Chapter 2
MEMS Accelerometers: Testing and Practical Approach for Smart Sensing and Machinery Diagnostics

A. Albarbar and S.H. Teay

Abstract Micro-Electro Mechanical Systems (MEMS)-based sensing elements are gaining wider acceptance and adoption for static and dynamic (mobile) applications. Recent increase in demands for reliable wireless sensing nodes has necessitated seeking alternatives to expensive conventional accelerometers to perform multi-control and monitoring tasks. Owed to their size and cost, MEMS accelerometers is one of the alternative options.

This chapter provides insight into the fundamental design, working principles and practical guidance to MEMS accelerometers. Details of experimental set-ups, signal conditioning and data processing are also provided to construct integrated performance assessment system. Performance assessments are carried out using sinusoidal excitations, impulsive (hummer testing) and random excitations. Subsequently, calculations and comments on frequency response functions, signal-to-noise ratios and phase distortions are outlined. Finally, guidelines to practical adoption of MEMS accelerometers such as packaging, establishing smart vibration sensing nodes and extraction of condition-related information are given.

Keywords MEMS accelerometers design and testing • Performance assessment of MEMS accelerometers • Vibration measurement using MEMS sensors • Smart sensor design and implementation • Machinery-condition monitoring

1 Introduction

Vibration analysis is one of the most usable methods in machinery-condition monitoring. It plays a significant role in the dynamic qualification of newly designed structural components, prediction of faults and structural aging-related problems, and several other structural dynamics studies and diagnosis [1–3]. One reason for

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Chapter 2 Mems Accelerometers Testing And Practical

Raouf A. Ibrahim

Chapter 2 Mems Accelerometers Testing And Practical:

Advanced Mechatronics and MEMS Devices II Dan Zhang,Bin Wei,2016-10-18 This book introduces the state of the art technologies in mechatronics robotics and MEMS devices in order to improve their methodologies It provides a follow up to Advanced Mechatronics and MEMS Devices 2013 with an exploration of the most up to date technologies and their applications shown through examples that give readers insights and lessons learned from actual projects Researchers on mechatronics robotics and MEMS as well as graduate students in mechanical engineering will find chapters on Fundamental design and working principles on MEMS accelerometers Innovative mobile technologies Force tactile sensors development Control schemes for reconfigurable robotic systems Inertial microfluidics Piezoelectric force sensors and dynamic calibration techniques And more Authors explore applications in the areas of agriculture biomedicine advanced manufacturing and space Micro assembly for current and future industries is also considered as well as the design and development of micro and intelligent manufacturing *Failure Analysis* Marius Bazu,Titu Bajenescu,2011-03-08 Failure analysis is the preferred method to investigate product or process reliability and to ensure optimum performance of electrical components and systems The physics of failure approach is the only internationally accepted solution for continuously improving the reliability of materials devices and processes The models have been developed from the physical and chemical phenomena that are responsible for degradation or failure of electronic components and materials and now replace popular distribution models for failure mechanisms such as Weibull or lognormal Reliability engineers need practical orientation around the complex procedures involved in failure analysis This guide acts as a tool for all advanced techniques their benefits and vital aspects of their use in a reliability programme Using twelve complex case studies the authors explain why failure analysis should be used with electronic components when implementation is appropriate and methods for its successful use Inside you will find detailed coverage on a synergistic approach to failure modes and mechanisms along with reliability physics and the failure analysis of materials emphasizing the vital importance of cooperation between a product development team involved the reasons why failure analysis is an important tool for improving yield and reliability by corrective actions the design stage highlighting the concurrent engineering approach and DfR Design for Reliability failure analysis during fabrication covering reliability monitoring process monitors and package reliability reliability resting after fabrication including reliability assessment at this stage and corrective actions a large variety of methods such as electrical methods thermal methods optical methods electron microscopy mechanical methods X Ray methods spectroscopic acoustical and laser methods new challenges in reliability testing such as its use in microsystems and nanostructures This practical yet comprehensive reference is useful for manufacturers and engineers involved in the design fabrication and testing of electronic components devices ICs and electronic systems as well as for users of components in complex systems wanting to discover the roots of the reliability flaws for their products **Springer Handbook of Nanotechnology** Bharat Bhushan,2004-01-19 This major

work has established itself as the definitive reference in the nanoscience and nanotechnology area in one volume In presents nanostructures micro nanofabrication and micro nanodevices Special emphasis is on scanning probe microscopy nanotribology and nanomechanics molecularly thick films industrial applications and microdevice reliability and on social aspects Reflecting further developments the new edition has grown from six to eight parts The latest information is added to fields such as bionanotechnology nanorobotics and NEMS MEMS reliability This classic reference book is orchestrated by a highly experienced editor and written by a team of distinguished experts for those learning about the field of nanotechnology

Handbook of Structural Life Assessment Raouf A. Ibrahim,2017-03-29 This important self contained reference deals with structural life assessment SLA and structural health monitoring SHM in a combined form SLA periodically evaluates the state and condition of a structural system and provides recommendations for possible maintenance actions or the end of structural service life It is a diversified field and relies on the theories of fracture mechanics fatigue damage process and reliability theory For common structures their life assessment is not only governed by the theory of fracture mechanics and fatigue damage process but by other factors such as corrosion grounding and sudden collision On the other hand SHM deals with the detection prediction and location of crack development online Both SLA and SHM are combined in a unified and coherent treatment *Advanced MEMS Packaging* John H. Lau,Cheng Kuo Lee,C. S. Premachandran,Yu Aibin,2009-10-22 A comprehensive guide to 3D MEMS packaging methods and solutions Written by experts in the field Advanced MEMS Packaging serves as a valuable reference for those faced with the challenges created by the ever increasing interest in MEMS devices and packaging This authoritative guide presents cutting edge MEMS microelectromechanical systems packaging techniques such as low temperature C2W and W2W bonding and 3D packaging This definitive resource helps you select reliable creative high performance robust and cost effective packaging techniques for MEMS devices The book will also aid in stimulating further research and development in electrical optical mechanical and thermal designs as well as materials processes manufacturing testing and reliability Among the topics explored Advanced IC and MEMS packaging trends MEMS devices commercial applications and markets More than 360 MEMS packaging patents and 10 3D MEMS packaging designs TSV for 3D MEMS packaging MEMS wafer thinning dicing and handling Low temperature C2C C2W and W2W bonding Reliability of RoHS compliant MEMS packaging Micromachining and water bonding techniques Actuation mechanisms and integrated micromachining Bubble switch optical switch and VOA MEMS packaging Bolometer and accelerameter MEMS packaging Bio MEMS and biosensor MEMS packaging RF MEMS switches tunable circuits and packaging Case-based Reasoning for MEMS Design Synthesis Corie Lynn Cobb,2008 *Enabling Technology for MEMS and Nanodevices* Henry Baltes,2004-08-06 Microstructures electronics nanotechnology these vast fields of research are growing together as the size gap narrows and many different materials are combined Current research engineering sucesses and newly commercialized products hint at the immense innovative potentials and future applications that open up once

mankind controls shape and function from the atomic level right up to the visible world without any gaps Sensor systems microreactors nanostructures nanomachines functional surfaces integrated optics displays communications technology biochips human machine interfaces prosthetics miniaturized medical and surgery equipment and many more opportunities are being explored This new series Advanced Micro Nanosystems provides cutting edge reviews from top authors on technologies devices and advanced systems from the micro and nano worlds **Applied Mechanics Reviews** ,2000 **Contact Mechanics--friction** ,2003 *Lecture series* ,2002 **Design and Testing of MEMS Accelerometers for Machine Condition Monitoring Applications** Ghalib Al-Busafi,University of Manchester,2007 **Practical MEMS** Ville Kaajakari,2024 **MEMS Accelerometer** Keith Hoffman (N.),2004 MEMS Silicon Oscillating Accelerometers and Readout Circuits Yong Ping Xu,2022-09-01 Most MEMS accelerometers on the market today are capacitive accelerometers that are based on the displacement sensing mechanism This book is intended to cover recent developments of MEMS silicon oscillating accelerometers SOA also referred to as MEMS resonant accelerometer As contrast to the capacitive accelerometer the MEMS SOA is based on the force sensing mechanism where the input acceleration is converted to a frequency output MEMS Silicon Oscillating Accelerometers and Readout Circuits consists of six chapters and covers both MEMS sensor and readout circuit and provides an in depth coverage on the design and modelling of the MEMS SOA with several recently reported prototypes The book is not only useful to researchers and engineers who are familiar with the topic but also appeals to those who have general interests in MEMS inertial sensors The book includes extensive references that provide further information on this topic Design, Modelling, Self-testing and Self-calibration of MEMS Accelerometers with Adaptive and Non-linear Digital Control Elie H. Sarraf,2013 Mems Silicon Oscillating Accelerometers and Readout Circuits Yong Ping Xu,2023-05-31 Most MEMS accelerometers on the market today are capacitive accelerometers that are based on the displacement sensing mechanism This book is intended to cover recent developments of MEMS silicon oscillating accelerometers SOA also referred to as MEMS resonant accelerometer As contrast to the capacitive accelerometer the MEMS SOA is based on the force sensing mechanism where the input acceleration is converted to a frequency output MEMS Silicon Oscillating Accelerometers and Readout Circuits consists of six chapters and covers both MEMS sensor and readout circuit and provides an in depth coverage on the design and modelling of the MEMS SOA with several recently reported prototypes The book is not only useful to researchers and engineers who are familiar with the topic but also appeals to those who have general interests in MEMS inertial sensors The book includes extensive references that provide further information on this topic MEMS Accelerometers Mahmoud Rasras,2019-05-27 Micro electro mechanical system MEMS devices are widely used for inertia pressure and ultrasound sensing applications Research on integrated MEMS technology has undergone extensive development driven by the requirements of a compact footprint low cost and increased functionality Accelerometers are among the most widely used sensors implemented in MEMS technology MEMS

accelerometers are showing a growing presence in almost all industries ranging from automotive to medical A traditional MEMS accelerometer employs a proof mass suspended to springs which displaces in response to an external acceleration A single proof mass can be used for one or multi axis sensing A variety of transduction mechanisms have been used to detect the displacement They include capacitive piezoelectric thermal tunneling and optical mechanisms Capacitive accelerometers are widely used due to their DC measurement interface thermal stability reliability and low cost However they are sensitive to electromagnetic field interferences and have poor performance for high end applications e g precise attitude control for the satellite Over the past three decades steady progress has been made in the area of optical accelerometers for high performance and high sensitivity applications but several challenges are still to be tackled by researchers and engineers to fully realize opto mechanical accelerometers such as chip scale integration scaling low bandwidth etc This Special Issue on MEMS Accelerometers seeks to highlight research papers short communications and review articles that focus on Novel designs fabrication platforms characterization optimization and modeling of MEMS accelerometers Alternative transduction techniques with special emphasis on opto mechanical sensing Novel applications employing MEMS accelerometers for consumer electronics industries medicine entertainment navigation etc Multi physics design tools and methodologies including MEMS electronics co design Novel accelerometer technologies and 9DoF IMU integration Multi accelerometer platforms and their data fusion **MEMS Accelerometers** Ibrahim (Abe) M. Elfadel,Ha Duong Ngo,Mahmoud Rasras,2019 Micro electro mechanical system MEMS devices are widely used for inertia pressure and ultrasound sensing applications Research on integrated MEMS technology has undergone extensive development driven by the requirements of a compact footprint low cost and increased functionality Accelerometers are among the most widely used sensors implemented in MEMS technology MEMS accelerometers are showing a growing presence in almost all industries ranging from automotive to medical A traditional MEMS accelerometer employs a proof mass suspended to springs which displaces in response to an external acceleration A single proof mass can be used for one or multi axis sensing A variety of transduction mechanisms have been used to detect the displacement They include capacitive piezoelectric thermal tunneling and optical mechanisms Capacitive accelerometers are widely used due to their DC measurement interface thermal stability reliability and low cost However they are sensitive to electromagnetic field interferences and have poor performance for high end applications e g precise attitude control for the satellite Over the past three decades steady progress has been made in the area of optical accelerometers for high performance and high sensitivity applications but several challenges are still to be tackled by researchers and engineers to fully realize opto mechanical accelerometers such as chip scale integration scaling low bandwidth etc This Special Issue on MEMS Accelerometers seeks to highlight research papers short communications and review articles that focus on Novel designs fabrication platforms characterization optimization and modeling of MEMS accelerometers Alternative transduction techniques with special emphasis on opto mechanical sensing Novel applications

employing MEMS accelerometers for consumer electronics industries medicine entertainment navigation etc Multi physics design tools and methodologies including MEMS electronics co design Novel accelerometer technologies and 9DoF IMU integration Multi accelerometer platforms and their data fusion **Design, Prototyping and Testing of Biaxial MEMS Accelerometers for Rigid-body Pose-and-twist Estimation** Xiaowei Shan,2017 The reported research work aims to develop a novel class of accelerometers applicable to the high accuracy estimation of rigid body pose and twist These accelerometers based on a monolithic biaxial architecture dubbed Orchid were designed for fabrication as MEMS microelectromechanical system with isotropic stiffness in the sensitive plane and high frequency ratios between the insensitive and sensitive directions The architecture is intended to accommodate any regular polygonal shape with a suspension that allows for an in plane translation of the proof mass with respect to the frame Structural optimization is conducted to yield high frequency ratios and a high degree of compliance in the suspension for low g applications and planar excitation Lam curves are introduced in the fillets to relieve the stress concentration The elastically isotropic structure in the sensitive plane is analyzed symbolically and validated numerically and experimentally The microfabrication process was then devised and conducted with high precision for triangular and square Orchid structures Techniques and recipes were studied to solve the wafer bonding problem with large cavities adhesive influence on structural etching and reflectivity adjustment of the sample surface Vibration tests were conducted in the MEMS prototypes to validate the isotropic sensitivity of the biaxial architecture In light of the isotropic Orchid architecture a novel biaxial MEMS accelerometer W30P4 was designed fabricated and tested for low g applications The accelerometer monolithic structure was optimally designed based on a fully symmetric architecture with a high frequency ratio between the insensitive and sensitive axes To facilitate the utilization of the proposed architecture an analysis environment is developed for the modal and static analyses of user defined structural parameters The sensing substructure was designed with a configurable comb structure for simultaneous biaxial capacitive sensing This accelerometer was fabricated with high precision and tested under 1 g acceleration both statically and dynamically Test results validate the isotropy of the Orchid architecture and the high signal to noise ratio of the W30P4 biaxial accelerometer Finally an accelerometer strapdown was designed and configured using the W30P4 accelerometers based on an octahedron frame inscribing the tetrahedron strapdown An embedded microsystem was devised and coded inside the accelerometer strapdown to convert and transmit the signals wirelessly to a host computer Moreover the mathematical and simulation models were established to estimate rigid body pose and twist using this accelerometer strapdown Test results on a haptic manipulator validate the effectiveness of its position estimation and provide insight into the hardware improvement **MEMS Accelerometer Specifications and Their Impact in Inertial Applications** Kei-Ming Kwong,2017 Recent development of microelectromechanical systems MEMS accelerometers improved their performance Coupled with their benefits of lower cost and smaller size enabled their increased utilization in navigation

automotive and consumer devices However specification and testing methodologies of these devices are not robustly defined This work investigates and defines a set of testing methodology for MEMS accelerometers making use of a 3D printer based testing platform and a scalable inertial sensor testing board Specification results show that Kionix KXRB5 and Invensense MPU6000 perform the best of the devices tested Furthermore commonly used inertial algorithms were applied to study the impact of accelerometer choice in an inertial navigation system INS Across a attitude estimation and dead reckoning tests results indicate that noise density has little impact on performance after inertial algorithms are applied Cross axis bias variability and step motion specification results are better indicators of performance after inertial algorithms are applied

Chapter 2 Mems Accelerometers Testing And Practical: Bestsellers in 2023 The year 2023 has witnessed a remarkable surge in literary brilliance, with numerous compelling novels captivating the hearts of readers worldwide. Lets delve into the realm of bestselling books, exploring the captivating narratives that have charmed audiences this year. Chapter 2 Mems Accelerometers Testing And Practical : Colleen Hoovers "It Ends with Us" This heartfelt tale of love, loss, and resilience has captivated readers with its raw and emotional exploration of domestic abuse. Hoover skillfully weaves a story of hope and healing, reminding us that even in the darkest of times, the human spirit can prevail. Chapter 2 Mems Accelerometers Testing And Practical : Taylor Jenkins Reids "The Seven Husbands of Evelyn Hugo" This captivating historical fiction novel unravels the life of Evelyn Hugo, a Hollywood icon who defies expectations and societal norms to pursue her dreams. Reids absorbing storytelling and compelling characters transport readers to a bygone era, immersing them in a world of glamour, ambition, and self-discovery. Chapter 2 Mems Accelerometers Testing And Practical : Delia Owens "Where the Crawdads Sing" This captivating coming-of-age story follows Kya Clark, a young woman who grows up alone in the marshes of North Carolina. Owens spins a tale of resilience, survival, and the transformative power of nature, captivating readers with its evocative prose and mesmerizing setting. These popular novels represent just a fraction of the literary treasures that have emerged in 2023. Whether you seek tales of romance, adventure, or personal growth, the world of literature offers an abundance of engaging stories waiting to be discovered. The novel begins with Richard Papen, a bright but troubled young man, arriving at Hampden College. Richard is immediately drawn to the group of students who call themselves the Classics Club. The club is led by Henry Winter, a brilliant and charismatic young man. Henry is obsessed with Greek mythology and philosophy, and he quickly draws Richard into his world. The other members of the Classics Club are equally as fascinating. Bunny Corcoran is a wealthy and spoiled young man who is always looking for a good time. Charles Tavis is a quiet and reserved young man who is deeply in love with Henry. Camilla Macaulay is a beautiful and intelligent young woman who is drawn to the power and danger of the Classics Club. The students are all deeply in love with Morrow, and they are willing to do anything to please him. Morrow is a complex and mysterious figure, and he seems to be manipulating the students for his own purposes. As the students become more involved with Morrow, they begin to commit increasingly dangerous acts. The Secret History is a brilliant and suspenseful novel that will keep you wondering until the very end. The novel is a warning tale about the dangers of obsession and the power of evil.

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