DESIGN AND QUALIFICATION OF THE MECHANISMS FOR THE ALADIN INSTRUMENT

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ABSTRACT

The ALADIN Instrument is the only instrument on the ADM-AEOLUS Satellite, which is the second Earth Explorer Mission within the European Space Agency's Living Planet Programme. This instrument is based on the Direct Detection Doppler Wind Lidar concept, operating in the near UV band (355 nm). It uses the same telescope for both emission and reception. The instrument fires laser pulses towards the atmosphere and measures the Doppler shift of the returning signal, which is back-reflected at different levels of the atmosphere.

Two mechanisms are present within the ALADIN Instrument, the *Laser Chopper Assembly* and the *Flip-Flop Mechanism*. This paper presents the design and qualification of these two mechanisms, which are currently being assembled and tested at Contraves Space AG. It also presents the major challenges during their development.

1 INTRODUCTION

The two mechanisms present on the ALADIN instrument are the *Laser Chopper Assembly* (LCA) and the *Flip-Flop Mechanism* (FFM). Their function can be summarised as follows:

- The FFM enables the mechanical switching between the primary and redundant laser source.
- The LCA, consisting of the *Laser Chopper Mechanism* (LCM) and the *Laser Chopper Drive Electronics* (LCDE), assures mechanically that during the pulses of the transmitting laser the receiver optics is not being blinded. The chopping is performed at a focal point of the optics by moving a shutter 0.3mm with ~100Hz between the two diaphragms.

Both mechanisms follow a Proto-Flight Model (PFM) development approach, in order to minimise schedule and costs.

The following sections give an overview on their design concepts, the challenges during their development and tests performed so far.

2 FFM

2.1 Requirements and Design

The FFM enables two stable configurations (see Fig. 1) when unpowered. They are reached by translating an Optical Invariant Component (OIC).

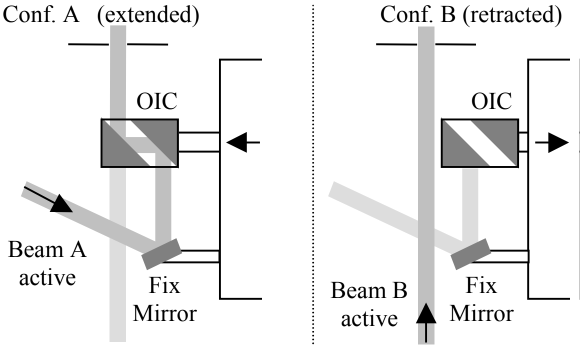

Fig. 1: FFM Configurations

By the formulation of the requirements, the design has was to make of use the PP5501 Binary Latched Paraffin Actuator from Starsys Inc. This actuator provides the required stroke, the two stable positions and has already been qualified on an ESA programme.

In order to save mass, the OIC is directly mounted to the PP5501 actuator shaft using a special bracket. This bracket also includes cam surfaces to actuate a number of micro-switches for the actuator telemetry.

The FFM is mounted on quasi-isostatic mounts and has features to aid alignment at ALADIN assembly level.

The FFM is shown in the following figures.

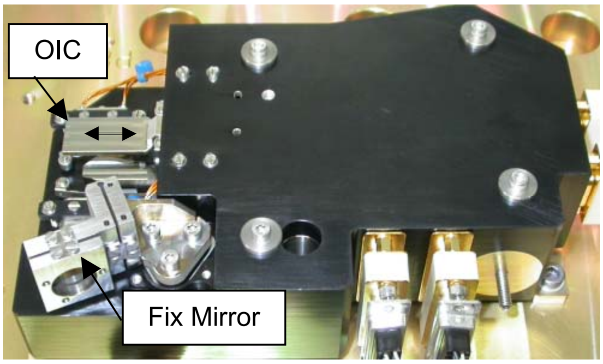

Fig. 2: FFM Hardware (Top View)

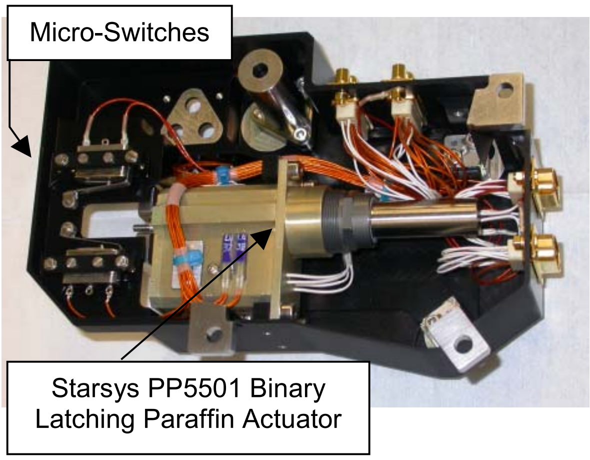

Fig. 3: FFM Hardware (Bottom View)

2.2 Challenges

The major challenge during building of this pretty simple mechanism was the use and adjustment of the micro-switches: It was required to add micro-switches to the mechanism for position monitoring and safety operation (as the ALADIN electronics reaction time is with ~10sec very slow. The following functions were required:

1. a switch that positively indicates the retracted position,
2. a switch that positively indicates the extended position and
3. (in addition to the switch internal to the PP5501 actuator which gives the signal to switch off the heater power) a switch at max. stroke of the mechanism for safety.

Especially the latter proved to be crucial during integration, as micro switches are not really precision devices.

2.3 Testing Status

At the time of writing, the FFM is under environmental testing.

3 LCM

3.1 Requirements and Design

The ALADIN instrument is based on one single large telescope for both, the emitting and receiving path for the measurements. Due to the high intensity of the emitted laser pulses, internal reflections at unavoidable mechanical parts such as support struts etc. are of a relatively high intensity and can blind the receiver instruments such that the back reflections from the earth atmosphere cannot be measured precisely. As there is a time lag between the internal (undesired) reflections and the (desired) reflections from the atmosphere, a mechanical shutter is used to block the receive path when the laser pulses and open it for the measurements.

This shutter is called the laser chopper and is the core of the LCM. It is placed at a focal point of the receive beam, as shown in Fig. 4. The shutter moves between two diaphragms, the smallest of them (Ø 0.1mm) being exactly at the focal point. The shutter has an active range of 0.3mm from the fully open to the fully closed position. The closing is in the order of 2ms. The closing/opening frequency is 100Hz, i.e. the shutter is closed/opened 100 times a second. A major requirement is that the shutter remains open when not powered, and shall have almost zero start-up time. The mechanism also has to operate almost permanently for several years, which amounts to some ~$6x10^9$ closures.

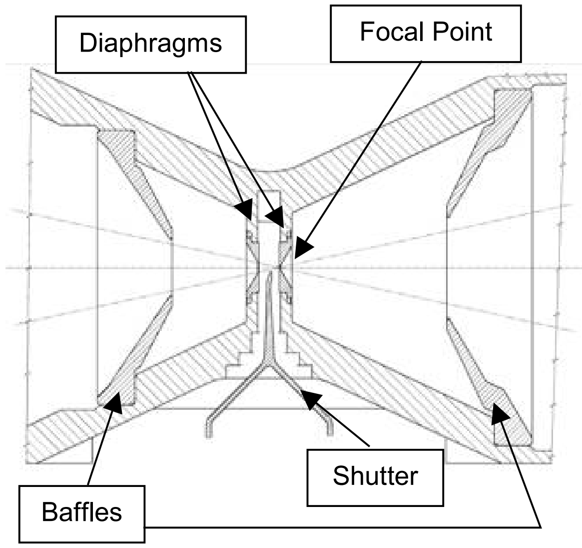

Fig. 4: LCM optical path cross-section

After trading off various concepts, one of them being the conventional Chopper Wheel concepts, it was decided to use technology available at Contraves Space from the Fine Pointing Assembly [1](FPA) development.

A voice coil actuator is used to move the shutter. In order to minimise the moving mass (and thus the required force and power consumption), a moving coil concept was chosen. The coils have redundant windings and are supplied with current by a pair of flex prints. Snubber features are incorporated at both ends of the travel in order to minimise movement during launch and to avoid the need for a launch lock. The total moving mass is ~2.4 grams, incl. the shutter.

The shutter and the coil are placed on a leaf spring. The natural position of the assembly is open, and it is only when voice coil is activated that the shutter is closed.

With this design, tribological features (contacts, friction ...) are avoided and the spring dimensioned for a theoretically infinite lifetime – i.e. stresses are below the fatigue strength.

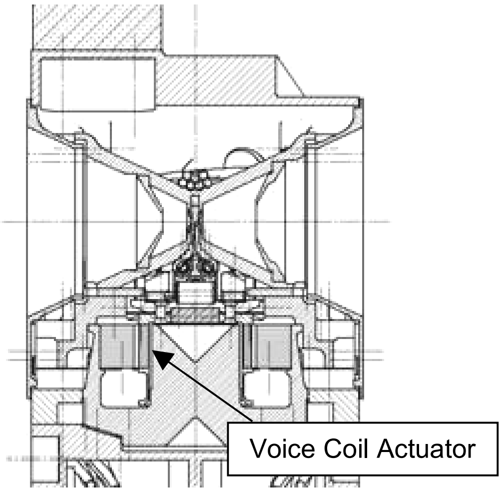

Fig. 5: LCM cross-section A

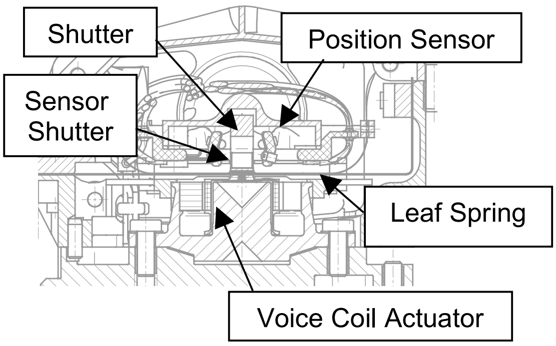

Fig. 6: LCM cross-section B

In order to minimise straylight effects, the system is surrounded by cones and special straylight baffles. A custom made position sensor was required as the available and qualified sensors (non-contacting) are too big for this application. (An impression on the sizes of this mechanism and especially the core with the shutter and the voice coil is obtained by the following figures).

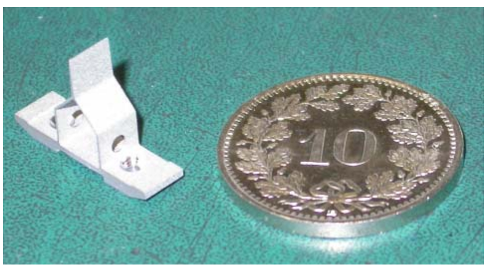

Fig. 7: LCM Shutter (Breadboard w/o coating)

Fig. 8: LCM large straylight baffle

In order to simplify the electrical design, an open-loop system has been implemented. When the LCDE receives the signal to switch on the LCM, it simply generates a sequence of current levels which flows through the voice coil. Using the MATLAB Simulink toolbox, optimal current waveforms (see Fig. 9) have been derived.

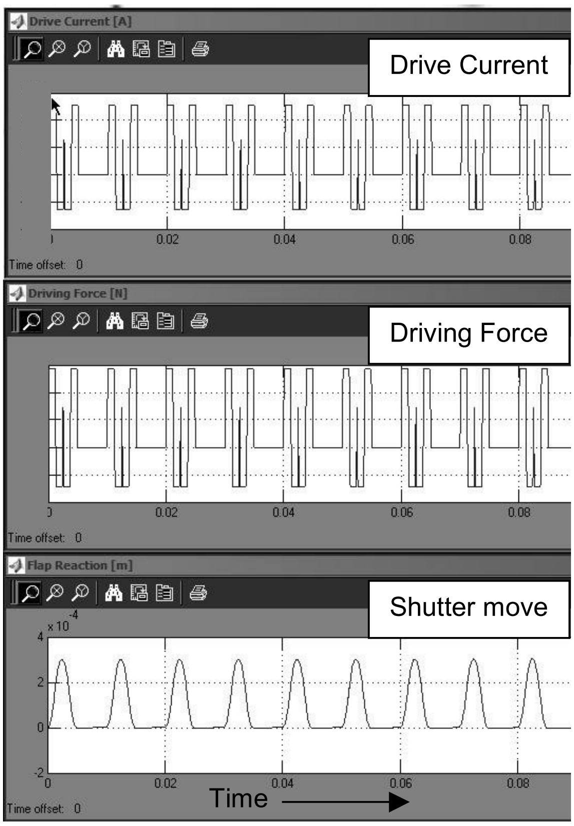

Fig. 9: Current Waveform and Shutter Movement

The LCDE includes an FPGA based control-electronics which drives the LCM shutter in open-loop.

3.2 Challenges & Pre-Tests

3.2.1 Custom made voice coil actuator

The actuator is based on the one used for the FPA [1]. However, a number of changes were necessary :

- Due to redundancy requirements, double windings on the coil were necessary (which was not needed in the case for the FPA)
- The FPA actuator has a moving magnet. This was to heavy for the LCM, where a movement of 0.3m within 2ms had to be reached. Thus, a moving coil concept has been implemented, where the coil is supplied with current by a pair of flex prints.
- The magnetic intensity of the FPA was too weak, which is why it was necessary to provide a better layout.
- The coil body (or former) has been designed such to incorporate a snubber feature to avoid over-travel of the coil during launch. Using this concept, no launch lock is necessary.
- Last but not least the PA requirements made it necessary to procure the coils according to MIL-STD-981 Class S with Group A and B inspection as well as DPA (Destructive Physical Analysis) on three of them.

The final design of the voice coil actuator is shown in Fig. 10a and b (Bread-Board).

In this context a voice coil actuator with the following characteristic has been built:

Description	**Value**
Max. Output force	1.177 N
Max. current at max. force	110 mA
Resistance per winding	120 Ω
Max. Power dissipation	1.5 W
Windings	2, bifilar
External diameter (exclusive attachment holes)	26 mm
Height	14 mm

Tab. 1: LCM voice coil actuator

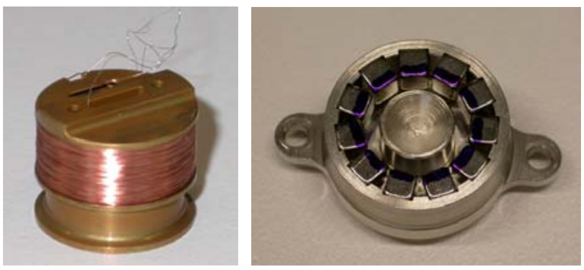

Fig. 10a: Parts of the custom made LCM voice coil actuator (Breadboard version)

Fig. 10b: Parts of the custom made LCM voice coil actuator (Breadboard version)

3.2.2 Proof of Open-Loop Controller

In order to prove the open-loop working principle, a bread board model (BBM) was necessary. However, it became clear, that this BBM only made sense if it was fully representative wrt. mass, damping and stiffness of the final design. Moreover, it was required to provide the data before PDR, which was ~6 months after beginning of the project.

All this basically meant, that within this period, the core of the LCM had to be defined to the need of the flight model, manufacturing drawings to be produced, the items to be manufactured and mounted and a representative control electronics to be built. Although the parts do not have to be flight standard, they are tiny (as seen in the figures before), and manufacturers had to be found who could prepare these parts (wall thickness down to 0.1 mm in Aluminium, size max. 10mm per item).

A problem turned out to be the measurement of the movement: The accessible surface is very small and additional mass on the moving part influencea the driving current profile. Hence, non-contacting solutions were needed with a high frequency and resolution output. The best way to solve this, was the use of an inductive sensor. The test setup is shown in the Fig. 11.

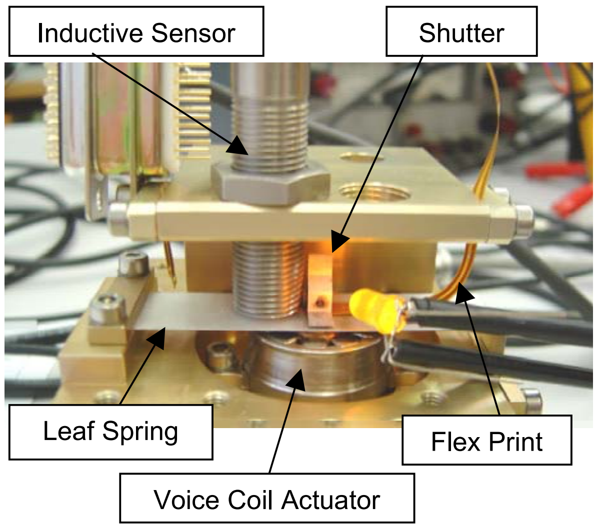

Fig. 11: Breadboard Test Setup

While preparing this setup, mass, damping and stiffness were measured and the Matlab model adapted. An updated current waveform was defined based on the new parameters and tested. Good correlation has been achieved, as can be seen in Fig. 12 and 13.

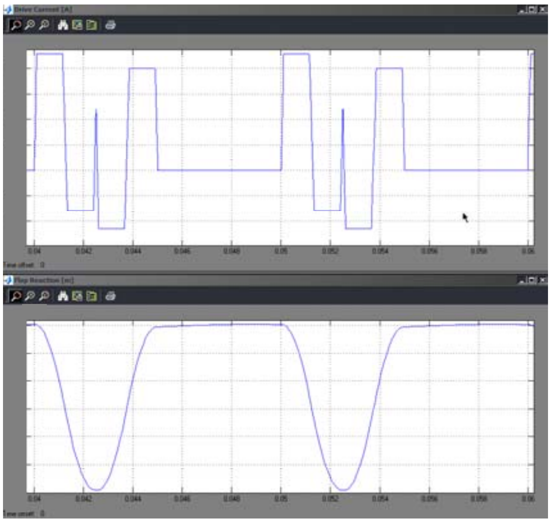

Fig. 12: LCM updated Matlab prediction

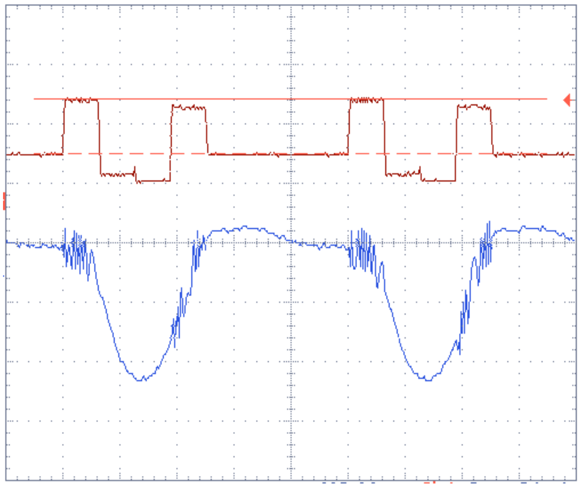

Fig. 13: LCM breadboard measurement

Thus it could be shown that the open loop drive is possible.

3.2.3 Position Sensor

As for the breadboard, an off-the-shelf, ESA space qualified position sensor for the flight item could not be found, especially for the size that is required for this application. Therefore, a miniaturised optical sensor has been developed, consisting of an LED and a photo diode, as shown in Fig. 14. In order to qualify these components LAT tests and radiation tests were necessary and have been performed.

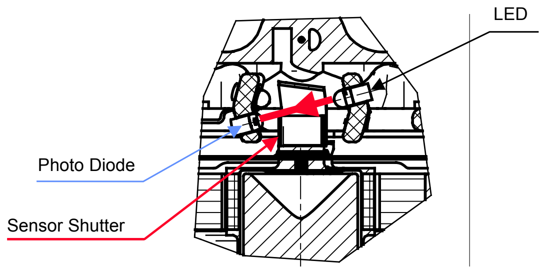

Fig. 14: LCM position sensor

Within the shutter, an additional shutter is implemented, perpendicular to the main shutter. This shutter moves in front of the photo diode. When the main shutter is open, the photo diode is illuminated fully by the LED. The illumination is reduced by the movement of the Sensor Shutter.

In order to meet the radiation and reliability requirement, two LEDs are implemented. The LCDE switches to the second LED, when no signal is received at the photo diode.

Miniature LEDs and photo diodes are used, with an outer diameter of 1mm. They are integrated to a sensor board, which at the same time guides and secures the connecting wires. The max. length of the board is ~40mm. The following fig. shows the sensor board during integration.

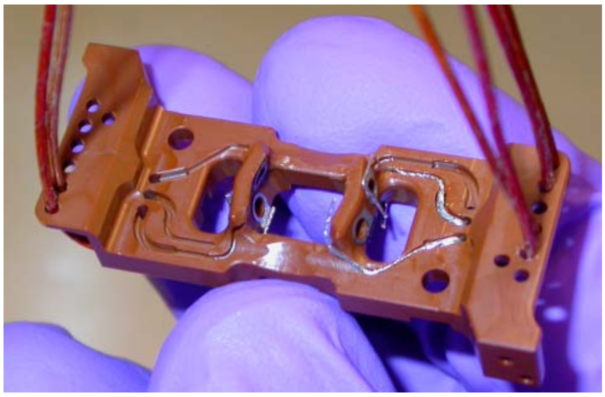

Fig. 15: LCM sensor board

3.2.4 Miniaturised items

One of the biggest challenges concerned the miniaturised parts and the level of detail with them, that evolved during the project.

1. The initial idea of the shutter had to be revised in order to implement a pair of additional Sensor Shutters for the position sensor. These are perpendicular to the main shutter.
2. Originally, a pair of diaphragms with equal diameter were foreseen. In the due course of the project this had to be replaced by the design shown

in Fig. 4, including the straylight baffles. The items need to be black anodised for straylight reasons, which makes their manufacturing very complex and time consuming.

3. The sensor board manufacturing was very complex. Moreover, the guiding of the wires to the LEDs and photo diodes is very complex due to the three-dimensional miniature routing. A larger problem was the assembly of the sensors with the miniature solder pads, wires and electro-optical items.

All this provided the opportunity to learn and prepare for future miniaturised mechanisms, wrt. to selection of suppliers and internal processes.

3.3 Testing Status

As the LCM is currently being assembled, no tests have been performed so far on the complete mechanism.

However, some tests have been successfully performed:

1. the already mentioned breadboard test in order to prove the open-loop control and
2. a life test on the concerned items.

The latter is discussed here. The life-test has been performed for the life critical items only, i.e. for the leaf springs an the flex prints. Fig. 14 gives and overview on the setup.

Three leaf springs and flex prints are excited by a voice coil actuator simultaneously. All items are mounted in a representative manner to the flight item. The cycling frequency was 275Hz, which resulted in a 9 month life-test for ~6E+9 cycles. The flex prints have been periodically controlled for continuity with an HBM measurement system at a 2.5kHz sampling rate.

The final findings of the test are:

- No damage on the leaf springs is detected, verified by dye penetrant technique
- No discontinuities on the flex prints.

Thus the life the was successfully finished.

4 Summary and Conclusions

The two mechanisms FFM & LCM for the ALADIN instrument are being built and qualified at Contraves Space AG.

The FFM is currently being environmental tested and expected to be qualified by beginning of August.

The LCM is currently being assembled and expected to be qualified by mid October. A miniature custom made voice coil actuator and an optical position sensor have been developed. Miniaturised items were needed to be used.

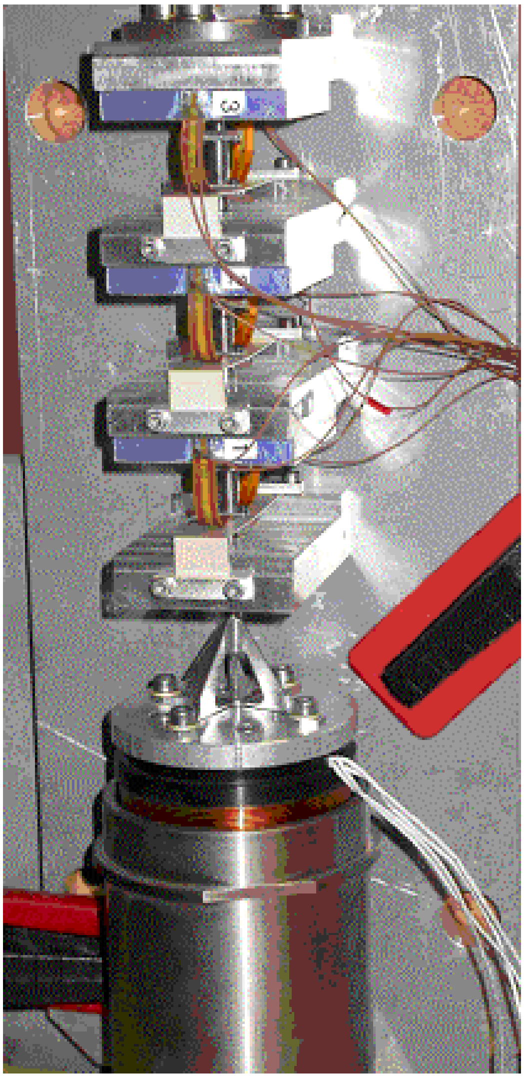

Fig. 14: LCM position sensor

For the LCM a successful life test on component level is available as well as a breadboard test showing that an open loop driving concept is feasible.

The most important lesson learned in the course of this program is:

"The devil lies in the detail"

References

1. Coppoolse W., et al., *Dual-Axis Single-Mirror Mechanism for Beam Steering and Stabilisation in Optical Inter Satellite Links,* Proceedings of the 10th ESMATS Symposium, San Sebastian, 2003