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The BepiColombo mission to Mercury and the Italian Spring Accelerometer (ISA) on-ground and in-flight calibration procedures

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Abstract

BepiColombo, the forthcoming ESA (cornerstone) mission to Mercury [1,10], will include a comprehensive set of experiments — denominated Radio Science Experiments (RSE) — in order to measure the gravitational field of the planet and its rotation [8] and to perform precise tests of Einstein's theory of general relativity versus other metric theories of gravity [9]. Among the onboard instruments, a fundamental role in the RSE will be played by ISA (Italian Spring Accelerometer) [5,2]. This paper is devoted to describe the accelerometer characteristics, performance and measurements, as well as to introduce the experimental procedures in order to calibrate its measurements on-ground and in-flight, during the cruise phase to Mercury and during the nominal phase of the mission around Mercury.

1. ISA characteristics and measurements in the context of the RSE

ISA is a three–axis high-sensitivity accelerometer, characterized by an intrinsic noise level of about $10^{-10} g_{\oplus}/\sqrt{\text{Hz}}$ in the frequency band $3\cdot10^{-5}$ — $1\cdot10^{-1}$ Hz. The main goal of ISA it to measure the very strong non–gravitational accelerations [7] acting on the MPO (Mercury Planetary Orbiter) spacecraft, which are an important source of error in the RSE measurements. The non-gravitational accelerations are proportional to the area-to-mass ratio of the spacecraft, and are very difficult to be properly modeled for a complex in shape and active satellite like the MPO. Indeed, the modeling depends on a set of parameters related with the physical properties of the satellite surface and structure, which will be strongly influenced, and with completely unknown laws, by the strong radiation environment in the surroundings of Mercury. In order to reach the ambitious objectives of the RSE, the *a posteriori* reconstruction of the MPO orbit should reach the 10^{-8} m/s^2 level in acceleration over a time span of one orbital revolution of the spacecraft around Mercury [3], i.e. about 2.3 hours. The ISA measurements have to be integrated with the radar tracking measurements [6] from Earth's stations in a very precise orbit determination procedure. The RSE are a complex mix of measurements and scientific objectives, and it is not possible to separate them neatly in independent experiments. These experiments are based, from one side, on a sophisticated and very precise tracking system [6], both in range and range-rate, that will use a full 5-way frequency link from Earth's ground stations to the MPO (X-band, Ka-band and a mixed mode). From the other side, a precise orbit determination software and procedure is needed in order to reconstruct the orbit of the MPO around Mercury, and of Mercury center-of-mass around the Sun, while solving in a complex least-squares fit for local and global parameters [8,9]. Finally, ISA measurements will be useful also to estimate the speed variations produced by the onboard thrusters firings during the offloading maneuvers of the spacecraft reaction wheels [4], at least one every 24 hours.

2. ISA on-ground and in-flight calibration procedures

A full exploiting of the instrument measurement capabilities will be possible only after a proper calibration of the instrument readings. The instrument is equipped with capacitive control actuators that allow to apply known acceleration (calibration) signals to the sensing masses. Some of the calibrations will be performed on-ground, while other in-flight, during the cruise phase and, especially, once in orbit around Mercury.

The on-ground calibration procedures will be aimed at characterizing the instrument as much as possible in the laboratory environment. In the following a brief description of the needed measurements is given. Among the various measurements to be performed on-ground, special care has to be devoted to the measurement of the transfer function of the three sensing elements and of their (possible) non linearities. Then the actuator and pick-up transduction factors have to be measured., These measurements enable the conversion between the voltage read at the capacitive bridge and the acceleration acting on the sensing mass . A fundamental activity will be the measurement of the sensing axes directions, to correct for the small misalignments from the ideal orthogonality of the three sensing elements; giving a known acceleration in a precisely determined direction and measuring the instrument output, it is possible to measure the actual sensing direction for each of the three elements. To this aim, a dedicated facility is being developed.

Once in-flight, it is foreseen to calibrate the instrument pick-up transducer factor by means of the control actuators. In the same calibration slot, the measurement and adjustment of the capacitive bridge working point will be performed. One very important in-flight calibration procedure will be devoted to determine the ISA sensitive axes orientation with respect to a dedicated reference frame. This calibration will be performed both during the cruise phase and once in orbit through dedicated slewing maneuvers around the spacecraft body axes.

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