The Development of a Cryogenic Optical Delay Line for DARWIN

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Abstract

TNO has designed a compact cryogenic delay line for use in the future ESA space interferometry mission DARWIN. The task of a delay line is to equalise the optical path lengths in an interferometer at nanometer level. A magnetic bearing based solution has been selected. The concept has a voice coil actuator for Optical Path Difference control, driving a two-mirror cat's eye optics. The cat's eye structure and mirrors are all constructed from Al6061. The assembly and integration of the delay line has been completed. The measured Path Difference stability is 1 nm rms. A full verification test program is currently being carried out.

1. Introduction

TNO (Nl), in cooperation with Micromega-Dynamics (B), SRON (Nl), Dutch Space (Nl) and CSL (B), has designed a compact breadboard cryogenic delay line for use in future space interferometry missions. The work is being performed under ESA contract in preparation for the DARWIN mission. The breadboard delay line is representative of a future flight mechanism, with all materials and processes used being flight representative.

2. Task, components and requirements

The task of a delay line is to equalise and fine-tune the optical path length of the beams coming from the observed star going though the different telescopes and ending at the detector. The optical path length must be equalised at nanometer level without introducing significant wavefront errors, beam tilt and beam deviation.

The main components of a delay line are: a retroreflector, a guide system and a metrology system.

The main requirements for the breadboard DARWIN Optical Delay Line (ODL) are given in Table 1 [1].

Table 1. Optical Delay Line main requirements.

Requirement:	Value:
Operational temperature	40 K
OPD stability	< 1 nm RMS
OPD range	20 mm
Dimensions	< 300 x 100 x 100 mm^3
Mass	<10 kg (target: <6 kg)
Overall power dissipation	< 2.5 W
Power dissipation in ODL	< 25 mW
Optical beam diameter	> 25 mm
Output beam tilt (over the full actuation range)	< 0.24 µrad
Wavelength range	0.45 – 20 µm
Wavefront distortion	<λ/20 RMS (λ = 633 nm)
Coating manufacturing reproducibility	• Relative spectral response < 10^{-4} • Chromatic phase differences < 0.1 nm • Relative polarization rotation < 0.1° • Ellipticity < 0.1°
Transmission	> 94%
Design lifetime	10 years

3. Design description

Retroreflector. The two-mirror cat's eye optics (retroreflector), which relaxes the sensitivity to tip/tilt motion, contains one 50 mm parabolic focusing mirror and one flat mirror (Figure 1).

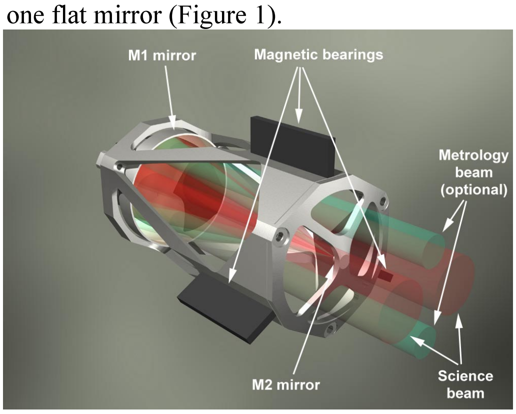

Figure 1. ODL configuration

Guide system. In order to enable single stage (one actuator) optical path length actuation, the delay line needs to have:

- a low moving mass,
- low friction variations (e.g. stick/slip, bearing noise, power and signal wire torques),
- low hysteresis, and
- linear behaviour.

An extensive trade off study has been performed to select the best concept for the DARWIN ODL guide system [2]. A magnetic bearing based solution has been selected for this application.

Metrology. A laser interferometer is used for the breadboard

TNO applies a minimum-number-of-stages philosophy to all delay lines it develops. A smaller number of actuation stages simplifies the optical path control algorithm. The selected concept has a single stage voice coil actuator for Optical Path Difference (OPD) control, driving the cat's eye optics. Five magnetic bearings constrain 5 degrees of freedom (the OPD controller constrains the other degree of freedom) and provide frictionless and wear free operation with zero-hysteresis. The cat's eye structure and mirrors are all constructed from Al6061. The mirrors are plated with Alumiplate™. This makes the design fully a-thermal. With a single stage delay line no relative movement between mirrors in the cats-eye occurs. This improves the optical quality of the outgoing beam.

4. Results

The assembly and integration of the delay line has been completed. The latest measured OPD stability is 1 nm rms on a test bench with 23 µm rms vibration level (note: the test bench has a much higher disturbance spectrum than the DARWIN spacecraft). Alcatel Space (F) and SAGEIS-CSO (F) are currently carrying out a full verification test program, including thermal vacuum testing at 40 K.

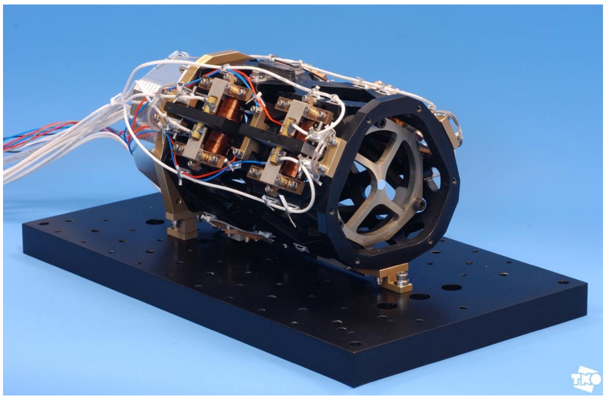

Figure 2. Delay Line with magnetic bearings

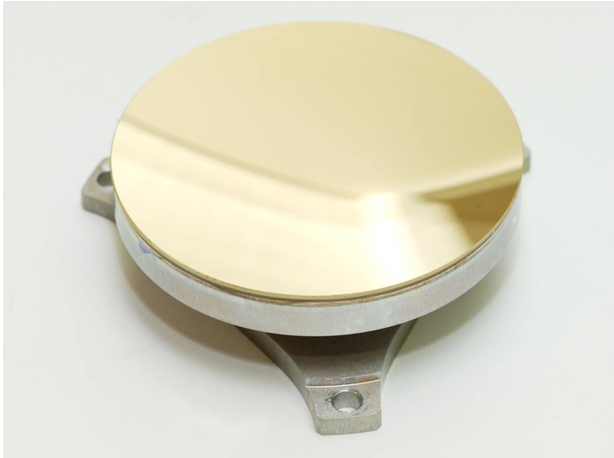

Figure 3. Parabolic mirror with Alumiplate™ and Gold coating.

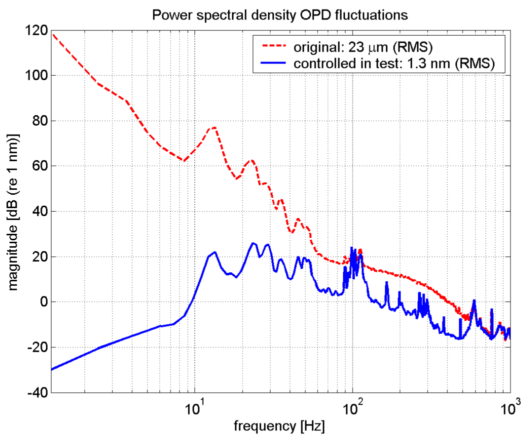

Figure 4. OPD stability without (red) and with (blue) OPD control.

5. Acknowledgements

TNO would like to thank Josep Maria Perdigues Armengol (ESA-ESTEC) and Joost Carpay (NIVR) for supporting the development of the delay line.

6. References

[1] Statement of Work, Optical Delay Lines, Programme Reference: TRP, ID-OP-12 TOS-MMO/2002/276, issue 2.0, 6 March 2003. Plus clarifications 1, 2 and 3.

[2] The design of a breadboard Cryogenic Optical Delay Line for DARWIN, SPIE 5528A-36, Glasgow 2004.