAV

Instrument Design Development Centre

THESIS SUBMITTED
IN FULFILMENT OF THE REQUIREMENTS OF
THE DEGREE OF

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA

October, 1991

पूज्य माता-पिता के चरण-कमलों में
सनर्पित

CERTIFICATE

This is to certify that the thesis entitled, "HOLOGRAPHIC LENSES IN SPECKLE METROLOGY AND SOLAR CONCENTRATION", being submitted by Mr. Hira Lal Yadav, to the Indian Institute of Technology, Delhi, for the award of the degree of "DOCTOR OF PHILOSOPHY' is a record of the bonafide research work carried out by him under our supervision and guidance. He has fulfilled the requirements for submission of this thesis, which to the best of our knowledge, has reached the required standard.

The material contained in this thesis has not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

Dr.B.N. Gupta
Chief Design Engineer
IDD Centre
I.I.T. Delhi.

Dr. Chandra Shakher
Chief Design Engineer
IDD Centre
I.I.T. Delhi.

ACKNOWLEDGEMENT

It is my privilege to record my deep sense of gratitude and unbound reverence to Dr. B.N. Gupta for his constant encouragement and inspiration throughout the course of my research work. I am thankful to him for it is he who enabled me to work at BHEL with Dr. Chandra Shakher. I am greatly indebted to Dr. Chandra Shakher for his most valuable and painstaking guidance and for providing the opportunity and research atmosphere all through my research work which enabled me to bring out the thesis upto this stage.

I wish to express my sincere thanks to BHEL (Corporate R & D Division, Vikas Nagar Hyderabad, India) management for permitting me to carry out some of the research work in experimental stress analysis group. I am thankful to Dr. G.V. Rao, Dr. U.M. Chaudary, and Dr. P.B. Godbole for their encouragement and inspiration throughout my stay at BHEL. I am very much thankful to Dr. V. Ramamurthy for his interest, stimulating discussions and valuable suggestions. I would like to thank Mr. P. Vijay Kumar for his help at BHEL. A special word of thanks to Dr. K. Thyagarajan for his suggestions and help during the preparation of the synopsis of the thesis. My sincere thanks to Dr. R. S. Sirohi for his encouragement and valuable suggestions.

I wish to acknowledge the kind help and moral support rendered by Ms. Anu Sharma without which it would have been

difficult to stay either at BHEL or at IIT Delhi to carry out my work.

I am thankful to all the faculty of I.D.D. Centre for their encouragement and inspiration.

I appreciate the cooperation and moral support of my colleagues Ms. Pramila, A.K. Nirala, Ghanshyam Rajendra Agrawal, S.K. Pandey, S.K. Verma, D. Ravi, Ms. Seema and Ms. Rina Sharma.

Thanks are also due to Mr. R.B. Verma for his generous personal cooperation and technical assistance. I thank Mr. Sc. Bansal and Mr. H.S. Sharma and all the staff of Optics Laboratory and IDDC Workshop. I would like to thank Mr. Iyer for his cooperation in getting the thesis typed, Mr. Prabhu Nath for his excellent drawings and Mr. Bhatia and Mr. Sukhdev Singh for the photographs of the experimental set-up

Finally, I want to express my heartfelt gratitude to my parents, wife and daughter for their cheerful encouragement, immeasurable patience and inspiration.

Hira Lal Yadav

Date : (Hira Lal Yadav)

ABSTRACT

Holographic optical elements (HOEs) like gratings, beam splitters, mirrors, lenses etc. are emerging as viable alternatives to conventional optical elements in many specific applications since they are cheap, compact and light weight. Large number of uses of HOEs as elements of head-up display, fiber optical couplers, white light imaging systems, interferometry, imaging system for speckle metrology and solar concentrators etc. have been successfully demonstrated. Hologram of a point source can be generated by interference of a plane wave and a spherical wave and such a hologram can be regarded as a 'holographic lens'(Hololens). Holographic lenses offer many interesting features such as light weight, thin film geometry, multiplexing possibility and mass production through replication. Hololens can be used to transform an optical wavefront in much the same way as a conventional lens. In this thesis, the use of hololenses in speckle metrology, photo mechanics, and solar concentration is investigated.

Chapter I provides brief introduction to holography, holographic optical elements, speckle metrology and solar concentrator for photovoltaic application. Chapter II considers imaging properties of two hololens imaging system and its use in

the measurement of in-plane translation and in-plane rotation using speckle photographic technique. Chapter III presents the investigations made on the use of two hololens imaging system to study the in-plane displacements/deformations around the crack tip in Aluminium beam specimens having central edge crack subjected to three point bending. Various fracture parameters like crack tip opening displacement(CTOD), stress intensity factor(K), crack tip plastic zone size (r_p^*) and rotational factor (r) are obtained using the experimentally measured values of crack mouth opening displacements (CMODs) and crack opening displacements(CODS). By using properly designed hololenses, the limitations on the sensitivity of measurement of double aperture speckle interferometer (Duffy's arrangement) due to finite size of the conventional lenses can be tackled effectively. The details of the experimental set-up and the results obtained are presented in chapter IV. Chapter V presents the investigations made on the dependence of diffraction efficiency (η) of holographic concentrators on the angle of illumination for different values of hologram thickness and depth of refractive index modulation at three different wavelengths (λ = 0.4880 μm, λ = 0.5145 μm and λ = 0.6328 μm).

The investigations presented in the thesis strongly support the contention that the hololens imaging system can be designed to perform better than conventional systems both for speckle metrology and solar concentration.

The work reported in the thesis has resulted in the following publications/presentations.

Paper published

(1) C. Shakher, H. L. Yadav and A. K. Nirala, "Design and analysis of low f-number imaging system using Holo-lenses", J.opt.(Peris),20 , 259(1989).

(2) C. Shakher, H. L. Yadav, "Dependence of diffraction efficiency of holographic concentrators on angle of illumination, hologram-thickness and wavelength of illuminating light",J.opt.(Paris),21, 267(1990).

(3) C. Shakher, H.L. Yadav, "Use of holographic optical elements in speckle metrology. Part 3: application to fracture mechanics", Appl. Opt. 30, 3607 (1991).

Papers presented/published in conferences/symposia

(1) C. Shakher, G. V. Rao, H. L. Yadav and B. N. Gupta, "Laser speckle Metrology using Holo-lens imaging system and its Application in Fracture Mechanics". Proceeding of 14th Congress of International commission of optics, Quebec, Canada, August 24-28, 1987: pp. 209.

(2) C. Shakher, V. Ramamurty and H.L. Yadav, "Optimization of Thick Phase Transmission Hologram Processing Parameters for PV Concentrator Applications". Ref: Proceedings of 9th European PV Solar Energy Conference and Exhibition) 25-29

Sept. 1989. Albert-Ludwing University, Freiburg, Fed. Rep. of Germany - pp. 779.

(3) C. Shakher, H.L. Yadav, A.J. Permila Daniel, "Design, Analysis and Realization of Holo-Lens Imaging System for Speckle Metrology", Proc. of Third International Conference on "Holographic Systems, Components and Applications", Heriot-Watt University, UK: 16-18 September, 1991.

(4) C. Shakher, H.L. Yadav and A.K. Nirala, "Design and Analysis of High f-number and low f-number imaging system using Holo-lenses", Presented at 17th OSI Symposium on optics and opto-electronics",26-28 April, 1989. C.S.I.O.,Chandigarh.

(5) C. Shakher, H. L. Yadav and Avinash Mishra, "Laser speckle metrology using Two-Holo-Lens Imaging System and its application in Fracture Mechanics", Presented at 18th OSI Symposium on optics and opto-electronics- Indian Institute of Astrophysics Banglore, 21-23 March 1990.

Papers Communicated

(1) H.L. Yadav , A.J. Pramila Daniel and C. Shakher , "Realization of double aperture speckle interferometer using hololenses", J.opt.(Paris).

CONTENTS