**ABSTRACT**

In the LISA Pathfinder mission, the injection of the 1.36 kg Au-Pt Test Mass into a geodesic trajectory represents a possible single-point failure of the whole mission. In this critical phase: • the格多in Positioning and Release Mechanism (GPRM) releases the test mass (TM) from the capped condition to free-fall by means of a fast retraction of two opposite tips; • a momentum transfer from the GPRM to the TM occurs due to adhesive bonds and possible asymmetry of the system; • the effective control authority is limited. The released TM may be captured by this system only if its residual velocity after release is below 5 μm/s.

In order to assess the risk, this critical phase is tested in an environment that simulates the conditions that will be experienced in operation. A combined experimental-analytical strategy has been conceived to this purpose:

1. the momentum transfer from an actuator to an adhered test mass is measured by means of a dedicated experiment characterizing the adhesion force-to-elongation law under dynamic failure (TMF);
2. in order to extrapolate these results to the in-flight conditions, a physical model of the GPRM release mechanism is proposed and experimentally identified;
3. this model is associated with the experimental adhesion force-to-elongation laws and the TM dynamics in order to describe the in-flight release;
4. the test mass state after injection is estimated by means of a Monte Carlo analysis.

**RELEASE MECHANISM (GPRM) MODEL AND IDENTIFICATION**

The GPRM is constituted by a piezo-stack that moves the Release Tip and is loaded by a washer spring. The constitutive equations are:

\[ R \frac{d}{dt}(\Delta r(t)) = C(t) \cdot \dot{e}(\theta(t)) + J(t) \sigma(t) + \dot{J} \sigma(t) \]

where the values of the parameters are obtained by minimizing the RMS between the modelled retraction and the measured one. The measurements were made by RUAG on the unloaded GPRM (no adhesion).

The uncertainties of the model, needed by the Monte Carlo simulation, are estimated with the following approaches:

1. a covariance matrix is associated to the model parameters with the formula (where \( z \) is the covariance matrix associated to residuals and noise and \( J \) the Jacobian of the retraction due to the parameters):
   \[ \sum_{x} = (J^T \sum_{J} J)^{-1} \]
2. by altering the nominal mechanism with a set of random forces. Each of these forces is generated such as its effect on the unloaded retraction has the same power spectral density (PSD) of the residuals.

**MONTE CARLO SIMULATIONS AND RESULTS**

**SIMULATION WITH ADHESION ON ONE TM SIDE (worst-case)**

**MOMENTUM TRANSFER DUE TO THE PRELOAD – DELAY EFFECT**

Another mechanism for transferring momentum from the tip to the TM is the combined effect of initial preload and delay between the retractions of the two tips. If the delay is small (≤ 100 μs) the residual velocity due to this effect is given by:

\[ \Delta V_{PRE-DELAY} = \frac{M}{M} \]

The small delay allows the use of this formula because the TM displacement is assumed to be negligible. The period of the GPRM + TM system is estimated in 3 ms.

Superimposing this effect to adhesion, the maximal allowable delay, with a preload of 0.3 N, is:

\[ \Delta = \frac{20.0}{0.3} \]

The velocity due to a generic delay is shown in the Figure.

**PRESENT AND FUTURE DEVELOPMENTS**

The experimental facility has recently been improved by adding a system capable of measuring the tip mock-up motion. This device is a differential optical shadow sensor (DOSS).

The force-to-elongation function is obtained by filtering the measured data instead of solving and identifying all the dynamical intrinsic parameters.

The measurements are then fitted with a sum of exponentials:

\[ F(t) = \sum A_i e^{t_{i+1}/t} \]

This function is consistent with the single-contact Johnson Kendall Roberts theory (JKR) extended to multi-contact surfaces ( Fuller and Tabor) such as rough surfaces.

The first results with this improved setup have recently been analyzed. The residual velocity PSD due to the single-sided release is (20000 runs):

\[ \sigma_{residual} = 0.145 \mu m/s \]

The results are useful for the following activities are planned:

- Improve the TM mock-up mass (better representativeness);
- Improve the adhesion theoretical model;
- Improve the dynamics of the system.

- Estimate the velocity by means of a testing campaign on the real GPRM.

- Improve the GPRM with a better model.