

## 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. Owing 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 (hammer 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

**Ibrahim (Abe) M. Elfadel, Ha Duong  
Ngo, Mahmoud Rasras**



## **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. It 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, 2017-04-17. 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 accelerometer; 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. [Applied Mechanics Reviews](#), 2000. *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 successes 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 *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

## Adopting the Melody of Expression: An Psychological Symphony within **Chapter 2 Mems Accelerometers Testing And Practical**

In a world consumed by screens and the ceaseless chatter of fast communication, the melodic beauty and emotional symphony developed by the prepared word frequently diminish in to the back ground, eclipsed by the persistent noise and interruptions that permeate our lives. Nevertheless, situated within the pages of **Chapter 2 Mems Accelerometers Testing And Practical** a marvelous literary treasure full of natural feelings, lies an immersive symphony waiting to be embraced. Crafted by an outstanding musician of language, this captivating masterpiece conducts viewers on a mental journey, skillfully unraveling the concealed tunes and profound impact resonating within each carefully constructed phrase. Within the depths with this poignant evaluation, we can investigate the book is central harmonies, analyze their enthralling writing fashion, and surrender ourselves to the profound resonance that echoes in the depths of readers souls.

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## **Chapter 2 MemS Accelerometers Testing And Practical Introduction**

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web jul 25 2020 het is dus belangrijk dat je de juiste ex terug methode gebruikt in dit artikel geef ik je 8 van de beste methoden strategieën en technieken die jou gaan helpen om de relatie met je ex te herstellen zo kun jij gemakkelijk jouw beste ex

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web de ex terug methode is een manier om je ex terug te krijgen de informatiepagina zegt dat je je ex vrij makkelijk kan terugkrijgen met een aantal psychologische triggers of dit geheel waar is moeilijk na te gaan wel kunnen we

**is de ex terug methode van edwin edinga de moeite waard** - Jan 29 2022

web de ex terug methode begint met een aantal fouten die je juist niet moet maken als je jouw ex terug wilt krijgen altijd handig door direct te weten wat je niet moet doen voorkom je dat je aan het begin al de mist in gaat daarvoor is het natuurlijk wel belangrijk dat je dit boek leest voordat je die fouten per ongeluk al gemaakt hebt

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web aug 2 2022 in je ex terugwinnen ga je een aantal belangrijke en bewezen toepassingen achter deze methode leren kennen de methode om je ex terug te winnen bestaat uit psychologische triggers die je op een positieve manier op je ex moet uitoefenen

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web ex terug methode review of het werkt en mijn mening een gelukkige relatie die opeens voorbij is dat is een van de meest vreselijke gevoelens die er zijn je hebt het heel lang ontzettend naar je zin gehad met iemand en die periode is plotsklaps voorbij maar je gevoelens zijn dat niet deze kunnen nog heel lang aanhouden

**10 belangrijke tips om snel je ex terug te winnen** - Jun 14 2023

web tip 1 probeer kalm te blijven dus jullie zijn uit elkaar gegaan en je denkt dat dit het einde van de wereld is je geeft jezelf de schuld en denkt aan alle dingen die je anders had moeten doen de paniek slaat toe dat de relatie nu wel eens definitief over is kalm blijven in tijden van tegenspoed is voor velen geen gemakkelijke opgave

**officiële site ex terug methode bestel nu met korting** - Oct 06 2022

web ik zal je stap voor stap uitleggen wat je moet doen om je ex terug te krijgen en wat er allemaal in je ex omgaat je zal weten wat er omgaat in het hoofd van je ex ontdekken hoe je de juiste knoppen van je ex indrukt je ex terugkrijgen binnen

enkele weken de relatie krijgen waar je altijd al van gedroomd hebt

**terug bij mijn ex een goed idee volg onze ex terugwinnen methode** - Jun 02 2022

web aug 13 2018 een belangrijk onderdeel in de ex terug methode is om niet koel te blijven als jullie een aantal keren hebben afgesproken zal je op een subtiele manier je ex moeten versieren ik zal hier een aantal doeltreffende versiertips [je ex terugwinnen met afbeeldingen wikipedi](#) - May 13 2023

web deel 1 de scheiding beoordelen 1 begrijp waarom het uit ging wat deden jullie beiden waardoor de breuk tot stand kwam de meeste relatieproblemen ontstaan niet zomaar onverwacht maar bouwen zich langzaam op de kans is groot dat het probleem niet van een kant komt en dat er tekenen waren dat het eraan zat te komen

*hoe krijg ik mijn ex terug win snel je ex terug en stop* - Mar 31 2022

web de ex terug methode kan je helpen om de juiste stappen te nemen om je ex terug te krijgen deze methode biedt praktische inzichten en technieken om je ex terug te krijgen en te voorkomen dat het weer fout gaat tussen jou en je ex  
beantwoorden s 11 september 2019 om 18 56 hallo

**hoe krijg ik mijn ex terug het geniale 3 stappenplan 12 tips** - Jul 15 2023

web ontdek hier mijn volledige methode en krijg zo snel mogelijk je ex terug ex terug methode risicovrij uitproberen 12 extra tips om je ex terug te krijgen het 3 stappenplan is slechts de basis om je ex terug te krijgen er is nog veel meer om rekening mee te houden wanneer je probeert om je ex terug te winnen

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web tip 1 ontdek de reden achter de breuk tip 2 neem even afstand van elkaar tip 3 wees bereid om te veranderen tip 4 plaats je ex niet op een voetstuk tip 5 stop met verwijten tip 6 flirt met andere mensen tip 7 blijf je partner altijd verleiden de beste methode om je ex terug verliefd te maken

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web may 12 2015 edwin edinga beloofd dat je dankzij zijn ex terug methode gaat leren hoe je simpelweg je ex terug kunt krijgen of je nou nog maar in een relatie zat of dat je te maken hebt gehad met een heuse scheiding dat zou volgens edwin niet uit maken

**review ex terug methode van edwin edinga ppreviews** - Sep 05 2022

web deze methode moet ervoor zorgen dat jij je ex terug kan krijgen of dat je ex zelfs smekend naar jou toe komt om hem of haar terug te nemen we willen bijna een ongeloveloos mike erin gooien maar laten we eerst maar eens kijken wat

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