Magnetic polarisation effects of temperature sensors and heaters (NTC’s) in LISA PathFinder

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Introduction

LISA PathFinder goal:

\[ S_{\text{NTC}}(\chi V/\mu B) \leq 3 \times 10^{-14} \left( \frac{w}{24 \text{ mm}} \right)^2 \text{ ms}^{-2} \text{ Hz}^{-1/2} \]

This requirement implies stringent limitations on internal environment fluctuations, specifically, thermal and magnetostatic fluctuations in the LTP must be very low.

The temperature diagnostic subsystem onboard the LTP includes 8 thermistors surrounding each of the TM’s. The inherent magnetic nature of the thermistor makes them potentially dangerous as they are placed quite near the TM’s. The problem arises from:

1. NTC’s are manufactured mixing and synthesising oxides doped with ferromagnetic materials.
2. NTC devices are attached to the outer faces of the Electrode Housing surrounding the TM’s: 4 as temperature sensors and 4 as heaters.
3. NTC’s are very close to the TM’s: 13 mm.
4. Magnetic field and magnetic field gradient induce parasitic acceleration in the TM’s.

The noise acceleration budget assigned to magnetic effects in the TM is

\[ S_{\text{NTC}}(\chi V/\mu B) \leq 3 \times 10^{-14} \left( \frac{w}{24 \text{ mm}} \right)^2 \text{ ms}^{-2} \text{ Hz}^{-1/2} \]

The steps performed in order to quantify the effect of the presence of the NTC’s around the LTP performance are basically:

1. Measurement of the magnetic properties of the NTC’s.
2. Calculation of the magnetic field and magnetic field gradient in the TM’s due to the presence of the 8 NTC’s surrounding the TM’s.
3. Evaluation of the impact on the TM acceleration.

Force fluctuations in the TM due to Magnetic Fields

The force fluctuation in the TM due to magnetic effects is:

\[ S_{\text{ac}}(\chi V/\mu B) = V \left( \frac{\chi}{\mu B} \right) S_{\text{B}} + \left( \frac{\chi}{\mu B} \right)^2 \left( \nabla B \right)^2 S_{\text{V}} \]

The noise acceleration due to magnetic effects is:

\[ S_{\text{ac}}(\chi V/\mu B) = 2.15 \text{ ms}^{-2} \text{ Hz}^{-1/2} \]

The effect of \( B_{\text{NTC}} \) in the TM acceleration has to be quantified.

Numerical calculations

• NTC’s assumed to behave like magnetic dipoles.
• NTC’s surrounding the TM considered.
• A Finite Element Model used for the calculations.
• Different magnetic moment orientations analyzed.
• Remanent magnetic moment after NTC saturation used (\( m_0 \text{ — worst possible scenario} \)).

Calculations considering different orientations of the 8 magnetic moments of the NTC’s allow us to know the worst possible combinations. A simple scheme of the magnetic moment orientations (arrows in the figure) surrounding the TM and the numerical values obtained are shown.

Excess TM noise calculations

The FMC for the BetaTherm NTC’s can be linearised near the full demagnetisation zone as:

\[ |m_{\text{NTC}}| \approx 1.45 \times 10^{-3} \mu \text{m} \]

The remanent magnetic moment after de-magnetisation is:

\[ |m_{\text{NTC}}| \approx 1.45 \times 10^{-3} \mu \text{m} \]

Acceleration noise for three different scenarios is compared:

• No presence of NTC’s.
• Presence of NTC’s with the maximum possible remanent magnetic moment, i.e., after saturation, \( |m_0| \).
• Presence of NTC’s after de-magnetisation, \( |m_{\text{NTC}}| \).

If \( \Delta < 10\% \) is required:

1. NTC’s must be de-magnetised
2. NTC’s should not be exposed to magnetic fields higher than 5 mT.

Conclusions

• NTC’s shown ferromagnetic behaviour.
• The magnetic properties of the NTC’s can degrade the performance of the LTP, increasing the magnetic noise by ~65% relative to the background in the very worst possible situation. Even in such extreme conditions the budgeted magnetic noise (12 l/s/mHz) is not reached.
• De-magnetisation of the NTC’s produces very good results: the magnetic noise they induce can be reduced by about an order of magnitude, which makes it mostly negligible.