TECHNISCHE UNIVERSITÄT
ILMENAU

50. Internationales
Wissenschaftliches Kolloquium

September, 19-23, 2005

Maschinenbau von Makro bis Nano / Mechanical Engineering from Macro to Nano

Proceedings

Fakultät für Maschinenbau /
Faculty of Mechanical Engineering

Impressum

Herausgeber:	Der Rektor der Technischen Universität Ilmenau Univ.-Prof. Dr. rer. nat. habil. Peter Scharff
Redaktion:	Referat Marketing und Studentische Angelegenheiten Andrea Schneider Fakultät für Maschinenbau Univ.-Prof. Dr.-Ing. habil. Peter Kurtz, Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte, Univ.-Prof. Dr.-Ing. habil. Gerhard Linß, Dr.-Ing. Beate Schlütter, Dipl.-Biol. Danja Voges, Dipl.-Ing. Jörg Mämpel, Dipl.-Ing. Susanne Töpfer, Dipl.-Ing. Silke Stauche
Redaktionsschluss: (CD-Rom-Ausgabe)	31. August 2005
Technische Realisierung: (CD-Rom-Ausgabe)	Institut für Medientechnik an der TU Ilmenau Dipl.-Ing. Christian Weigel Dipl.-Ing. Helge Drumm Dipl.-Ing. Marco Albrecht
Technische Realisierung: (Online-Ausgabe)	Universitätsbibliothek Ilmenau ilmedia Postfach 10 05 65 98684 Ilmenau
Verlag:	isle Verlag ISLE, Betriebsstätte des ISLE e.V. Werner-von-Siemens-Str. 16 98693 Ilmenau

ISBN (Druckausgabe):	3-932633-98-9	(978-3-932633-98-0)
ISBN (CD-Rom-Ausgabe):	3-932633-99-7	(978-3-932633-99-7)

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=15745

50. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
19.-23. September 2005

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Reliability Aspects of Microsystems for Automotive Applications

ABSTRACT

In automotive applications, microsystems play an essential and still increasingly important part in a variety of complex vehicle functions such as motor management, powertrain control, chassis systems, safety, but just as well in comfort and convenience systems. They have to accomplish their tasks with demanding requirements in a harsh environment. Therefore, for commercial suppliers, reliability issues have moved more and more into the focus of research, development and manufacturing activities. The failsafe operation of microsystems is not only a vital prerequisite in safety-critical applications, reliability aspects have also evolved to a factor of economic success in a rapidly growing market.

Sensors for automotive applications

During the past decades, we have witnessed a tremendous progress in automotive technology. The outward appearance of a modern car largely reflects the change of customers taste and concessions to the requirements of the overall objectives of a resource saving fuel consumption and likewise of a reduction of pollutant emission by decreasing the air resistance coefficient (cw-value). The real technological breakthroughs took place under the hood and behind the interior paneling. Present-day cars comprise a large variety of electronic functions that provide the fundaments to achieve the vision of a clean, safe and economic car. Besides innovative motor management, safety features like airbags, antilock braking systems, anti-skid systems, belt tensioners or the electronic stability program are standard fittings even in economy class cars.

These systems strongly rely on the availability of accurate data, monitoring the current condition of the powertrain, engine load and driving situation. The requirements can be met favorably using sensors based on microsystem technologies (MEMS). Automotive systems certainly represent killer applications for MEMS. The modern car provides a wide variety of applications where MEMS devices can effectively prove their unique properties enabling innovative approaches with new functionalities, increased reliability, though on a reduced cost level. Microsensors establish the interface between the vehicle with its complex functions of motor management, chassis systems, safety as well as comfort and convenience systems on the one hand and the respective control units on the other. The necessary database comprises information about temperature, pressure, acceleration, force, torque, angles, angular rates, distance etc. Sensors perform the tasks to provide these data as input parameters for the electronic control units with high accuracy and reliability.

Reliability requirements in automotive applications

The implementation of MEMS in the hostile operating environment of automotive applications poses a serious challenge on the reliability of systems and components. They have to endure temperatures between -40°C an +140°C, to withstand thermal cycling, mechanical vibrations and shock type load as well as salt spray and humidity. Since many of the systems in which MEMS play a dominant role are critical to safety, engineers are making huge efforts to avoid failures and ensure a failsafe operation. Concerns about the reliability of microsystems in automotive applications are keeping research and development engineers extremely busy. They have to assure an accurate and faultless operation during the entire lifetime required by the car manufacturers, which typically extends to 15 of even 20 years.

Reliability as a success factor for MEMS development

If reliability is considered a feature of minor importance that can be added on in a later stage of product development, the expenses of correcting problems overlooked in an earlier phase push costs higher as development moves onward. Hence, reliability is a key to success in this highly contested market. Therefore, an essential goal of a holistic design approach is to focus not only on the required functionality of automotive systems, but also on the demands and the impacts of reliability and the entire process flow in all phases of product development. The underlying idea is to implement a model-based relationship between so-called ‘model parameters’, comprising material and geometric parameters on the one hand and ‘functional parameters’ on the other. Any promising approach to increase reliability must be focused on a root cause analysis elucidating the basic failure mechanisms that limit the lifetime of structural elements, components and systems. Consequently, the fundament of any effective reliability technology is a thorough understanding of the underlying physics of failure. While quality is an attribute ensuring that a product meets the requirements and expectations of the customer at the time it is shipped to the user and put into operation, reliability is defined as the sum of all characteristics of a device concerning its ability to achieve specified requirements under well-defined conditions over the entire operating life expectancy. In this sense, reliability is a constituent of quality and describes the changing of quality over time.

Reliability methodology

In addition to safety aspects, cost considerations are the driving force behind the goal of focussing on reliability as a major target of MEMS development. Very often the main topics of MEMS design are functionality, producibility and costs. Reliability is frequently considered a feature of minor importance that can be added on at a later stage. But the expenses of correcting problems overlooked in an early phase of product development increase drastically as development moves onward. Feedback about indispensable corrective measures concerning design, materials, and processes is more valuable the earlier it is communicated to the engineering team. In very early stages, improvements can still be initiated and incorporated into the product design at relatively low costs.An essential goal is to consider reliability aspects from the very beginning of a development project and to include it already in the concept and design phases ('design for reliability'). Our holistic approach to increase sensor lifetime is based on the idea of considering reliability aspects in all phases of product development (Fig. 1). The key to success is a process comprising the steps of experimental verification of failures by accelerated lifetime testing, combined with numerical or analytical simulation, the set up of reliability models and finally the deduction of design rules for increased reliability (figure 2).

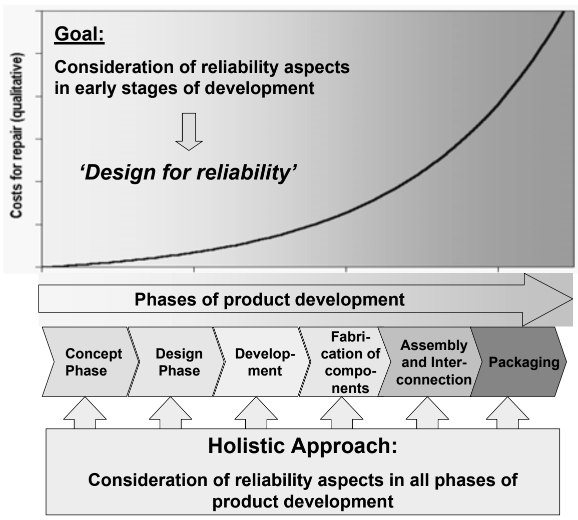

Fig. 1: Holistic approach to considering reliability in all phases of development.

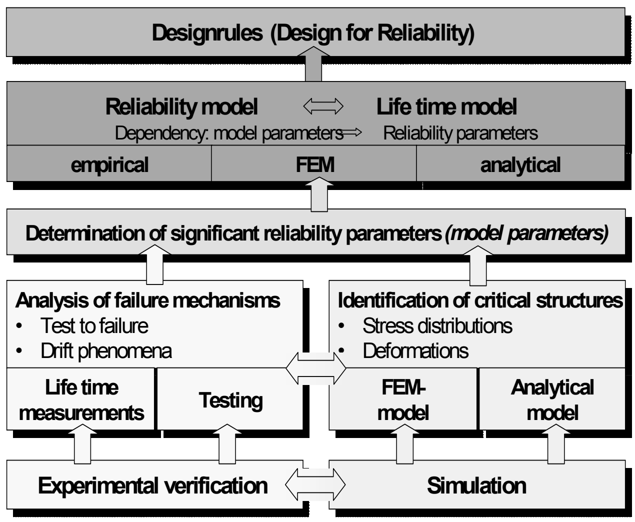

Fig. 2: Systematic steps towards increasing the lifetime of microsystems.

Reliability aspects of MEMS reveal some basic differences in comparison to lifetime considerations for macro devices or electronic circuits. The ratio of surface to volume increases linearly with ongoing miniaturization, resulting in forces that are no longer dominated by mass but by surface effects. Consequently, friction and sticking are typical problems of micro-structures, which have to be considered in design. Although the fabrication processes for MEMS are, to some extent, based on processes established for high-volume production of IC's, the scope of MEMS reaches far beyond the utilization of IC processes. The whole range of micromachined mechanical elements such as membranes, movable beams, and comb structures poses totally new challenges on the assurance of reliability.

Reliability issues of microsystems can roughly be divided into two major fields: Issues of the micro-structure itself and issues related to assembly and packaging. Reliability aspects concerning the microstructure are for instance inherent mechanical and electrical material properties, but also effects caused by the combination of different materials. In the micro world, material parameters can differ considerably from those of the respective bulk properties and are oftentimes not known. Sophisticated characterization methods are needed to extract the required material parameters. Therefore, metrology and test are equally important constituents of a holistic design approach.

The reliability parameters, such as the mean time to failure, have to be examined in experiments under well-defined conditions. Since hazard rates of microsystems for automotive applications are typically in the range of a few ppm (parts per million), reliability investigation faces the problem of 'lack of failures' in the sense that too few defective devices are available from field failures for a statistically significant analysis. Therefore, accelerated lifetime testing (ALT) is an indispensable tool to provide the necessary statistical data basis within a reasonable time. Failures have to be forced under laboratory conditions by exposing the sensor to well-defined increased stress in such a way that there is a stringent correlation between normal operation and test conditions. ALT can either be qualitative with the goal to identify the underlying failure modes or the more challenging quantitative ap-proach, with the test data providing the basis to predict the life of the device at normal use conditions. This requires sophisticated lifetime models. In contrast to microelectronics, where a large library of models for typical failures has been built up during the past decades, different microsystems can exhibit totally different failure modes and the investigation of the root causes of failures has to start from scratch in many cases.

Reliability issues of assembly and packaging

Assembly and packaging have the important task to protect the micro-structure from environmental influences like humidity, corrosive atmospheres or mechanical impact. Packaging plays a much more important role in the world of MEMS than for ICs, since the package directly influences the way in which the measurand is applied to the transducer. Many of the packaging processes imply high temperatures, frequently in combination with increased pressure. In many cases, such as for resonantly driven moving structures, a very low pressure has to be maintained within an enclosed cavity in the package in order to assure the required quality factor. Therefore, hermeticity of the package is a major concern for a variety of applications, which in this way is totally unknown in the world of ICs.

Summary

A thorough understanding of the sensor and its functionality is vital for the reliability team. This can only be accomplished by a networked interdisciplinary co-operation covering diverse scopes from sensor design and layout, modeling and simulation, process technology, material science, high-volume manufacturing, assembly and packaging through characterization and accelerated lifetime testing.

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