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The ISA accelerometer, in view of BepiColombo launch

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Abstract

The BepiColombo Italian Spring Accelerometer (ISA) is a component of the dedicated suite of instruments which will perform the so-called Radio Science Experiments in order to study gravitational field, internal structure and rotational state of the planet Mercury, and to verify important predictions of the general theory of relativity. Its main role is the measurement of non-gravitational accelerations acting on the surface of the Mercury Planetary Orbiter spacecraft, thereby enabling to work on a virtually drag-free satellite. In this talk the concept, design and development of the instrument are reviewed, along with its main scientific products. The development and testing of the data processing procedures, as well as the definition of the instrument operations for the various mission phases, are also presented, with special emphasis on the activities foreseen for the cruise phase.

1. Introduction

The ESA mission BepiColombo (BC) is a challenging programme aimed at the exploration of planet Mercury and its space environment [1, 13]. It comprises two spacecraft, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO) that will be launched in the second half of 2018 and will reach Mercury after almost seven years of cruise. The MPO spacecraft will be dedicated mainly to the study of the geology and geophysics of the planet itself; it will host a suite of instruments devoted to the so-called Radio Science Experiments (RSE) in which, by precisely tracking the MPO orbital motion and carefully modelling its dynamics, the gravitational field and rotation state of the planet could be reconstructed, along with a series of tests of general relativistic effects. For a deep discussion of the RSE concept and its realisation, see [9, 10, 5, 11, 12].

The parameters of interest (related as said to Hermean geophysics and to fundamental physics) can be extracted from the observational data using a procedure of orbit determination and parameter estimation, usually called POD (precise orbit determination). A model for the orbital dynamics of the spacecraft is fitted to the tracking data, in this case distance and velocity (called also *range* and *range-rate*) of the spacecraft with respect to one or more Earth-bound stations. The model should be sufficiently accurate to describe the orbital dynamics at a level comparable to the information content of tracking. It has to be noticed that, while the majority of the forces acting on the spacecraft in orbit around Mercury comes from its gravitational attraction as well as from the attraction of the other bodies of the Solar System, a non-negligible part is constituted by surface forces resultant from the interaction of the spacecraft body with particles and fields in the near-Mercury environment (the so-called *non-gravitational perturbations*). A precise modelisation of these forces is not easy [7]: an effective alternative is the direct measurement of the total resulting acceleration via an on-board accelerometer. This is the BC choice, employing the ISA (Italian Spring Accelerometer) accelerometer [3, 4, 2]. ISA is a three-axis accelerometer: it features three sensing elements arranged in a suitable geometrical configuration, each one sensing a one-dimensional component of the overall signal. These three channels can then be properly combined in order to obtain the total acceleration vector acting on a given reference point (called *vertex*). The time series of acceleration values so measured is then an input to the POD: the MPO becomes therefore a sort of *a posteriori* drag-free satellite.

2. Scientific objectives and accelerometer role

The BC RSE can be roughly divided into three different but nevertheless deeply connected experiments, respectively gravimetry, rotation and relativity. The gravimetry and rotation experiments aim to determine respectively the global Mercury gravity field and its rotational state, to constrain models of the planet internal structure. Goal of the relativity experiment is to test selected predictions of the general relativity theory (namely the perihelion precession and the Shapiro time delay), constraining several PPN (parameterized post-Newtonian) parameters. An effective POD is the key for the achievement of these objectives.

The ISA accelerometer will directly measure the surface accelerations acting on the MPO spacecraft, to be subsequently used in the POD procedure. These accelerations are mainly due to photons from the Sun or from the planet surface being reflected-absorbed-diffused by the surface of the spacecraft, and to radiation anisotropically emitted by the spacecraft body. they are rather difficult to model, depending in a complex way on the spacecraft attitude and on the (possibly time-dependent) optical properties of its surfaces. A simple, *cannonball*, model for the strongest effect (*direct solar radiation pressure* — see e.g. [8, 6]) can only provide order-of-magnitude estimates of the force. More elaborate models (that would take into account the response of the various parts, as solar panels and antennae) could reasonably hope to achieve an accuracy of at most 10 % of the total expected signal [7]; this is not enough for the RSE purposes, and this is indeed the motivation for measuring them directly with an accelerometer.

An ideal accelerometer is a device which measures the three components of an acceleration vector acting on a defined reference point, usually the center of mass (CoM) of the spacecraft. Such an ideal instrument, placed just at the spacecraft CoM, measures only the non-gravitational accelerations: it is completely insensitive to gravitational effects. A real, extended accelerometer could sense also spurious effects, due e.g. to gravitational gradients. The induced measured spurious signal has to be properly accounted for (filtered out / modelled). This task is generally known as *data reduction*.

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