An optical readout system for the drag free control of LISA

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We present a study for an optical readout system for the LISA GRS

The goal is not the replacement of the capacitive sensor with an optical one but the integration of the optical readout in the present design of the GRS (with minimum modification)

the motivations are:

• risk reduction: in order to have a back-up readout in case the capacitive one fails after the launch

• redundancy: an independent readout provides extra information on couplings etc.

• sensitivity: an optical readout is potentially more sensitive for some DOF.
In order to be implemented on LISA, the system should fulfil some condition

• enough sensitivity => we assume as an acceptable levels:

\[ \delta x \leq 10^{-9} \text{ m/Hz}^{1/2} \]
\[ \delta \theta \leq 5 \cdot 10^{-8} \text{ rad/Hz}^{1/2} \]

• low back action => we assume:

\[ \delta F \leq 6 \cdot 10^{-16} \text{ N/Hz}^{1/2} \]

• The system should require very small modifications of the hardware already tested on flight with LTP (it should better be tested on LTP but there is very little time left).
Optical lever sensor

With these requirements in mind we have selected as a simple solution the usage of optical levers:

A laser beam is sent through a SM optical fibre to the test mass and the position of the reflected beam is measured with a position sensor (Quadrant photodiode of PSD)

the sensitivity depends on input power and measurement range (beam size for QPD or detector size for PSD)

with a suitable combination of three beams and sensors we can recover the six DOF of the test mass.
some relevant noise sources

shot noise

$$\tilde{x}_{sm} \approx 2.8 \cdot 10^{-11} \left( \frac{633 \text{nm}}{\lambda} \right)^{1/2} \left( \frac{1 \text{mW}}{P_0} \right)^{1/2} \left( \frac{0.78}{\eta} \right)^{1/2} \left( \frac{L}{1 \text{mm}} \right) \left[ \frac{\text{m}}{\sqrt{\text{Hz}}} \right]$$

amplifier current noise

$$\tilde{x}_I = \frac{L \cdot \tilde{I}_n(f)}{\alpha \cdot P_0} \approx 4.2 \cdot 10^{-10} \left( \frac{\tilde{I}_n(1 \text{mHz})}{1.7 \cdot 10^{-10}} \right) \left( \frac{1 \text{mW}}{P_0} \right) \left( \frac{1 \text{mHz}}{f} \right)^{1/2} \left( \frac{L}{1 \text{mm}} \right) \left[ \frac{\text{m}}{\sqrt{\text{Hz}}} \right]$$

power fluctuations

$$\tilde{F} = \frac{2 \cdot \tilde{P}}{c} \leq 6 \cdot 10^{-16} \left[ \frac{\text{N}}{\sqrt{\text{Hz}}} \right] \quad \Rightarrow \quad \tilde{P} \leq 10^{-7} \left[ \frac{\text{W}}{\sqrt{\text{Hz}}} \right]$$
Some bench-top measurements

the bench is machined from a single block of stainless-steel and has interfaces for fiber couplers and sensors.

the "test mass" has some mirror attached and can be moved for calibration.

the system is symmetric for differential measurements.

the whole set-up is closed in a box to reduce thermal variations and prevent effect of air flows etc.
Preliminary results (single arm)

beam power 140μW

spot size 350 μm
Radiation pressure

The DC force is very small and can be compensated electrostatically:

\[ F \leq \frac{2 \cdot P}{c} \approx 6 \cdot 10^{-12} \left( \frac{P}{1\text{ mW}} \right) \text{[N]} \]

The force due to power fluctuation can be reduced within the specification by active stabilization.

**Example:**

laser diode

total power 1.2 mW

feed-back on laser current
Integration in LISA
position sensors

fiber couplers
Top view

Position detectors

z, \theta_x, \theta_y

x, \theta_y, \theta_z

Position detector (PSD)

y, \theta_x, \theta_z

Optical fiber couplers
Front view

Position detectors

Optical fiber coupler

Position detector

$z, \theta_x, \theta_y$

$x, \theta_y, \theta_z$

$y, \theta_x, \theta_z$
CONCLUSION

• An optical readout based on optical levers is potentially compliant with LISA GRS specifications

• Preliminary bench-top experiments show a sufficient sensitivity down to 5 mHz – work is in progress

• We have a principle design for the integration in LTP (?) and LISA

• Still there are several technical aspects to be defined

• We plan to test a prototype on the Trento torsion pendulum next year