IAC-08-B1.3.7

THE ULTRA SENSITIVE ACCELEROMETERS
OF THE ESA GOCE MISSION

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ABSTRACT

By combining Satellite Gradiometry with SST-high-low GPS tracking, the ESA GOCE mission aims to provide a high resolution Earth Gravity Field to the scientific and engineering communities. In addition, continuous compensation of non-gravitational forces, thanks to on–board accelerometers, opens the way to the direct measurement of the second derivative of the gravitational potential, to deduce the gravity field mapping with an unprecedented accuracy about 1-2 mgal and a resolution of 100 km at the highest order.

The gradiometer is made of 3 accelerometer pairs (sensors and electronic units), an ultra stable carbon-carbon structure to support the accelerometer and an accurate passive and active thermal control.

The paper describes the 6 accelerometers provided by ONERA to Thales Alenia Space as Gradiometer prime, together with the test plan developed to guarantee the level of reliability and acceleration resolution which were required by the scientific performance goal of the mission.

INTRODUCTION

The aim of ESA's Gravity Field and Steady-State Ocean Circulation Explorer mission (GOCE[1]) is to generate accurate global mapping of the Earth's gravity field for applications in oceanography, geophysics, hydrology or climatology. This mission embarks, for the first time, a three-axis gradiometer consisting of 6 electrostatic accelerometers offering an outstanding resolution less than $2\times10^{-12}\,\mathrm{ms^{-2}/Hz^{1/2}}$. Such accelerometers, named GRADIO, take benefits from the experience acquired from previous missions that carried electrostatic accelerometers of which it is the successor, in particular STAR[2] and SuperSTAR[3] respectively used on the CHAMP and GRACE satellites.

THE GOCE MISSION

The GOCE mission is an ESA's Earth Explorer Core Mission, due for launch on 2008, September 10th from Plesetsk by a Rockot launch vehicle. The satellite will be on sun-synchronous, quasi circular and quasi polar (96.5°) orbit at altitudes about 250 km. Two science measurement phases, separated by a long-eclipse hibernation phase, will take place after a 3 months commissioning and calibration phase. Weighting 1 ton and with a length of 5 meters, the spacecraft has a very rigid structure without moving parts and with limited cross section (1 m diameter) in order to reduce the drag.

The GOCE mission exploits performing technical solutions for instrument, sensors and actuators, namely:

- an onboard GPS receiver used as Satellite-to-Satellite Tracking Instrument (SSTI),
- a ionic propulsion,
- a continuous compensation system for all non gravitational forces acting on the spacecraft ,
- an Electrostatic Gravity Gradiometer (EGG) as the main instrument.

The data derived from GOCE will provide an unprecedented model of the Earth's gravity field. The GOCE mission is complementary to the CHAMP and GRACE missions, respectively launched in 2000 and 2002, in that it is a high resolution gravity-field mission and will address a completely new range of spatial scales, in the order of 100 km.

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THE GOCE GRADIOMETER PRINCIPLE

Accelerometer Principle

The ONERA's accelerometers are based on the electrostatic suspension of an inertial proof mass (PM) which is controlled to remain motionless at the centre of a cage by applying adequate voltages on the electrodes which are machined on the internal walls of the cage. The control voltages (V) are representative of the PM acceleration (Γ_{pm}) with respect to the cage or to the S/C center of gravity (Γ_{sc}), assuming that it is rigidly connected to the S/C structure.
The relative acceleration is given by[†]:

$$\left(\vec{\Gamma}_{pm}-\vec{\Gamma}_{sc}\right)=[A]\,\overrightarrow{GO}-\vec{D}+\frac{\vec{F}_{pm}}{m} \qquad (1)$$

$$with\quad [A]\approx[T]-\left[\Omega^2\right]-\left[\dot{\Omega}\right]$$

The matrix $[T]$ represents the Gravity Gradient tensor $[T]=\begin{bmatrix} T_{XX} & T_{XY} & T_{XZ} \\ T_{XY} & T_{YY} & T_{YZ} \\ T_{XZ} & T_{YZ} & T_{ZZ} \end{bmatrix}$ with $T_{ij} = \dfrac{\delta^2 U}{\delta x_i\, \delta x_j}$

and the matrices $\left[\Omega^2\right],\left[\dot{\Omega}\right]$, where Ω_α are the components of the S/C angular acceleration, are defined as:

$$\left[\Omega^2\right]=\begin{bmatrix} -(\Omega_Y^2+\Omega_Z^2) & \Omega_X\Omega_Y & \Omega_X\Omega_Z \\ \Omega_X\Omega_Y & -(\Omega_X^2+\Omega_Z^2) & \Omega_Y\Omega_Z \\ \Omega_X\Omega_Z & \Omega_Y\Omega_Z & -(\Omega_X^2+\Omega_Y^2) \end{bmatrix}$$

$$\left[\dot{\Omega}\right]=\begin{bmatrix} 0 & -\dot{\Omega}_Z & \dot{\Omega}_Y \\ \dot{\Omega}_Z & 0 & -\dot{\Omega}_X \\ -\dot{\Omega}_Y & \dot{\Omega}_X & 0 \end{bmatrix}$$

- $\vec{D}$ represents the external linear acceleration of the spacecraft due to non gravitational forces (mainly atmospheric drag)

- $\vec{F}_{pm}$ represents the forces acting on the PM, mainly satellite self gravity and magnetic field.

Applying electrostatic forces on the PM, $\vec{F}_{elec}(V)$, the relative acceleration is cancelled ($\vec{\Gamma}_{pm}-\vec{\Gamma}_{sc}=\vec{0}$). As a standalone instrument, when placed at the S/C center of gravity (G=O), the voltages V provide the non gravitational acceleration measurement as far as $\vec{F}_{pm}$ is negligible:

$$\frac{\vec{F}_{elec}(V)}{m}=-\vec{D}+\frac{\vec{F}_{pm}}{m}$$

Gradiometric measurement principle

Assembling two accelerometers as a pair along the axis joining their center, OiOj, we can define common and differential acceleration measurement as:

$$\vec{\Gamma}_{m,c}=\frac{1}{2}\left[\frac{\vec{F}_{elec}(V_i)}{m_i}+\frac{\vec{F}_{elec}(V_j)}{m_i}\right]$$

$$\vec{\Gamma}_{m,d}=\frac{1}{2}\left[\frac{\vec{F}_{elec}(V_i)}{m_i}-\frac{\vec{F}_{elec}(V_j)}{m_i}\right] \qquad (2)$$

From [1], we deduce, assuming identical accelerometers symmetrically arranged wrt G:

$$\vec{\Gamma}_{m,c}=-\vec{D}+\frac{1}{2}\left(\frac{\vec{F}_{pm,i}}{m_i}+\frac{\vec{F}_{pm,j}}{m_j}\right)$$

$$\vec{\Gamma}_{m,d}=\left[T-\Omega^2-\dot{\Omega}\right]\overrightarrow{O_jO_i}+\frac{1}{2}\left(\frac{\vec{F}_{pm,i}}{m_i}-\frac{\vec{F}_{pm,j}}{m_j}\right) \qquad (3)$$

We deduced that:

- The first equation shows that the combination of the two accelerometers voltages measures the non gravitational forces at the middle of their axis. This property is used to create a drag free condition at this point by controlling the main engine thrust via the accelerometer common mode outputs.
- The second equation shows that the combination of the two accelerometers voltages directly provides information on the gravity gradient along their axis, mixed with angular accelerations which shall be retrieved from transverse axes measurements.

Gradiometer concept

The gradiometer concept directly derives from the above equations by arranging 3 pairs of accelerometers on a tri-axis orthogonal structure (Figure 1).

[†] Coriolis component is neglected as PM velocity is nearly null.

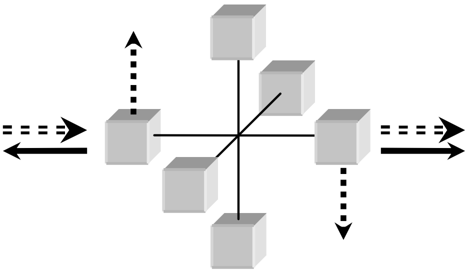

Figure 1: Six tri-axis accelerometers in a gradiometer structure. Different combinations (sum, difference) of the outputs of one pair provide different data.

- In-line differential mode:

  ⟵ ⟶

  provides the gravity gradient on one axis. This is the main science data, but it also contains angular accelerations, which must be retrieved.
- Transverse differential mode:

  ⇡ ⇣

  provides angular accelerations and angular rates (by integration) about the three axes around the gradiometer centre.
- In-line common mode:

  ⇢ ⇢

  provides external acceleration on the satellite. It is sent to the Drag-Free system for cancellation.

GOCE is the first mission to access directly the components of the Gravity Gradient Tensor (GGT) in orbit.

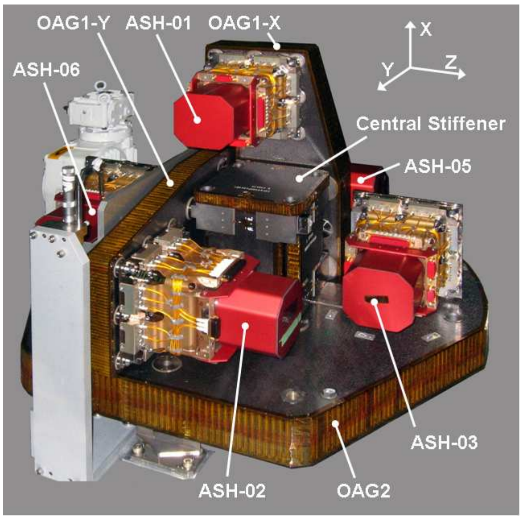

Figure 2: View of the FM Gradiometer core with accelerometer sensor heads (ASH) on the carbon-carbon structure (Photo from Thalès Alenia Space).

The Gradiometer is made of 6 accelerometric chains (sensors and electronic units), ultra stable carbon-carbon structure to support the 3 accelerometer pair and an accurate passive and active thermal control (Figure 2). The accelerometers are arranged in the so-called diamond configuration which means they are located at 6 positions symmetrically about the origin of the Gradiometer Reference Frame. The distance between 2 ASHs of one pair, baseline length, is equal to 0.5 m.

THE GOCE ACCELEROMETRIC CHAINS

The main functions of the accelerometric chains are to provide:

- The time-stamped voltages corresponding to the 3D linear accelerations at the position of each accelerometer sensor. These data are delivered at 1 Hz in the Science mode of the Gradiometer and are called science data. They are used to retrieve the final components of the GGT.

- The real-time 3D linear accelerations at the accelerometer position. This information is delivered to the Drag Free and Attitude Control System (DFACS) at 10 Hz, which deduces the linear acceleration at the centre of the gradiometer, close to the spacecraft centre of gravity. They also provide angular accelerations of the satellite to be associated with star tracker data.

These chains are associated by pairs, each of them constituting an axis of the Gradiometer, and made of 2 ultra-sensitive inertial sensors (ASH) connected to a Front End Electronics Unit (FEEU) (Figure 3). Data exchanges with the satellite, remote controls and power of these three gradiometric chains are carried out by a digital electronics unit (GAIEU) which also contains the software component of the 36 feed-back loops that control, in translation and rotation, the six proof masses of the sensors.

In these three different units are respectively implemented the sensing, conditioning and processing functions. In order to fulfil the thermal constraints requested by the level of performance of each of these functions, these units are implemented at three different locations inside the Gradiometer with dedicated thermal control performances.

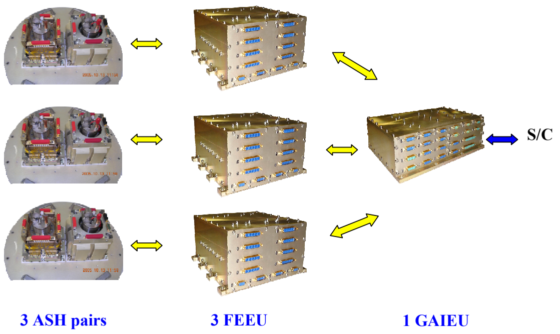

Figure 3: Constitutive elements of the 6 accelerometric chains of the Gradiometer (3 gradiometric chains).

The Accelerometric Sensor

Three axes electrostatic accelerometers developed at ONERA are based on the electrostatic levitation of an inertial mass. Measurements of the voltages necessary to create the electrostatic forces and torques which will maintain the mass motionless with respect to the sensor cage, provide the outputs of the accelerometer.

The Pt-Rh, 320g, proof mass is free to move within the cage (Figure 4) as no blocking system is implemented. The cage is made of ULE plates on which 8 electrodes pairs are engraved and gold coated. The four pairs are dedicated to sensitive axes (Y-Z translations and Φ rotation) and four pairs are used for the remaining X translation and Θ-Ψ rotations. The 6 translation and angular degrees of freedom (dof) of the PM motion are obtained by an appropriate combination of the 8 electrode channels. This configuration allows, thanks to the implementation for the first time of an analog-digital control loop for each of the 8 electrodes channel, flexibility and redundancy in the 6 dof retrieval.
The electrode-PM gap defines the capacitance of the PM position detector working at 100 KHz and of the PM position actuator which control voltage is updated at 1024 Hz.

X	Y,Z
32 µm	299 µm

Nominal PM-electrode gap values

The only mechanical links between the proof-mass and the core is a 5 µm gold wire allowing to polarise the proof-mass, avoiding any variation of the patch effect in orbit.
Mechanical stops are implemented within the core to prevent any direct contact with core electrodes. The PM-stop gap, when centred, is 15 µm along X and 30 µm along Y and Z axes. So, impact of the proof-mass motion under vibration loads during launch and qualification/acceptance test shall be minimised. They consist, either in stress induced in ULE plates under proof-mass shocks on the stops and possible material transfer between them leading to a strong reduction of proof-mass free motion below acceptable range. Specific development activities were devoted to assess these two points.
To maintain the core cleanliness, to shield the proof-mass against the magnetic field and ensure the performance of the sensor, the core is enclosed in a hermetic housing and the vacuum is ensured by a ionic pump during the ground functional test and passively by the getter after delivery (figure 5).

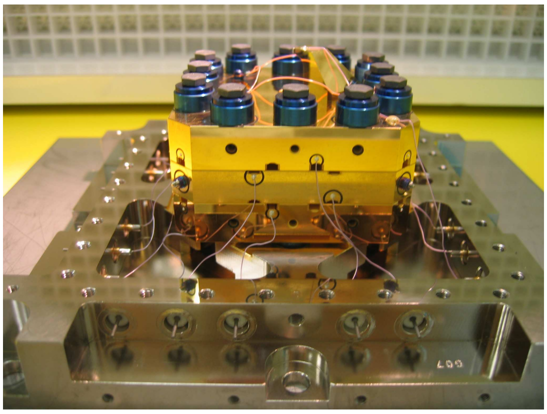

Figure 4: ASH-02 ULE core containing the Pt-Rh proof mass. The lower metallic structure is the sole-plate providing the reference frame interface with the carbon-carbon gradiometer arm.

Figure 5: ASH-05 before delivery to Thales Alenia Space Gradiometer Team. On the top of the ASH, there is the ionic pump used during functional test on ground and the getter housing .

Operating mode

There are two operating modes for the accelerometers:

- Acquisition mode and Science mode
-

The operation of an accelerometer requires the proof-mass to be set at a potential Vp+Vd through a loose Ø 5 µm gold wire where:

- Vp is a static polarisation voltage which linearises the acceleration-voltage law. Its value is switched from 27 V in Acquisition mode to 7.5 V in Science mode.
- Vd is a 100 kHz sine voltage; it constitutes a carrier voltage for the capacitive sensing and then allows a lock-in detection of the proof-mass motion. It is switched from 1.3 Vrms in Acquisition mode to 7.6 Vrms in Science mode.

The Acquisition mode uses a reduced detection voltage to insure a large range of position sensing, but with a non optimum resolution. The level of the polarization voltage (Vp) has been chosen in order to successfully move the proof-mass to the centre of the cage in all conditions of specified external acceleration and proof mass initial position.

The Science mode is the scientific measurement mode. It combines high resolution detection and weak action, in order to work at the maximum sensitivity once the satellite is under control (drag and spin).

ACCELEROMETER PERFORMANCE

The performance of an accelerometer is defined by a validity domain in a frequency-amplitude space. In the GOCE mission, a particular frequency bandwidth is targeted: 5 mHz to 100 mHz. Most of the engineering design activity consists in first- reducing, and second- optimising and tuning the noise of the various contributors with respect to the target bandwidth.

The result is shown on Figures 6-7, where only main contributors have been selected:

- The detector noise (pink). It is basically due to the electronic noise in the detector circuit; the control loop induces a detector noise increase with frequency.
- The wire damping (orange). Minimised by the use of a 5µm diameter gold wire, the effect of the wire damping in the control loop produces a noise level limit which remains far below the requirement.
- The readout ADC quantification noise (ADC2 in blue). Usually in digital circuits, the quantification step of the measurement device is designed well below the noise level of the instrument and is not a limiting point. In the case of the GOCE mission, the range / resolution ratio requirement is so high that no margin could be given either downwards to improve the quantification step, or upwards for the measurement range. The present situation is the best trade off between range needs during the calibration phase and measurement noise.
- The thermal sensitivity of the bias (green). The temperature variation, despite of the thermal control of the gradiometer, leads to the variation of the accelerometer bias at low frequency. The main contributor is the thermal sensitivity of the radiometer effect, due to the difference of temperature between the faces of the proof-mass.

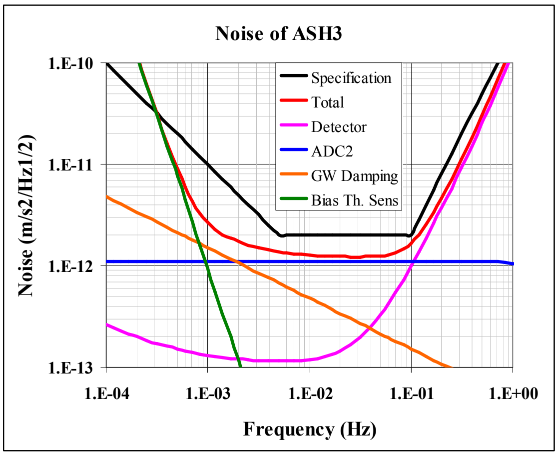

Figure 6 : Noise performance of the GOCE Accelerometric Chain of ASH-03

	5 mHz	**100 mHz**
Requirement	$\mathbf{2.04 \times 10^{-12}}$	$\mathbf{2.04 \times 10^{-12}}$
ASH-01 (X)	1.42×10^{-12}	2.02×10^{-12}
ASH-04 (X)	1.52×10^{-12}	1.90×10^{-12}
ASH-02 (Y)	1.49×10^{-12}	1.87×10^{-12}
ASH-05 (Y)	1.44×10^{-12}	1.75×10^{-12}
ASH-03 (Z)	1.38×10^{-12}	1.67×10^{-12}
ASH-06 (Z)	1.50×10^{-12}	1.78×10^{-12}

Accelerometer noise level at MBW limit (in $ms^{-2}/Hz^{1/2}$*)*

With an acceleration range of ± 6.5×10^{-6} ms^{-2} in Science Mode, we obtained a signal dynamic larger than 3 10^{6}. The design effort is appreciable when compared to the performance level of the accelerometers of the CHAMP and GRACE missions resp. of 3.0×10^{-9} $ms^{-2}/Hz^{1/2}$ and 1.0×10^{-10} $ms^{-2}/Hz^{1/2}$.

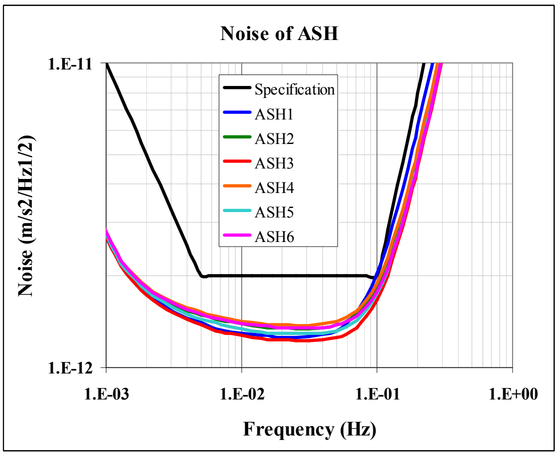

Figure 7: Noise performance of the 6 GOCE Accelerometric Chains.

FUNCTIONAL TESTS OF THE ACCELEROMETERS

Under a relative PM acceleration Γi, the accelerometer applies a voltage on the control electrodes to keep it motionless at the centre of the cage.

At first order the voltage applied is proportional to the acceleration along and around each axis,k:

$$\Gamma_{i,k} = (2\frac{C_{i,k}V_p}{md_k})V_{i,k} = G_{i,k}V_{i,k}$$

C_{ik} is the PM-electrode k capacitance with a gap d_k and Vp is the PM polarisation voltage. These two parameters are key values to adjust accelerometer characteristics.

One fundamental aspect of the ONERA's accelerometers is to provide the possibility of extensive functional tests on ground by levitating the PM under $\vec{g}$. For this, the vertical axis (X) is designed (Gik value) in order to allow this levitation at reasonable value of Vx. As a consequence, this axis is less sensitive than the two in plane (Y,Z) axes which are designed to fulfil the ultimate performance requirement. This explains the specific ASH arrangement on the gradiometer core structure in order to have always ultra sensitive axis for gravity gradient and angular accelerations retrieval.

Thanks to these a very complete test plan can be applied to assess as far as possible on ground the nominal behaviour of the accelerometer.

The Test Plan is organized as following:

1. Test of each chain units
    a. ASH FM are tested at ONERA
    b. FEEU and GAIEU FM are tested under Thalès Alenia Space France (TAS-F) responsibility
2. Test of (ASH pair + FEEU) with GAIEU EGSE (ONERA)
3. Test of (ASH pair + FEEU + GAIEU) (ONERA + TAS-F)

The tests sequences under ONERA responsibility are described hereafter:

1. ASH alone functional test with referenced EGSE
2. ASH environmental test
3. ASH alone functional test with ref. EGSE

Step 1 allows to check the perfect ASH behavior after integration (levitation conditions, transfer function, nominal electrostatic stiffness, linearity, scale factor). In Step 3 we proceed with the same verification to validate the acceptance test. Functional test is performed on dedicated test bench (pendulum) made of suspended platform precisely controlled in horizontality to limit the in-plane acceleration resulting from the $\vec{g}$ projection within the science range.

Figure 8: Pendulum test bench for gradiometric pair functional testing.

4. ASH + FEEU functional test

Step 4 allows to check both FM units integration and functionality on controlled pendulum (Figure 8).

5. Free Fall test

Free Fall test of an ASH pair with FEEU is performed in the ZARM Drop Tower in Bremen (Figure 9). It allows checking the accelerometer chain behavior in low gravity environment for the 3 axes: it is the most representative test wrt in-flight conditions. It consists mainly in verifying the complete PM acquisition and control at the center of the cage during the fall duration (4.7 sec), in both acquisition mode and science mode.

Figure 10 shows the accelerometer DFAC output for acceleration along X axis. The post release capsule stabilization lasts about 1.5-2 sec. The PM control and centering is acquired in less than 3.7 sec, at which the transition to fine science mode is triggered. We can observe the very good similarity in the behavior of the two ASHs (Y pair) and the science mode sensitivity.

Figure 9: Drop capsule configuration with GOCE ASH pair under test.

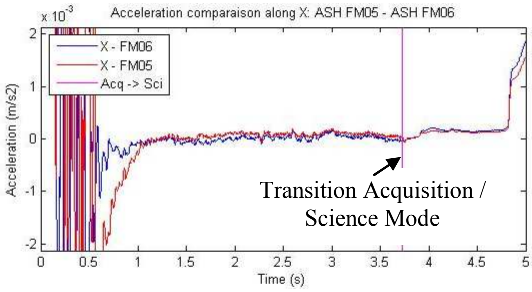

Figure 10: Acceleration output along the ASH X axis (vertical axis during the drop), with the transition between the Acquisition and the Science mode at 3.7 seconds.

The steps 1 to 5 shall be mandatory successfully passed for final ASH FM acceptance. Next test is mainly ASH main parameters characterisation.

6. Scale factor and Quadratic factor verification

Actually the (Γ,V) relation is linear only at first order. Taking into account bias (b) and noise (n) and non linearity, we come to:

$$\Gamma_{i,} = b_i + G_i\,(1 + K_{1,i})V_i + (K_{2,i})G_i^2 V_i^2 + n_i$$

in which $K_{1,i}$ represents the measurement error in $G_{1,i}$ and $K_{2,i}$ the quadratic factor. The quadratic factor results from ultimate imperfections of the accelerometer cage as differences in opposite electrode surfaces or in electronic component real data. The consequence is that the center of applied electrostatic forces does not match exactly with the cage center. This bias in position can be recovered from the knowledge of K2, introducing a corresponding position bias in the position detector.
The capability to levitate the proof-mass on ground, provides the means to verify the differential scale factor (1/2(Gi-Gj) or $1/2(K_{1,i}-K_{1,j})$) and the quadratic factor of each accelerometers which appear in the above equation (also misalignment of an accelerometer pair).

Differential scale factor verification

The differential scale factor verification consists in applying on two accelerometers the same external acceleration and to verify the difference of measurement. On-ground, it is performed by tilting the pendulum: each accelerometer measures the projection of the local gravity along the horizontal axis perpendicular to the tilt (Figure).

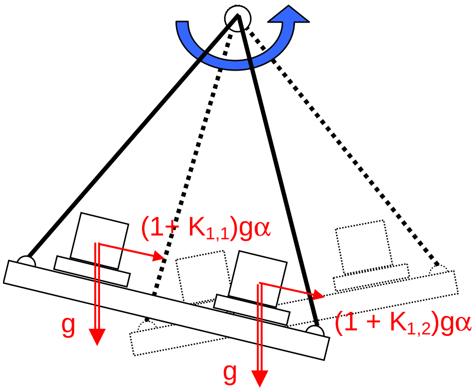

Figure 11: Principle of the differential scale factor verification on ground.

The half difference of measurement gives the differential scale factor multiplied by the projection of the local gravity. As the local gravity is not known exactly, the average of measurement of each accelerometer (common mode) is used to estimate this acceleration. In consequence, the computation doesn't give exactly the differential scale factor, but the ratio between the differential scale factor and the common scale factor ($1+K_1$).

The tilt of the pendulum is applied at 0.1 Hz, leading to a signal at this frequency in the differential measurement proportional to the differential scale factor. The test was done over 7 hours of measurement in order to have an accuracy of the test better than 10^{-4}. The ratio of peak at 0.1 Hz of the common and differential acceleration measurement was found less than 3.2 10^{-3}, which is in accordance with the specification (Figure 12).

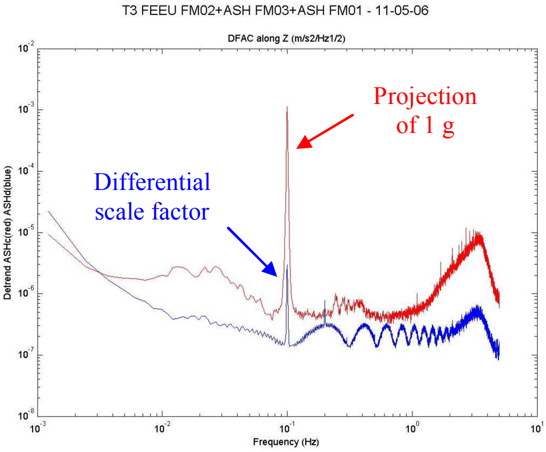

Figure 12: Spectral density of common (red curve) and differential (blue curve) accelerometer measurement during scale factor verification.

Quadratic factor verification

The method of pendulum tilt could be used to estimate the quadratic factor of an accelerometer pair (a peak at 0.2 Hz appears in Figure 11), but it is not enough accurate as the quadratic factor of the pendulum control loop is mixed to the one of the accelerometers.

So the verification on ground has used the same method than the one foreseen for the in-flight calibration. The principle of the test is to send at the output of the PID, a quadratic factor calibration signal, made of a 100 Hz sine signal modulated by a square carrier at a frequency inside the accelerometer MBW. The linear response of the control loop is null, as the high frequency sine is out of the bandwidth of the loop. But, due to the non linearity of the control loop, a term at the frequency of the square modulation appears in the measurement. By this method, the quadratic factors of each accelerometer and along each axis are estimated one after one.

The test is done on the pendulum with a pair of accelerometer in order to improve the accuracy of the test by using the differential measurement between the accelerometer which is less noisy.

Figure 13 presents the spectral density of the in-line common and differential acceleration of the accelerometer pair. The peak due to the quadratic factor appears clearly at 0.1 Hz on the differential measurement.

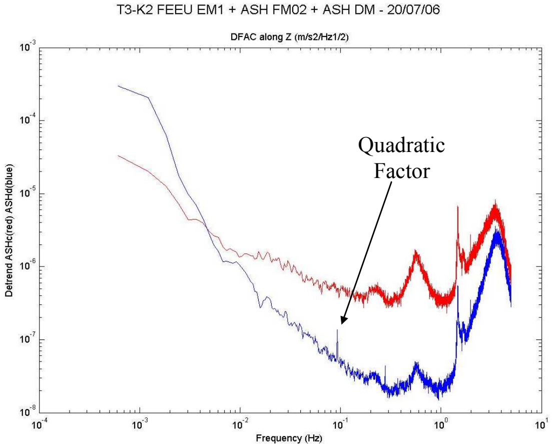

Figure 13: Spectral density of common (red curve) and differential (blue curve) accelerometer measurement during quadratic factor verification.

7. GAIEU+FEEU+ASH functional test

The full integrated chain, from ASH pair to GAIEU, but limited to 1 pair, is tested in levitation condition to check the compliance of the failure detection and recovery function which is implemented in the GAIEU software.

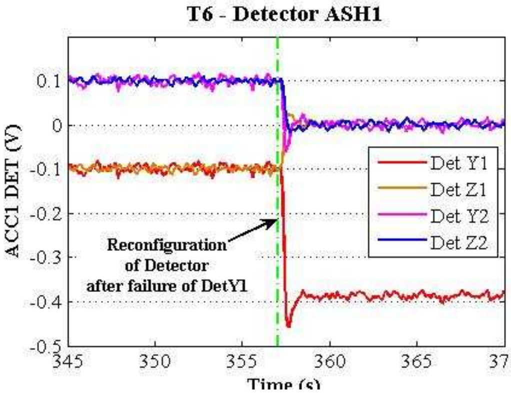

Figure 14: Test of the automatic detector reconfiguration after a false detector saturation.

One example is presented in Figure 14 above, in which an electrode recombination is automatically triggered due to simulated detector saturation on detector Y1 appearing at t= 357 sec.
Before failure, the outputs of the detectors reflect the impact of the detector biases. The instantaneous reconfiguration consists in suppressing the failed detector (among the 4 ones for Y and Z) from the combination.

After reconfiguration, the 3 safe detectors are sufficient to manage the 3 degrees of freedom associated with Y and Z axes. The failure is recovered: all the detector outputs are put to 0 by the control loop (in 3 detectors conditions, the PID succeed in cancelling the different bias contribution). The detector Y1, which is no more used in the control loop of the accelerometer, supports all the residual bias of all the detectors.

After delivery, during Gradiometer integration and S/C integration no more PM levitation is possible but partial verification of the accelerometer are still possible in order to assess the good health status of the gradiometer as close as possible to the launch date, on the launch site.

CONCLUSION

Based on the design of STAR and SuperSTAR electrostatic accelerometers of the CHAMP and GRACE mission, the GRADIO accelerometer developed for the ESA GOCE mission has been optimised on several points (design, integration procedure, test plan) to meet the challenging requirements of such a scientific mission.

Electronics function were severely selected to allow to reach an acceleration resolution better than 2.0 10^{-12} $ms^{-2}/Hz^{1/2}$ with a dynamical range of about 3 10^{6} in accordance with space quality requirements.
The mechanical sensor was optimised in terms of design, manufacturing and integration processes to reach not only the necessary resistance but the stability requirement of the accelerometer reference frame during the launch phase. Such a stability has been successfully proven during environmental qualification tests.

As an acceleration sensor to drive the Drag Free and Attitude Control of the spacecraft, it provides highly accurate 6 axes data to evaluate the S/C centre of mass position, its attitude to survey and control the electric propulsion thrust.
As a scientific instrument, the GRADIO accelerometer is a key factor of the GOCE mission being the main contributor to the gradiometric performance objectives of $11mE/Hz^{1/2}$ in the [20 mHz-100 mHz] part of the measurement bandwidth.

ACKNOWLEDGEMENTS

The realization of the accelerometers of the GOCE mission of ESA was carried out under contract with Thales Alenia Space France (Cannes) acting as Prime Contractor of the Gradiometer, while Thales Alenia Space Italy is prime contractor of the Satellite.

The authors are grateful to their colleagues Yann Alonso, Gérard Campergue, Dominique Chauvin, Pierre Leseur, and Pierre-Damien Maigret, for their efficient and continuous contribution to the accelerometers manufacturing, assembling, integration and test.

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