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Estimation of the Magnetic Noise Contribution to LISA Pathfinder Differential Acceleration

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Abstract. The payload of LISA Pathfinder (LPF) is the LISA Technology Package (LTP), which is designed to measure relative accelerations between two test masses in nominal free fall placed in a single spacecraft. The differential acceleration reading will be perturbed by disturbances such as thermal fluctuations or magnetic effects. The Magnetic Diagnostics System is one of its modules and it will perform two main tasks: (1) estimate the magnetic properties of the test masses, i.e., their remanent magnetic moment and susceptibility, and (2) infer the magnetic field and its gradient at the location of the test masses. The present paper describes the first task and how an estimation accuracy of 1% relative error is attained.

1. Introduction

The LISA Technology Package is designed to measure relative accelerations between two test masses in nominal free fall placed in a single spacecraft. The differential acceleration reading will be perturbed by disturbances such as thermal fluctuations or magnetic effects. The Magnetic Diagnostics Subsystem includes two coils which generate controlled magnetic fields at the locations of the test masses. These magnetic fields will excite the dynamical response of both test masses, that will be used to infer the magnetic properties of the test masses.

2. Simulation and estimation

The force and torque exerted by the coils are:

$$\mathbf{F} = \left\langle \left[\left(\mathbf{M} + \frac{\chi}{\mu_0} \mathbf{B} \right) \cdot \boldsymbol{\nabla} \right] \mathbf{B} \right\rangle V \qquad \mathbf{N} = \langle \mathbf{M} \times \mathbf{B} + \mathbf{r} \times [(\mathbf{M} \cdot \boldsymbol{\nabla})\ \mathbf{B}] \rangle\, V \tag{1}$$

This dynamical response is modeled and can be simulated within the SSM (State Space Model) framework of the LTPDA toolbox (LISA Technology Package Data Analysis toolbox). Specifically, the magnetic excitations are modeled within a specific Magnetic SSM Module that pipelines magnetic forces and torques to the dynamic model of the payload. This infrastructure allows to assess the effect of magnetic perturbations onto the test mass dynamics and, also, the kinematic excursions experienced by the test masses due to these excitations (see Figure 1). This feature is essential to determine the magnetic properties of the test masses and it was not available in other mission simulators. The kinematic excursions of the test masses are processed by an adequate data analysis pipeline which allows for the estimation of the magnetic properties of the test masses, i.e. **M** and χ.

We estimate the magnetic characteristics by applying least square techniques on the 3 dimensional kinematic response delivered by the interferometer, i.e. displacement and rotation excursions. We correct also the errors induced by cross-talks, and we maximize a joint function

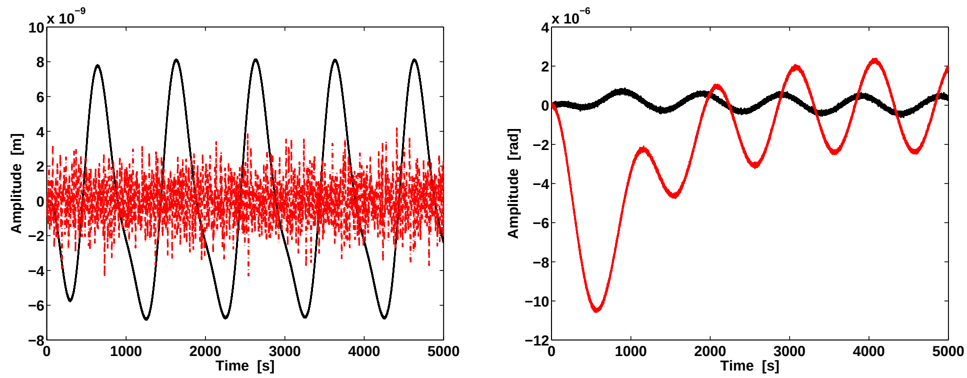

Figure 1. Left panel: relative displacement of the test masses measured using the differential channel of the interferometer (solid black line). The dashed red line shows the absolute displacement with respect to the optical bench. Right panel: rotation about the *y*-axis — black solid line — and the *z*-axis — red line. Both panels show the response of test mass 1 when only coil 1 is fed with a current of 1 mA and 1 mHz. For this specific example we have adopted $M_x = 16.4\times10^{-5}$ A/m, $M_y = 9.1\times10^{-5}$ A/m, $M_z = -6.8\times10^{-5}$ A/m (a random orientation of the maximum M) and $\chi = 2.5\times10^{-5}$.

that takes into account frequency dependent effects, model uncertainties and Signal to Noise ratio. Further detail can be found in Diaz-Aguilo et al. (2012).

3. Conclusion

The SSM modeling framework allows for the modeling of the magnetic perturbations and assesing their effects on test mass dynamics of LTP. By feeding the LISA Pathfinder coil with 1mA, kinematic excursions of 8nm and of 2 μrad are detected by the interferometer. This represents sufficient Signal to Noise Ratio to estimate magnetic properties. Estimation algorithm includes crosstalk compensation, robustness in front of model uncertainties and maximization of SNR. The magnetic properties of the test masses can be estimated inflight within 1% accuracy level. This represents one order of magnitude enhancement in estimation quality.

References

Diaz-Aguilo, M., García-Berro, E., & Lobo, A. 2012, Phys. Rev. D, 85, 042004