Simulation of Torsion Pendulum Discharging Measurements


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Introduction

As part of preparation for LISA Pathfinder, discharging measurements have been made with the four-mass torsion pendulum experiment at the University of Trento. The discharging properties of the system are dependent on a number of interrelated factors. These include the photoelectric and reflective properties of the inertial sensor surfaces as well as the distribution of the illuminating UV light. In addition, the geometry of the system and the presence of varying electric fields play important roles. In order to better understand the discharging system as a whole, simulations have been produced which incorporate all these factors and where possible use measured parameters to describe them. The simulation has been used to help understand some unexpected discharging results from the pendulum experiment and can be used in future to optimise the design of the LISA system.

The simulation consists of two distinct parts. First, a ray-tracer written in Geant4, models the propagation of the UV light within the inertial sensor which determines the percentage of light absorbed on the various surfaces. The second part is written in MATLAB and uses the calculated absorption ratios to model the flow of the emitted photoelectrons, within region-specific electric fields. This allows discharge rates and the instantaneous test mass potential to be estimated under a variety of operating conditions.

UV Ray Trace

The UV ray trace is written in the Geant4 framework. While originally created to model the propagation of particles through matter, Geant4 also contains reflection physics models and highly versatile methods for describing complex geometries. Once the system geometry has been described within Geant4 the ray trace follows a common procedure:

1) A ray is generated within the ISUK tip with a random polarisation and a direction randomly sampled from the experimentally measured ISUK light distribution.

2) The ray propagates in a straight line through the geometry until it is incident with a surface.

3) Using the Fresnel equations, it is then either absorbed or reflected, depending on the reflective properties of the surface, the angle of incidence and the ray’s polarisation. The complex refractive index at 254 nm is used to determine reflection properties of the surface. The smooth surfaces within the sensor (r.m.s<10 nm) are known to reflect specularly while the unknown reflective properties of the rougher surfaces can be varied.

4) If a ray is reflected it is given a new direction, dependent on the reflection properties of the surface. The smooth surfaces within the sensor has been measured and agrees with the literature values.

5) If the ray is reflected it is eventually absorbed. This is repeated for a user-specified number of rays, typically greater than 108.

6) The inertial sensor is split into regions and the percent of light absorbed by each is recorded and outputted to an ASCII file at the end of a run.

While the simulated results are generally very good there are some discrepancies. This is not surprising given the simplicity of the model and can likely be explained by a combination of two weaknesses. Firstly, although the UV ray trace can approximately predict the total amount of light absorbed by either the test mass or housing, the exact distribution of absorbed UV light is still uncertain. To predict this with confidence one requires measurements of the reflection properties of the rough surfaces. As the distribution in absorbed light determines which electric fields emitted photoelectrons are influenced by, this affects the discharge behavior. It should be noted that the distributions currently predicted with $\sigma_{\text{h}}=15$ and $\sigma_{\text{tm}}=25$ do not seem far off the true properties given the subsequent good agreement with the measured discharge properties. Possible evidence for this theory is the fact that the predictions of the model fit less well with a large applied injection bias. This may suggest the amount of UV absorbed within the injection regions is slightly out.

Conclusions

The ability of the photoelectron flow model to reproduce the behaviour observed at the four-mass experiment is encouraging and also builds further confidence in the UV ray trace. So far the simulation has performed very well in fitting results obtained while applying dc voltages to sensor electrodes. Further work is on-going to test the model against measurements made with ac biases, while using the same set of parameters.