MEMS for space applications: a reliability study

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Objectives of the reliability study

- The use of MEMS is one possible step forward towards the miniaturisation of space platform electronics, therefore it is essential to investigate MEMS suitability for Space Applications.

- **TO UNDERSTAND THE PROBLEMS OF MEMS RELIABILITY.**

- Overview of MEMS failure mechanisms, definition of MEMS reliability test methods and validation through actual testing.

- Specific case of an inertial type of MEMS: the SiRRS01 single-axis rate sensor from British Aerospace Systems.

- Use this study as the first building block for guidelines for the space evaluation of MEMS.
SiRRS01 single-axis rate gyro

- Gyro made of a mechanical part, the ‘sensor head’, and an ASIC to put the gyro into vibration, control the vibration and measure the rate of turn.

- Vibrating Structure Gyro based on the coriolis effect.

- ‘Deep trench etching’ process enabling the production of the tiny micromachined silicon ring.
Working principle of the SiRRS01 gyro

- Based on the Coriolis Effect: Coriolis acceleration experienced by a particle undergoing linear motion in a rotating frame of reference.
- Resulting acceleration directly proportional to the rate of turn.
- Vibratory motion coupled from a primary vibrating mode into a second mode when sensor experiencing angular rate.
Construction of the SiRRS01 gyro

- Bulk micro-machining technology: silicon etched to create the sensor ring
- Silicon-on-insulator (SOI) substrate: silicon anodically bonded to a glass support
Functional testing: specification and measurements

**Scale factor**  
18.2mV/°/s  
1% linearity  
Gyro set on a 2-axis table and put into rotation: measurements performed for 6 input speed values, between +/- 30°/s, and 6 temperature values from –

**Bias stability**  
+/-0.3°/s (ambient temperature)  
Gyro set on a 2-axis table and kept fixed with the sensitive axis in vertical position: measurements performed for 6 temperature values from –40°C to 75°C.

**Angular Random Walk**  
0.2°/√hr  
Measured through Allan variance  
Gyro mounted on a fixed support. While keeping the gyro fixed, the measurements are acquired during 12 hours at ambient temperature.

**Bias repeatability**  
0.1°/s  
Gyro set ON and OFF: measurement of bias stability.  
Gyro mounted on a fixed support. While keeping the gyro fixed, the measurements are acquired during 5 successive periods of 10 min. The gyro is set ON and OFF between each period.
Functional testing: Astrium measurements

- Gyros show a rather stable behaviour over temperature
- Higher value of ARW (0.7°/√hr instead of 0.2°/√hr)
Approach for investigation of potential failure mechanisms

- MEMS process combines *micro-machined technologies* for the *mechanical part* and traditional *integrated circuit technologies* for the *electronics part*.

- Reliability of MEMS devices depends on the reliability of the traditional integrated electrical circuitry, the reliability of the *miniature mechanical structure* and the *interactions between both systems*.

**SiRRS01 GYRO:**

- List of materials used: *Si / Glass / PolySi / Al / Fe*
- List of MEMS elements: *Vibrating structure / Springs*
- *Destructive Physical Analysis (DPA) to understand the structure and links between elements and sometimes evidence weakness points: Humidity / Spokes to watch up (holes cut in the spokes)*
Potential failure mechanisms on SiRRS01 gyro

Focus made on the sensor head: {silicon ring / metallic resonator / glass bonded}

- **Fracture**
  - Single-crystalline Si (anisotropic material)

- **Delamination**
  - At interfaces such as Can base/ support glass

- **Fatigue**
  - Not expected in glass and Si: brittle materials
  - Yes in coatings and polySi

- **Stiction / Wear**
  - No surfaces in contact

- **Radiation**
  - Expected to be sensitive

- **Dampening effects**
  - Not operating at resonant frequency and hermetically sealed

- **Particulates**
  - Dust particles from iron can

- **Temperature changes**
  - Mechanical properties affected?
Tests versus failure mechanisms

- SiRRS01 silicon rate sensor more sensitive to fracture and delamination.

- **Thermo-mechanical** tests and even life-test may evidence these failure mechanisms.
  - Shocks and temperature testing may induce fracture and delamination
  - Shocks could lead to early end of life of the structure, and vibrations too
  - Symmetry of the ring design offer excellent rejection of linear vibration.

- Electronics in a closed loop around the sensing part may prevent the system from reaching its functional limits even under harsh conditions.
  - The possibility to perform radiation testing on isolated sensor head is under investigation
Performance and reliability testing

- No space testing specification at equipment level for angular rate sensors.
- Test conditions defined using the SiRRS01 rate sensor specification and published data on other types of MEMS.

- Mechanical shocks will be performed on a sample up to destruction.
- Failure Analysis will be performed when encountering anomalous parameter measurements or destructive events.

- Limited number (7) of gyros including a reference sample to perform reliability testing.
- Sensor and electronics kept together in the same package during tests.

<table>
<thead>
<tr>
<th>Operating temperature</th>
<th>-40°C to +75°C</th>
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</thead>
<tbody>
<tr>
<td>Humidity</td>
<td>100% RH</td>
</tr>
<tr>
<td>Vibration (operational)</td>
<td>10g rms [20Hz to 2KHz]</td>
</tr>
<tr>
<td>Shock (operational)</td>
<td>60g (30ms, ½ sine)</td>
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</tbody>
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Basic performances (Bias / Bias repeatability / Noise) to be performed between each tests.
3 gyros will undergo temperature testing and 3 others mechanical testing.
Conclusion

- SiRRS01 Angular Rate Sensor from BASE = vibrating gyro based on Coriolis effect.

- Functional testing (Bias / Bias repeatability / Scale factor / Noise / ARW) performed by Astrium. Higher value of Angular Random Walk found. Additional discussion with manufacturer required for better understanding.

- Thermo - mechanical tests expected to evidence fracture and delamination which are considered to be the most likely failure mechanisms for the sensor structure.

- Reliability testing on-going at CNES. Radiation test planned at ESA.

- Results expected to help in the definition of draft guidelines for the evaluation of MEMS.