MEMS Reliability Assessment Program – Progress to Date

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ABSTRACT

As the Army transforms into a more lethal, lighter and agile force, the technologies that support these systems must decrease in size while increasing in intelligence. Micro-electromechanical systems (MEMS) are one such technology that the Army and DOD will rely on heavily to achieve these objectives. The MEMS devices within these systems may be required to last as long as the lifetime of the weapon systems in which they are embedded which may be decades. MEMS devices may also be required to function properly after extended periods of inactivity while in storage.

Even though the reliance on MEMS devices is increasing, only limited studies have been performed to determine their reliability and failure mechanisms. Accordingly, the US Army Corrosion Office at Picatinny Arsenal, NJ has initiated the MEMS Reliability Assessment Program to address this issue.

Keywords: Micro-electromechanical Systems, MEMS, Reliability, Testing, Army, Department of Defense

1 INTRODUCTION & PROGRAM DRIVERS

Recent conflicts abroad underscore the need for the rapid response to varying missions, which often necessitate secure, accurate, and timely transmission of information. Attributes such as speed, reduced power consumption, network-centricity, and overall awareness have become essential for current and future forces. In addition, as the U.S. Army transforms into a more lethal, lighter, and agile force, the technologies embedded in military vehicles and weapon systems must be decreased in size and weight while providing improved reliability, capability, and intelligence. Micro-electromechanical systems (MEMS) represent an enabling technology that the Department of Defense (DOD) in general, and the Army in particular, may rely on heavily to meet these emerging requirements.

MEMS cannot be categorized as any one single application or device, nor can they be defined by a single fabrication process, nor by a standardized set of construction materials. Rather, MEMS technology involves a complex, systematic fabrication approach that utilizes the advantages of miniaturization, multiple components, and microelectronics to design and construct integrated electromechanical systems. The U.S. Army Corrosion Office defines MEMS as Micro-electromechanical systems that employ an ever-expanding set of micro-fabrication methods to create and integrate micro-machined sensors, actuators, mechanical elements, and microelectronics on a single substrate. MEMS technology enables the manufacture of small systems with increased functionality that will lead to performance enhancement of both current systems and entirely new systems.

All branches of the DOD are currently investigating applications for MEMS devices in military systems. Examples of current and future military systems that may incorporate MEMS devices in the near future include: safety and arming devices, fuzing devices, various guidance systems, sensors/detectors, reduced/micro power systems, inertial measurement units, tracking devices, radio frequency devices, wireless Radio Frequency Identification tags (RFIDs) and network systems, global positioning systems (GPSs), radar systems, mobile base systems, information technologies, satellites, and missiles.

Incorporating MEMS into the applications mentioned above will provide the military with new levels of speed, awareness, lethality, and information dissemination. The system capabilities enhanced by MEMS will translate directly into tactical and strategic military advantages. However, the successful incorporation of MEMS in military systems is dependant upon their reliability within those systems. The ensured performance of MEMS devices in aggressive environments cannot be assumed. The operational and storage environments of military MEMS devices are vastly different those of the commercial sector. Military MEMS devices will be required to last the lifetime of the weapon system in which they are embedded, which may be decades. In addition, MEMS devices may be required to function properly after extended periods of inactivity while in storage. This poses a tremendous challenge as corrosion and material migration can cause device anomalies to materialize.

Although the impacts of storage, transportation, and operating environments upon the long-term performance of MEMS in DOD utilization are critical, they are not well understood. Reliability tests and test methods are essential to demonstrate the desired reliability for MEMS that are, or will be, used in critical military applications. These devices must often serve a number of functions within a particular system, and the functions can be impeded by continuous operation and storage in aggressive environments.

2 DISSCUSION

2.1 Department of Defense MEMS Utilization

As more interest is placed on MEMS technology, numerous applications will emerge, resulting in a greater need for an accurate assessment of reliability. Thus, as the industry grows, MEMS devices will expand into numerous fields and applications, including military, automotive, medical, aviation, communication, and others.

The principal U.S. Government organizations engaged in MEMS development and utilization include the U.S. Department of Defense (U.S. Army, Navy, Air Force, NSA, OSD, DARPA, ONR, Homeland Security, etc.), NASA, Health and Human Services Department, National Sciences Foundation (NSF), and Department of Energy (DOE).

The DOD currently has four primary areas of interest for MEMS utilization: 1) Inertial Measurement, 2) Distributed Sensing, 3) Power Systems, and 4) Information Technology[1]. The majority of the DOD's MEMS efforts are focused on these areas, although there are ongoing efforts in other areas such as Safety & Arming, Fuzing technologies, and Energetics. Some examples of advanced MEMS technology applications in DOD Systems include[2]:

- Acoustic Microsensors
- Velocimeters
- Magnetometers
- Micromechanical-Based Spectrometers
- Low Power Wireless Integrated Microsensors
- Surveillance Systems
- Multifunctional Electro-optical Sensors
- MEMS Infrared Remote Micro Sensors
- Magnetic Resonance Imaging Systems (MRI)
- MEMS Uncooled Infrared (IR) Imaging Arrays
- Gyroscopes
- Embedded Sensor Systems
- Unmanned Vehicles (Land, Air, Space, Sea, etc.)
- Battle Space Awareness

Cooperation with commercial industries facilitated the emergence and rapid acceptance of these primary areas by military developers. The secondary areas are rapidly growing but there are little or no commercial expertise and/or partners with the knowledge and capability to assist in this domain. With the Army's transformation to the Future Combat System (FCS) the need for robust, safe and reliable MEMS devices is essential.

2.2 Barriers to Implementation

There are several barriers slowing the implementation of MEMS into both military and commercial applications. One major barrier is the lack of documented reliability data for MEMS and their related devices. The prime focus of MEMS to date has been on the development and implementation of vast arrays of devices; often, little consideration is paid to reliability. Furthermore, data on MEMS reliability from the commercial sector is nearly impossible to track, or is not readily accessible due to its propriety nature. While many MEMS manufacturing organizations claim to have reliability test data on their devices, the majority of these organizations keeps this data "in house" and are reluctant to disseminate information. As a result, failure mechanisms and failure rates for many devices are not well characterized.

Successful utilization of MEMS in military systems will be largely dependent upon their long-term performance within these systems. There are many aspects of MEMS performance in military applications that are yet unstudied. Military applications are quite different from commercial uses. Military MEMS systems may be required to last for the entire mission profile (lifetime) of the weapon system in which they are embedded, which may be decades.

Another barrier to MEMS utilization is the storage, transportation, and operational environments to which they may be exposed. Functionality and performance in military systems may be required after extended periods of inactivity during storage (which may be greater than 20 years). This poses a tremendous challenge with respect to corrosion, materiel migration, and device anomalies. Additionally, military MEMS devices may potentially be exposed to extreme environments.

The types of environments that military MEMS devices are expected to operate in are far more severe than most commercial applications. Harsh environment aspects of a typical Army weapon system's mission profile could include any or all of the following[3]:

- Continuous operations in high humidity & moisture
- Continuous operations in areas of high wind
- Significant off-road driving
- Continuous operations in areas of high heat
- Continuous operations in sub-zero temperatures
- Extreme high & low pressured environments
- Continuous operations in sandy regions, where sand ingestion, infiltration, & contamination are commonplace
- Large variations and rapid changes in temperature due to diurnal cycles and deployment from aircraft
- Extreme G-forces due to airdrop delivery & gun launch

Transportation and shipping induces considerable shock and vibration to exposed devices. 70% of military vehicle mission profiles involve off-road conditions[4]. Current missions in the Middle East have brought another environment condition to the forefront: sand. Sand exposure and intrusion is a significant issue with all military equipment that is participating in current operations. In all, the environments that MEMS are and will be exposed to during deployment play a critical role in determining reliability of these devices. Beyond these physical extremes, security and encryption (communication, tracking, and/or data reporting devices) must also be considered in some military MEMS applications.

Long-term storage is another major factor affecting the reliability of MEMS devices. Factors that must be considered with regard to long-term storage include compatibility of materials (potential to induce galvanic and other forms of corrosion), hermeticity of packaging, creep of materials, and stresses on interfaces caused by temperature or vibratory cycling.

Material compatibility may be the most critical issue with regard to long-term storage. The MEMS industry is employing numerous new material combinations in emerging devices, with minimal data on their compatibility. As previously mentioned, materials such as metallics, polymers, composites, ceramics, and numerous fluidics are all being incorporated into MEMS devices. The compatibility of these materials directly impacts reliability. The potential for galvanic couples with these new materials is currently under investigation.

3 PROGRESS TO DATE

3.1 Identification of MEMS Devices, Existing Reliability Data, & Test Methods

Extensive literature searches, interviews, and data mining have taken place in an attempt to collect information about devices, reliability data, and test methods. As previously mentioned, there are four prime areas of interest to the DOD. Based on these areas, interviews and search were performed to determine what devices are currently being developed for use in military systems. It was also concluded that there is little useful reliability data available. Furthermore, there is no standardized methodology for assessing reliability.

It was found that most reliability data and tests methods currently being used are based on Micro-Electronics (MEs) and Integrated Circuits (ICs) tests and standards; whereas the MEMS being utilized by the DOD and government agencies are far more complex that typical MEs & ICs. MEMS devices have unique properties, materials, applications, etc, therefore current IC and silicon chip standards and test are often not applicable. A process map was developed to help identify test points and issues (Figure 1).

Some common tests and quality procedures currently utilized by the DOD and industry were found to include[8].

- High-temperature burn-in
- High-temperature storage test (bake)
- High-temperature reverse bias (HTRB) test
- Application of electrical overstress
- Thermal shocks
- Temperature cycling
- Mechanical shock tests
- Centrifugal spinning
- Package leakage tests (hermeticity)
- Humidity tests
- Particle impact noise detection (PIND) test
- Accelerated Reliability Testing (ART)
- Reliability Growth Testing (RGT)
- Environmental Stress Screening (ESS)
- Highly Accelerated Stress Screening (HASS)
- Highly Accelerated Life Testing (HALT)

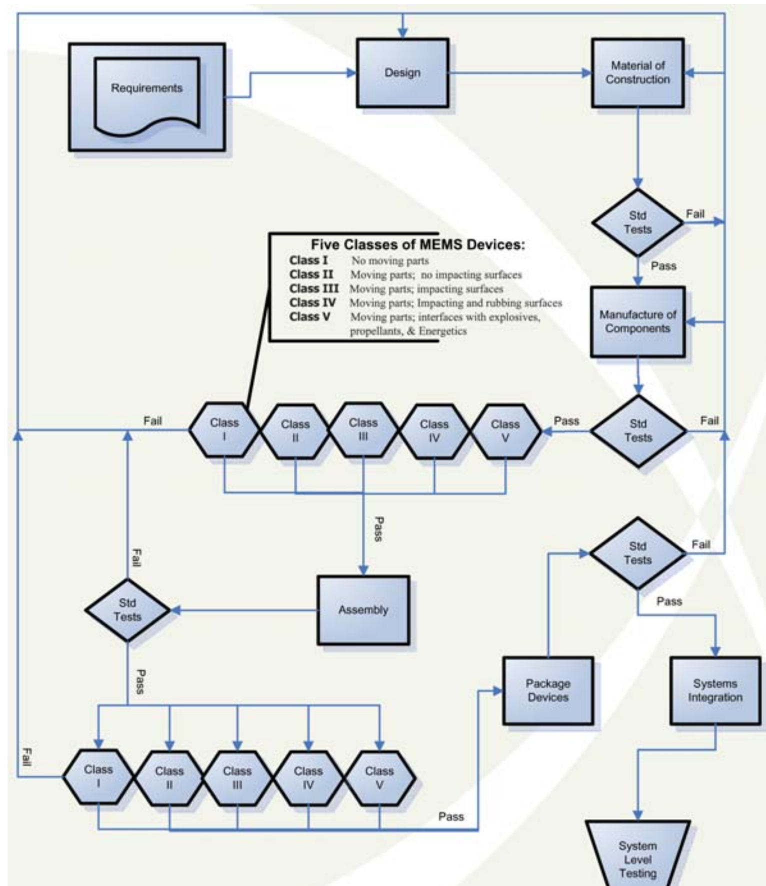

Figure 1. MEMS Process Flow Map

3.2 Development of Test Guidelines & JTPs

To address the lack of standards and common test methods, the Army Corrosion Office is developing test guidelines with the intent that they may become standards for the DOD and potentially the MEMS industry.

The first set of test guidance documents are Environmental Stress Screening (ESS) test plans. To date, ESS test plans have been developed for several Army MEMS devices. Testing has been initiated in accordance with these test plans. By running ESS tests to induce and detect failures, failure analysis can be performed and the information can be fed back for future test plan development, assessment of applicability, and design criteria recommendations.

Along with the guidelines, more specific Joint Test Protocols (JTPs) are under development. The first of which is “Degradation of MEMS”. This JTP predominantly focuses on the corrosion of MEMS. Once approved, these documents will form the basis of assessing corrosion potential of MEMS for the DOD.

3.3 Identification of Test Capabilities

In conjunction with the identification and development of test methods for the assessment of reliability, the ACO is identifying capability for conducting these tests and the subsequent failure analysis. To date, several DOD and non-DOD facilities have been identified as potential test facilities.

3.4 Modeling & Simulation

Several reliability modeling software packages, including PRISM, CALCE and Coventor software, are being evaluated under the program. At the current time, because of data input requirements, PRISM currently appears to be the most applicable. Since the PRISM software models system reliability from a component level, it will still be necessary to obtain parts lists for the MEMS devices of interest in order to model them using this software.

3.5 Relevant Documents

Along with guidance documents and identification of capabilities, several reports and papers have been generated. Studies of the current and predicted future commercial and military MEMS industry are reported in *MEMS Standards, Tests, and Applications in U.S. Department of Defense Activities*[1].

Several papers have been written addressing Army's utilization of MEMS technologies and their operational environments:

- *Micro-electromechanical Systems (MEMS) Reliability Assessment Program for Department of Defense Activities*[2]
- *Assessment for Department of Defense MEMS Utilization*[3]
- *Assessment of the Impact of Iraq Environment on Army Materie*[6]
- *Long-term Storage Performance and Standards of Micro-Electromechanical Systems (MEMS)*[7]

As more information is obtained, further reports and papers will be published to disseminate information that will help further the design, development, and testing of MEMS devices.

4 CONCLUSIONS

The DOD is currently investigating enabling technologies, to meet emerging threats, enhance weapon systems performance, reduce life cycles costs and improve system reliability. MEMS, because of the benefits associated with miniaturization, is one such technology that the DOD may rely on to meet these objectives. In order for MEMS to be employed in weapon systems, they must be highly reliable in extreme environments and this reliability must be demonstrable. To be proactive in meeting these objectives, the ACO has initiated the MEMS reliability assessment program.

As detailed above, the ACO is continuing to identify the devices, operational conditions, and applications of MEMS in military systems. The development of test protocols and testing of representative devices continues. Work towards the adoption of standards has begun. The information gained from these activities, and the data gained from failure analyses will aid in the transition of MEMS technologies from the labs to the field where it is needed.

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