N90-20560

4/

THE GRADIO SPACEBORNE GRAVITY GRADIOMETER: DEVELOPMENT AND ACCOMMODATION

A. BERNARD

Office National d'Etudes et de Recherches Aérospatiales
BP 72, 92322 Chatillon Cedex, France

ABSTRACT

1. INTRODUCTION

The european ARISTOTELES mission aims at the determination of the Earth Gravity field at short wavelength with a global coverage. Gravity gradient measurements will be achieved during six months by the GRADIO instrument on board a dedicated satellite in a near dawn-dusk sun-synchronous orbit at an altitude of 200 km. The objective is an accuracy of better than 5 mgals for gravity anomalies, at ground level for blocks of 1° x 1°.

According to the present knowledge of the potential, the recovery of the higher spherical harmonics (degree and order greater than 30) is of main importance. This leads to focus on the variations of the measured components T_{ij} of the gravity gradient tensor, at frequencies greater than 5×10^{-3} Hz. The resolution, required for the gradiometer, is 10^{-2} Eötvos (i.e. 10^{-11} s^{-2}) with an averaging time of 4 s. [Balmino et al, 1984 ; Balmino and Bernard, 1986].

2. GRAVITY GRADIOMETRY ON BOARD A NON DRAG FREE SATELLITE

The components T_{ij} are determined by means of differential measurements between highly sensitive accelerometers composing the gradiometer [Runavot et al, 1983; Bernard et al, 1983]. Each of them measures the resultant $\vec{\gamma}_i$ of the effects of gravity gradient [T], angular motion $\left(\vec{\Omega},\dot{\vec{\Omega}}\right)$ and acceleration $\vec{\Gamma}$ due to drag and radiation pressures.

Linear combinations of the measured $\vec{\gamma}_1$ allow us to determine separately the components of: $\left[[-T] + [\Omega^2]\right]$, $\dot{\vec{\Omega}}$, $\vec{\Gamma}$.

The variations of $[\Omega^2]$ which cannot be distinguished from those of $[T]$ have to be minimized and estimated. This requires high performances for the attitude control and restitution: over periods of 200 s, the variations of $\vec{\Omega}$ and $\dot{\vec{\Omega}}$ must be less than 10^{-6} rad/s and 10^{-7} rad/s^2.

In practice, the accelerometric measurements are corrupted by mismatchings of the accelerometer scale factors and aligments, non linearities, bias drifts and noise. The gradiometer baseline being about one meter, the accelerometers must be designed in order to achieve a resolution of 5×10^{-12} ms$^{-2}/\sqrt{\text{Hz}}$.

To take advantage of such a performance, sufficient rejections of the disturbances, due to drag variations in particular, must be obtained for the differential accelerometric measurements. Accelerometer scale factors and alignments have to be accurately matched. For that purpose, sine wave calibrating accelerations are applied by means of two pairs of unbalanced wheels rotating at constant angular velocities. Synchronous demodulations of the accelerometer outputs at the angular frequencies of the wheels provide the information necessary for the estimations of the deviations. The expected accuracies are 10^{-5} for scale factor matchings and 10^{-5} rad for alignments.

Nevertheless, the instrument being accommodated on board a non drag free and Earth pointed satellite, the acceleration in the along track direction $\vec{x}$ is about 10^{-4} ms^{-2} with variations that can reach 6 % for periods less than 200 s. In these conditions, it appears hopeless to obtain a resolution of 10^{-2} Eötvös in the direction $\vec{x}$. Thus, for the ARISTOTELES mission, the gradiometer is composed of four accelerometers located at the corners of a square in the plane $(\vec{y},\vec{z})$ perpendicular to the drag. With this configuration, the diagonal component T_{yy} ($\vec{y}$ cross-track direction) can be directly measured; the variations of $[\Omega^2]$ must be rejected for the determination of T_{zz}; T_{yz} is very sensitive to the variations of the roll angle.

3. *GRADIO ACCELEROMETER PRE-DEVELOPMENT*

This 3-axis accelerometer is based on the electrostatic suspension of a cubic proof-mass which is maintained motionless with respect to a set of electrodes forming a cage around it [Bernard, 1987]. The accelerometric measurements are derived from the drive voltages, applied to the electrodes in order to control the six degrees of freedom of the suspended mass.

GRADIO benefits of the experience acquired in ONERA with the CACTUS accelerometer [Boudon et al, 1978; Bernard et al, 1982] and with further studies of 3-axis electrostatic accelerometers supported by the french ministry of Defence (DRET) and Space Agency (CNES) [Bernard et al, 1985].

The GRADIO accelerometer is designed in order to insure preliminary tests under normal gravity conditions: the vertical axis (drag direction on orbit) is less sensitive but permits the electrostatic suspension of the proof-mass on ground.

Experimental feasability studies have been performed since 1986 with suspensions of 70 gram proof-masses made in silica. The horizontal axes of these laboratory models have, on ground, a measurement full scale range of 10^{-3} G.

A pendulum bench has been realized in order to preserve the accelerometers from the seismic noise in the laboratory. A soft environment of about 10^{-8} G r.m.s in a 0.1 Hz bandwidth is achieved.

The on ground testing of the 2 sensitive horizontal axes is nevertheless, limited by any variation of the coupling with the vertical axis or of the accelerometer orientation. Because of these limitations and of the necessity of testing the final configuration for flight, tests in the ONERA drop tower facility will have also to be performed under microgravity conditions.

In 1988, the pre-development of the GRADIO accelerometer has been undertaken under ESA contract. The design has been optimized to meet the requirements while insuring the compatibility with the on ground testing. The proof-mass is made in platinum-rhodium alloy: its mass is 320 grams for a size of 4 × 4 × 1 cm. The high density minimizes the disturbances due to non gravitational forces. The electrode set, obtained by ultrasonic machining and grinding of three silica plates, exhibits a high geometrical stability.

The feasability of the electrostatic suspension of such an heavy proof-mass under 1 G is demonstrated. The manufacturing of two models is on going and differential tests, rejecting the residual seismic noise, will be done to evaluate their performances.

4. CONCLUSION

The first step of the GRADIO accelerometer development has been achieved through the electrostatic suspension of a 300 gram proof-mass, on ground.

By maintaining our efforts in the next years, the first space gravity gradiometer can be developed for a Solid Earth mission at mid-nineties.

REFERENCES

Balmino G., Letoquart D., Barlier F., Ducasse M., Bernard A., Sacleux B., Bouzat G., Runavot J.J., Le Pichon X., Souriau M., Bull. Géod. 58, pp. 151-179, 1984.

Balmino G., Bernard A., Satellite Gradiometry, Proceedings of an ESA Workshop SESAME, Ising-am-Chiemsee, 1986.

Bernard A., Gay M., Juillerat R., The accelerometer CACTUS, AGARDograph n° 254, 1982

Bernard A., Sacleux B., Touboul P., GRADIO: Orbital Gravity Gradiometry through differential Microaccelerometry, IAF, Budapest, 1983.

Bernard A., Foulon B., Le Clerc G.M., Three-axis electrostatic accelerometer, Symposium Gyro Technology, Stuttgart, 1985.

Bernard A., Triaxial electrostatic accelerometers developed at ONERA, Rech. Aérosp., n° 1987-6, 1987.

Boudon Y, Bernard A., Barlier F., Juillerat R., Mainguy A.M., Walch J.J., Synthèse des résultats en vol de l'accéléromètre CACTUS pour des accélérations inférieures à 10^{-9} g, IAF, Dubrovnik, 1978.

Runavot J.J., Bouzat C., Bernard A., Sacleux B., Acta Astronautica, vol. 10, n° 9, pp. 599-607, 1983.