A two-stage torsion pendulum for ground testing free fall conditions on two degrees of freedom

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A two-stage torsion pendulum for ground testing free fall conditions on two degrees of freedom

M Bassan[1], A Cavalleri[2], M De Laurentis[3,4], F De Marchi[5], R De Rosa[3,4], L Di Fiore[3], R Dolesi[2], N Finetti[6,7], F Garufi[3,4], A Grado[3,8], M Hueller[2], L Milano[3,4], G Pucacco[1], R Stanga[6,9], D Vetrugno[2], M Visco[1,10], S Vitale[2] and JW Weber[2]

1 University and INFN of Roma Tor Vergata , 2 University of Trento and INFN-TIFPA, 3 INFN Napoli, 4 University of Napoli "Federico II", 5 DIMA Università di Roma Sapienza, 6 INFN Firenze-Urbino, 7 University of l'Aquila, 8 INAF-OACN, 9 University of Florence, 10 INAF-ISS

luciano.difiore@na.infn.it

Abstract. Ground testing with torsion pendulums played a key role in the development and characterization of the Gravitational Reference Sensor (GRS) of LISA-Pathfinder (LPF). We report on a torsion pendulum facility with 2 soft degrees of freedom (DOF), realized by off-axis cascading two torsion fibers. This instrument, developed for testing on two DOFs the LPF GRS, allows simultaneous measurement of force and torque acting on the suspended test mass (TM), approaching free-fall condition on two DOFs down to a few mHz. We will report on the results of some measurement campaigns devoted in particular to the characterization of force to torque and torque to force actuation cross-talks (CT).

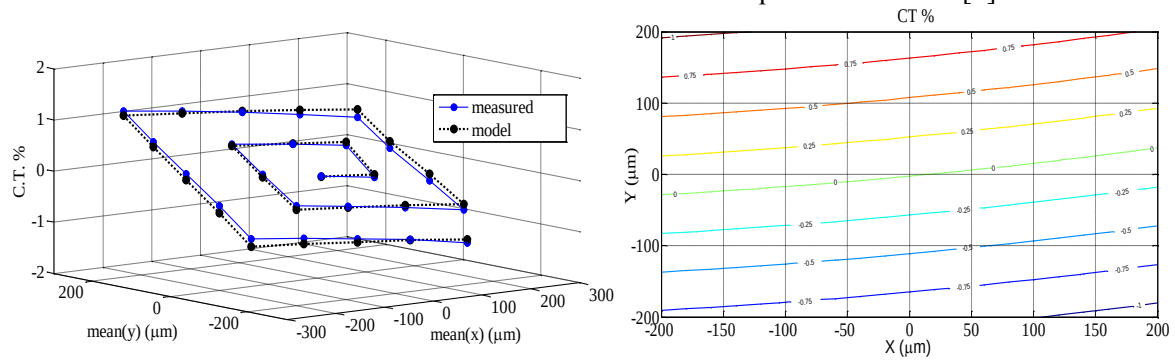
1. Introduction

PETER (PEndolo Translazionale E Rotazionale, namely Translational and Rotational Pendulum) is a two DOFs torsion pendulum facility [1]. A first fiber hangs a cross shaped stage; at one end of the cross a second fiber supporting the TM is suspended. Three counter weights are supported by rigid rods attached to the other arms of the cross. The system shows two soft DOFs, namely the rotation around the upper fiber (φ_a) and the rotation around the lower fiber (φ_b). These coordinates are simply related to two TM DOFs, i.e. displacement and rotation. With respect to these, the TM can be considered, above the resonance frequencies (1.3 and 2 mHz), in free fall. The suspended TM is enclosed in an engineering model of the LPF GRS which provides capacitive readout of the 6 DOFs of the TM as well as electrostatic actuation. Optical Read-Out (ORO) sensors, based on optical levers [2], provide independent measurement of TM and upper stage displacement. The GRS is mounted on motorized stages that allow to move it with respect to the TM in 5 DOF (2 translations and 3 angles). The GRS electronics, provided by ETHZ, is very similar to the flight model.

2. Application to ground testing of LPF and LISA: actuation CT measurement

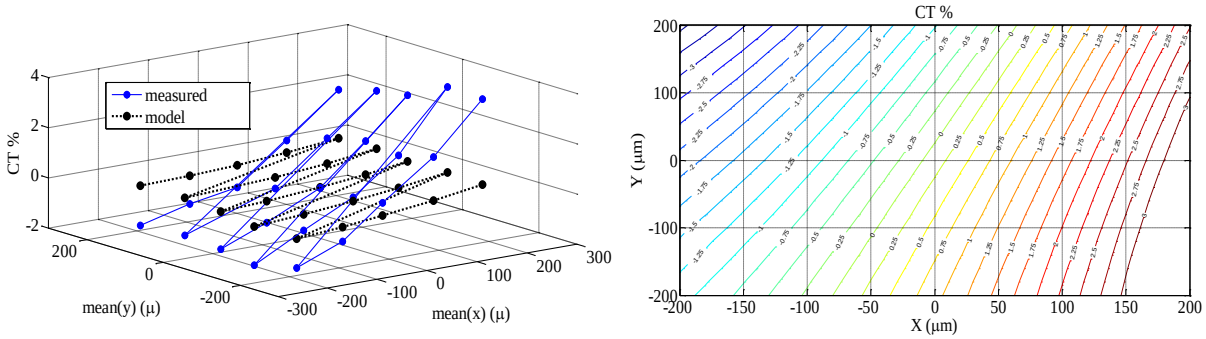
As an example of how PETER can provide useful ground testing for LPF, and future LISA mission, we describe here the measurement of actuation CT. We recall that the LPF test mass is in free fall along the x axis, while under feedback control on the remaining DOFs: an undue CT of these feedback

signals into the x channel would spoil the quality of geodesic motion. We show here actuation CTs measured by acting in force (F) on the suspended TM and measuring the CT torque (τ) and vice-versa. We report, as an example, the results of a $CT_{F\rightarrow\tau}$, and a $CT_{\tau\rightarrow F}$ measurement runs performed in May and June 2015 respectively. In both cases, we moved the GRS along a regular patterns in x and y, around the TM, for a total of 25 positions. For each position the CT measurement is averaged for 2 h. The total measurement time is 50 h. In figures 1 and 2, we show the data in 3D plots compared to the GRS analytical model and contours plots of second order surfaces fitted to the data for the two measurement runs. For further details on the measurement technique see reference [2].



(a) (b)

Figure 1. measured $CT_{F\rightarrow\tau}$, (solid line) compared to the analytical model (dotted line). (b) measured $CT_{F\rightarrow\tau}$, contour plot (0.25 % level spacing). The CT is quite small and in good agreement with the model.



(a) (b)

Figure 2. (a) measured $CT_{\tau\rightarrow F}$ (solid line) compared to the analytical model (dotted line). (b) measured $CT_{\tau\rightarrow F}$ contour plot (0.25 % level spacing).. In this case, the CT is larger than expected, but, in the central part of the GRS measurement range, it drops to small values (<0.3 % within $\pm$ 20 μm from GRS center).

3. Conclusion and perspectives

We have performed several repeatable measurement of actuation CT, the first available for the LPF GRS before flight. The CTs measured with PETER are, in the central part of the GRS, quite small and within specs; they should not represent a problem for GRS operation. We think that the simulation of free fall on ground of multiple DOFs, first demonstrated with PETER, will be very useful for the testing of flight hardware of LISA and other space missions requiring drag-free control.

References

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