

High-sensitivity reflection-transmission moiré deflectometer

Oded Kafri and Ilana Glatt

A new moiré deflectometer setup with a built-in telescope is proposed. This setup is equally suitable for measuring both phase objects and specular surfaces requiring only minor adjustments. The telescope-based design enables high-sensitivity testing of large optical components with a 2.54-cm (1-in.) aperture optical system.

Moiré deflectometry, a novel technique of ray deflection mapping, has proved an efficient, straightforward, and relatively low-cost tool for optical testing.¹⁻³ Moiré deflectometry enables comprehensive diagnostics of optical components and is fundamentally compatible with interferometry, since the data—ray deflection angles—can be translated into phase retardation by integration. The technique applies equally well for phase objects and specular surfaces, as demonstrated in numerous uses.³ The sensitivity of the method or alternatively the spatial resolution can be enhanced using telescopic⁴ or microscopic⁵ modes of operation, respectively. In the microscopic mode, the beam is expanded after passing through the test object, thus reducing the angular sensitivity and increasing the spatial resolution of the instrument. In the telescopic configuration, on the other hand, a reverse process is carried out: the angular resolution increases at the expense of the spatial resolution.

In this short paper we present an improved setup for a telescopic moiré deflectometer, which, besides increasing the sensitivity (we observed 1 order of magnitude improvement in angular resolution), is superior to the former configuration in two other respects: (1) the same setup is used for measurements of phase objects and specular surfaces; (2) nonflat (curved) specular surfaces can be tested.

The classical approach to a moiré deflectometer design requires different setups for testing transparent

and reflective objects as described in Fig. 1. In the basic setup for phase objects a collimated beam passes through the tested object and then traverses a set of gratings G_1 and G_2 of identical pitch p , separated by a distance Δ . The moiré pattern is formed by the overlap of the shadow of the first grating with the second grating and viewed on a mat screen attached to G_2 . To analyze reflective surfaces the setup is modified, as described in Fig. 2. The collimated beam is first projected on a specular surface at an angle ϕ , and the reflected beam passes the gratings' set. This setup suffers from an inherent distortion $1 \times \cos\phi$ in one axis. In addition other interfering effects such as shadowing might occur at higher angles.

The new setup is described in Fig. 3. Unlike the classical deflectometer setup, where the beam expansion is achieved by a reverse telescope comprising a microscope objective and telescope mirror (Newtonian telescope) attached to a laser, the new setup uses a Galilean telescope like the Fizeau interferometer. After the laser beam is expanded to the required width, passing through the set of microscope objective and a large objective lens, it passes through the phase object (assuming that it remains parallel within the paraxial approximation) and is then reflected back into the telescope by a flat mirror, thus passing twice through the phase object. The retraced beam is diverted 90° by a beam splitter into a smaller objective lens and is recollimated. Now a small-diameter deflectometer might be used to detect ray deflections. This setup can be easily modified to measure specular objects simply by replacing the flat reflector with the tested surface. With a small modification this setup can also measure surfaces with large curvature, where the paraxial approximation does not hold. For example, to measure a spherical mirror with a focal length f , the position of the large objective lens is adjusted so that the divergence of the reflected beam is identical to that of the incident one. Measuring lenses of short focal

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High Sensitivity Moire

**Cesar A. Sciammarella, Federico M.
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High Sensitivity Moire:

High Sensitivity Moiré Daniel Post, Bongtae Han, Peter Ifju, 1997-04-24 A description of both the theory and practice of physical measurements that use high sensitivity moir principally moir interferometry The focus here is on the mechanics and micromechanics of materials and structural elements and the book includes new studies published for the first time Diverse fields are addressed advanced composite materials thermal stresses electronic packaging fracture metallurgy time dependence strain gage calibration All the methods can be applied for whole field measurements on nearly and solid bodies This reader friendly book will serve engineers and scientists who are concerned with measurements of real phenomena while also stimulating students to pursue the treasures of experimental analysis

High-Sensitivity Moire D. Post, B. Han, P. Ifju, 1997-05-01

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Metal Matrix Composites W. Steven Johnson, 1989 Fourteen peer reviewed papers on testing techniques analysis approaches and descriptions of various failure processes From the Symposium on title held at Sparks NV April 1988 Annotation copyright Book News Inc Portland Or

Advanced Materials for Electromagnetic Shielding Maciej Jaroszewski, Sabu Thomas, Ajay V. Rane, 2018-11-29 A comprehensive review of the field of materials that shield people and sensitive electronic devices from electromagnetic fields Advanced Materials for Electromagnetic Shielding offers a thorough review of the most recent advances in the processing and characterization of the electromagnetic shielding materials In this groundbreaking book the authors noted experts in the field discuss the fundamentals of shielding theory as well as the practice of electromagnetic field measuring techniques and systems They also explore applications of shielding materials used as absorbers of electromagnetic radiation or as magnetic shields and explore coverage of new advanced materials for EMI shielding in aerospace applications In addition the text contains methods of preparation and applicability of metal foams This comprehensive text examines the influence of technology on the micro and macrostructure of polymers enabling their use in screening technology technologies of shielding materials based on textiles and analyses of its effectiveness in screening The book also details the method of producing nanowires and their applications in EM shielding This important resource Explores the burgeoning market of electromagnetic shielding materials as we create depend upon and are exposed to more electronic devices than ever Addresses the most comprehensive issues relating to electromagnetic fields Contains information on the manufacturing characterization methods and properties of materials used to protect against them Discusses the important characterization techniques compared with one another thus allowing scientists to select the best approach to a problem Written for materials scientists electrical and electronics engineers physicists and industrial researchers Advanced Materials for Electromagnetic

Shielding explores all aspects in the area of electromagnetic shielding materials and examines the current state of the art and new challenges in this rapidly growing area

Experimental Mechanics of Solids Cesar A. Sciammarella, Federico M. Sciammarella, 2012-03-26 Experimental solid mechanics is the study of materials to determine their physical properties This study might include performing a stress analysis or measuring the extent of displacement shape strain and stress which a material suffers under controlled conditions In the last few years there have been remarkable developments in experimental techniques that measure shape displacement and strains and these sorts of experiments are increasingly conducted using computational techniques Experimental Mechanics of Solids is a comprehensive introduction to the topics technologies and methods of experimental mechanics of solids It begins by establishing the fundamentals of continuum mechanics explaining key areas such as the equations used stresses and strains and two and three dimensional problems Having laid down the foundations of the topic the book then moves on to look at specific techniques and technologies with emphasis on the most recent developments such as optics and image processing Most of the current computational methods as well as practical ones are included to ensure that the book provides information essential to the reader in practical or research applications Key features Presents widely used and accepted methodologies that are based on research and development work of the lead author Systematically works through the topics and theories of experimental mechanics including detailed treatments of the Moire Speckle and holographic optical methods Includes illustrations and diagrams to illuminate the topic clearly for the reader Provides a comprehensive introduction to the topic and also acts as a quick reference guide This comprehensive book forms an invaluable resource for graduate students and is also a point of reference for researchers and practitioners in structural and materials engineering

Adhesively Bonded Joints W. Steven Johnson, 1988 Optical Methods of Engineering Analysis Gary L. Cloud, 1998-05-28 Fundamental measurement problems in engineering mechanics manufacturing and physics are now being solved by powerful optical methods This book presents a lucid up to date discussion of these optical methods Beginning from a firm base in modern optics the book proceeds through relevant theory of interference and diffraction and integrates this theory with descriptions of laboratory techniques and apparatus Among the techniques discussed are classical interferometry photoelasticity geometric moire spatial filtering moire interferometry holography holographic interferometry laser speckle interferometry and video based speckle methods By providing a firm base in the physical principles and at the same time allowing the reader to perform meaningful experiments related to the topic being studied the book offers a unique user oriented approach that will appeal to students researchers and practising engineers

Fracture Mechanics of Piezoelectric and Ferroelectric Solids Daining Fang, Jinxi Liu, 2014-12-12 Fracture Mechanics of Piezoelectric and Ferroelectric Solids presents a systematic and comprehensive coverage of the fracture mechanics of piezoelectric ferroelectric materials which includes the theoretical analysis numerical computations and experimental observations The main emphasis is placed on the mechanics description of

various crack problems such static dynamic and interface fractures as well as the physical explanations for the mechanism of electrically induced fracture The book is intended for postgraduate students researchers and engineers in the fields of solid mechanics applied physics material science and mechanical engineering Dr Daining Fang is a professor at the School of Aerospace Tsinghua University China Dr Jinxi Liu is a professor at the Department of Engineering Mechanics Shijiazhuang Railway Institute China

Experimental Mechanics I. M. Allison, British Society for Strain Measurement, European Permanent Committee for Experimental Mechanics, 1998

Optical Inspection of Microsystems Wolfgang Osten, 2018-10-03

Where conventional testing and inspection techniques fail at the micro scale optical techniques provide a fast robust and relatively inexpensive alternative for investigating the properties and quality of microsystems Speed reliability and cost are critical factors in the continued scale up of microsystems technology across many industries and optical techniques are in a unique position to satisfy modern commercial and industrial demands *Optical Inspection of Microsystems* is the first comprehensive up to date survey of the most important and widely used full field optical metrology and inspection technologies Under the guidance of accomplished researcher Wolfgang Osten expert contributors from industrial and academic institutions around the world share their expertise and experience with techniques such as image correlation light scattering scanning probe microscopy confocal microscopy fringe projection grid and moir techniques interference microscopy laser Doppler vibrometry holography speckle metrology and spectroscopy They also examine modern approaches to data acquisition and processing The book emphasizes the evaluation of various properties to increase reliability and promote a consistent approach to optical testing Numerous practical examples and illustrations reinforce the concepts Supplying advanced tools for microsystem manufacturing and characterization *Optical Inspection of Microsystems* enables you to reach toward a higher level of quality and reliability in modern micro scale applications

Recent Advances in Experimental Mechanics E.E. Gdoutos, 2007-05-08 This book contains 71 papers presented at the symposium on Recent Advances in Experimental Mechanics which was organized in honor of Professor Isaac M Daniel The symposium took place at Virginia Polytechnic Institute and State University on th June 23 28 2002 in conjunction with the 14 US National Congress of Applied Mechanics The book is a tribute to Isaac Daniel a pioneer of experimental mechanics and composite materials in recognition of his continuous original diversified and outstanding contributions for half a century The book consists of invited papers written by leading experts in the field It contains original contributions concerning the latest developments in experimental mechanics It covers a wide range of subjects including optical methods of stress analysis photoelasticity moir etc composite materials sandwich construction fracture mechanics fatigue and damage nondestructive evaluation dynamic problems fiber optic sensors speckle metrology digital image processing nanotechnology neutron diffraction and synchrotron radiation methods The papers are arranged in the following nine sections Mechanical characterization of material behavior composite materials fracture and fatigue optical methods n destructive evaluation neutron diffraction and synchrotron

radiation methods hybrid methods composite structures and structural testing and analysis Thermal Stress and Strain in Microelectronics Packaging John Lau, 2012-12-06 Microelectronics packaging and interconnection have experienced exciting growth stimulated by the recognition that systems not just silicon provide the solution to evolving applications In order to have a high density performance yield quality reliability low cost and light weight system a more precise understanding of the system behavior is required Mechanical and thermal phenomena are among the least understood and most complex of the many phenomena encountered in microelectronics packaging systems and are found on the critical path of nearly every design and process in the electronics industry The last decade has witnessed an explosive growth in the research and development efforts devoted to determining the mechanical and thermal behaviors of microelectronics packaging With the advance of very large scale integration technologies thousands to tens of thousands of devices can be fabricated on a silicon chip At the same time demands to further reduce packaging signal delay and increase packaging density between communicating circuits have led to the use of very high power dissipation single chip modules and multi chip modules The result of these developments has been a rapid growth in module level heat flux within the personal workstation midrange mainframe and super computers Thus thermal temperature stress and strain management is vital for microelectronics packaging designs and analyses How to determine the temperature distribution in the electronics components and systems is outside the scope of this book which focuses on the determination of stress and strain distributions in the electronics packaging **Simulation and Experiment in Laser Metrology** Zoltan Füzessy, Werner Jütner, Wolfgang Osten, 1996 These proceedings document about 45 contributions to the International Symposium on Laser Applications in Precision Measurement held in Balatonfured Hungary during June 3-6 1996 Special emphasis was given to the Combination of Simulation and Experiment in Laser Metrology International experts provide a survey over a large variety of their latest achievements and developments in this rapidly advancing field Over the last years optical measurement techniques like structured illumination holographic interferometry and tomography were applied more and more in combination with CAE tools such as CAD and FEM This combination has found a world of new applications in scientific and industrial branches interested in highly exact but nondestructive and noncontact measurement of technical components Each of the four sections contains an overview article given by international leading experts With that the proceedings should be considered to be a state of the art report combining the areas of mathematical modeling of objects experimental testing under definite stresses computer aided evaluation and measuring of objects Optical Methods of Measurement Rajpal Sirohi, 2018-09-03 Optical Methods of Measurement Wholefield Techniques Second Edition provides a comprehensive collection of wholefield optical measurement techniques for engineering applications Along with the reorganization of contents this edition includes a new chapter on optical interference new material on nondiffracting and singular beams and their applications and updated bibliography and additional reading sections The book explores the propagation of laser beams metrological applications of

phase singular beams various detectors such as CCD and CMOS devices and recording materials It also covers interference diffraction and digital fringe pattern measurement techniques with special emphasis on phase measurement interferometry and algorithms The remainder of the book focuses on theory experimental arrangements and applications of wholefield techniques The author discusses digital hologram interferometry digital speckle photography digital speckle pattern interferometry Talbot interferometry and holophotoelasticity This updated book compiles the major wholefield methods of measurement in one volume It provides a solid understanding of the techniques by describing the physics behind them In addition the examples given illustrate how the techniques solve measurement problems

Selected Papers on Optical Moiré and Applications Guy Indebetouw,1992 Optical Inspection of Microsystems, Second Edition Wolfgang Osten,2019-06-21 Where conventional testing and inspection techniques fail at the microscale optical techniques provide a fast robust noninvasive and relatively inexpensive alternative for investigating the properties and quality of microsystems Speed reliability and cost are critical factors in the continued scale up of microsystems technology across many industries and optical techniques are in a unique position to satisfy modern commercial and industrial demands Optical Inspection of Microsystems Second Edition extends and updates the first comprehensive survey of the most important optical measurement techniques to be successfully used for the inspection of microsystems Under the guidance of accomplished researcher Wolfgang Osten expert contributors from industrial and academic institutions around the world share their expertise and experience with techniques such as image processing image correlation light scattering scanning probe microscopy confocal microscopy fringe projection grid and moire techniques interference microscopy laser Doppler vibrometry digital holography speckle metrology spectroscopy and sensor fusion technologies They also examine modern approaches to data acquisition and processing such as the determination of surface features and the estimation of uncertainty of measurement results The book emphasizes the evaluation of various system properties and considers encapsulated components to increase quality and reliability Numerous practical examples and illustrations of optical testing reinforce the concepts Supplying effective tools for increased quality and reliability this book Provides a comprehensive up to date overview of optical techniques for the measurement and inspection of microsystems Discusses image correlation displacement and strain measurement electro optic holography and speckle metrology techniques Offers numerous practical examples and illustrations Includes calibration of optical measurement systems for the inspection of MEMS Presents the characterization of dynamics of MEMS

Advances in Manufacturing and Processing of Materials and Structures Yoseph Bar-Cohen,2018-09-03 Advances in Manufacturing and Processing of Materials and Structures cover the latest advances in materials and structures in manufacturing and processing including additive and subtractive processes It is intended to provide a compiled resource that reviews details of the advances that have been made in recent years in manufacturing and processing of materials and structures A key development incorporated within this book is 3D printing

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Shokrieh,2021-06-22 The residual stress is a common phenomenon in composite materials They can either add to or significantly reduce material strength Because of the increasing demand for high strength lightweight materials such as composites and their wide range of applications it is critical that the residual stresses of composite materials are understood and measured correctly The first edition of this book consists of thirteen chapters divided into two parts The first part reviews destructive and non destructive testing NDT techniques for measuring residual stresses There are also additional chapters on using mathematical analytical and numerical methods for the calculation of residual stresses in composite materials These include the simulated hole drilling method the slitting crack compliance method measuring residual stresses in homogeneous and composite glass materials using photoelastic techniques and modeling residual stresses in composite materials The second part of the book discusses measuring residual stresses in different types of composites including polymer and metal matrix composites The addition of nanoparticles to the matrix of polymeric composites as a new technique for the reduction of residual stresses is also discussed In the Second Edition of this book each of the original chapters of the first edition has been fully updated taking into account the latest research and new developments There are also five new chapters on the theoretical and experimental studies of residual stresses in the composite integrated circuits residual stresses in additive manufacturing of polymers and polymer matrix composites residual stresses in metal matrix composites fabricated by additive manufacturing the eigenstrain based method for the incremental hole drilling technique and the estimation of residual stresses in polymer matrix composites using the digital image correlation technique Residual Stresses in Composite Materials Second Edition provides a unique and comprehensive overview of this important topic and is an invaluable reference text for both academics and professionals working in the mechanical engineering civil engineering aerospace automotive marine and sporting industries Presents the latest developments on theoretical and experimental studies of residual stresses in composites Reviews destructive and non destructive testing NDT techniques for measuring residual stresses Discusses residual stresses in the polymer matrix metal matrix and ceramic matrix composites Considers the addition of nanoparticles to the matrix as a new technique for reduction of residual stresses in polymeric composites Introduces the latest advancements of research on the residual stresses in additive manufactured polymer and metal matrix

composites **Photomechanics** Pramod K. Rastogi, 2003-07-01 Presenting the use of photonics techniques for measurement in mechanics this book provides a state of the art review of this active and rapidly growing field It serves as an invaluable resource for readers to explore the current status and includes a wealth of information on the essential principles and methods It provides a substantial background in a concise and simple way to enable physicists and engineers to assess analyze and implement experimental systems needed to solve their specific measurement problems

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