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An Improved Accurate Beam Steering Piezoelectric Mechanism for ATLID Instrument

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Abstract:
A new tip tilt mechanism based on low voltage piezoelectric actuators has been designed by Cedrat Technologies to answer the high level of stability required for the Earthcare satellite. The Beam Steering Assembly aims ~~to~~ deviate a pulsed high energy UV laser beam to compensate for misalignment between the emission and reception paths of ATLID [1] with a very high stability and resolution.
In this paper, the authors points out the BSM development with the main mechanism design issues including performances, mechanical and thermal stability; low power consumption; high integration level; high reliability and safety; cleanliness requirements and give the results of the qualification campaign done at Cedrat Technologies' to establish the final functional performances in preparation of the Flight Models deliveries for the BSM.

Keywords: Piezo, Tip-tilt, Stability, Strain gages

Introduction

Context

ATLID (ATmospheric LIDar) (Fig.1) is one of the four instruments of EarthCARE, it shall determine the vertical profiles of cloud and aerosol physical parameters such as altitude, optical depth, backscatter ratio and depolarisation ratio.
The Beam Steering Assembly (BSA) function is to compensate for the misalignment between the emission and reception paths of ATLID with a very high stability, and resolution.

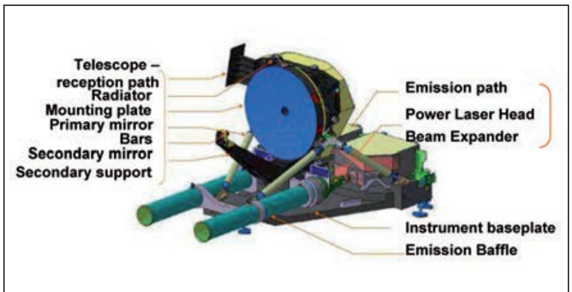


Fig. 1: *ATLID Instrument overview [1]*

The BSA is implemented is composed of :

- A unit including optics, mechanics and electronics (BSMFE) made tip-tilt mirror (BSM) and Front End Electronics (BSFE)
- An Electronics Unit (BSME)
- A Harness (BSH) composed of two cables

Cedrat Technologies was sub-contracted by Sodern to design, manufacture and test the performances of the BSM - See Fig. 2 for the exact definition of BSM perimeter.

Mechanism description

The Beam Steering Mechanism (BSM) consists of a 2-axis ("Tip Tilt"), small range and pointing mechanism, mounted on a bracket including front end conditioning for position sensors (see Fig.2).

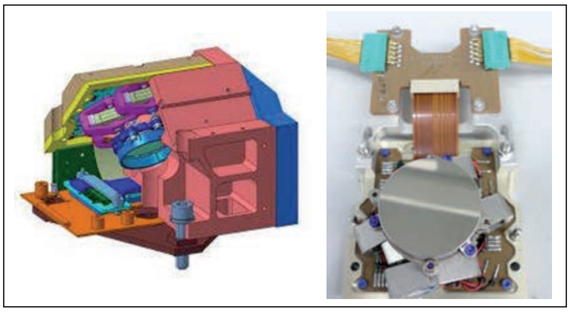


Fig. 2: *EQM of the BSM: a- CAD view of BSM b-TTM stand alone*

Technical challenges

The direction of the laser beam needs to be co-aligned with the reception path of the instrument to maximize the detection of the LIDAR echo signal. The BSM should compensate for the pointing misalignment between the emission and reception paths of ATLID with a high resolution and a very high stability.
The BSM is required to steer the incoming laser beam through a range of ± 3 mrad. The critical requirements are the accuracy of the movement, the stability (short term, mid term and long term) and the repeatability. All performance requirements shall be fulfilled for any contributors and for any optical angles [6].
Several additional requirements make the design and the validation of the BSA challenging, such as

temperature stability, launch conditions survival, micro-vib susceptibility…
These challenging requirements necessitated to improve the mechanism design.

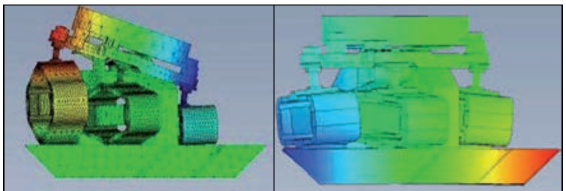
BSM descriptions

The BSM design tasks were performed to develop the different parts: BSM, BSMFE and BSME.
The design optimizes the dimensions of the BSMFE in order to facilitate its implantation in PLH. Proximity electronics need to be near the actuators and sensors in order to have the same regulated temperature. (Fig. 3)

Beam Steering Mechanism mechanical design

The BSM is a 2-axis Tip-Tilt mechanism (TTM), mounted on a bracket. It supports the BSFE.
The BSM is based on two stiff push pull pairs of APA60SM® actuators [3] equipped with Strain Gages (SG). This design allows a mechanical resonant frequency above 2kHz thus avoiding the use of a launch locking mechanism and limiting the micro-vibration susceptibility. Detailed design is described in [6].

The position of the piezo actuators was selected to allow a different stroke between the two rotation axes. This choice enables maximisation of the applied voltages on the piezo ceramics and hence improving the overall sensitivity of the mechanism.
Once the piezoactuators were sized, several simulations were performed to validate simultaneously angular range, stress resulting from integration, thermal environment, vibration/shocks environments and micro sliding at screwed links in regards of the thermal and vibration/shocks environments (Fig. 5). All the stress contributions were summed and complied with the ECSS safety margins for both non-operational and operational modes.



a- Calculated maximum displacements during YUmm axis actuation	*b- Thermal deformation of the TTM under 10°C variation*

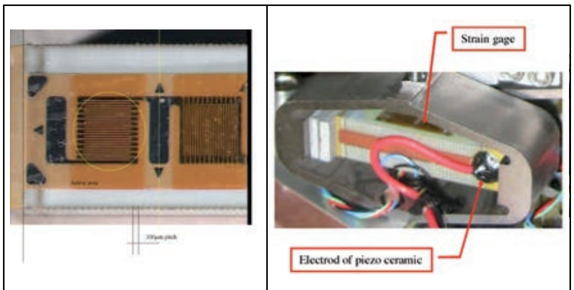
Fig. 5: *Some results of FEM simulations*

Concerning the cleanliness, several design rules have been applied on each BSM parts, such as surface accessibility, no blind holes, surface roughness…

Position transducers on the BSM

The high level of accuracy and stability required for the BSA necessitated including high reliability position sensors for each axis.
Because of the small allocated volume for the BSM and small deflection movement, this prohibited the use of contactless sensors like capacitive sensors. So, Cedrat Technologies has proposed a contact sensing transducer using improved strain gage elements mounted in the Wheatstone Bridge configuration and glued directly on the piezoelectric ceramics (Fig. 6).

To improve the accuracy and the stability of the strain gage measurements, several precautions were taken. A full bridge configuration was selected to improve the sensitivity while limiting the thermal impact and non linearity errors on its performance. The initial sensitivity is given in [4,5]. Full description is given in [6].



a- Strain gage glued on the piezo ceramic	*b- Implementation of the SG in the APA® shell*

Fig. 6: *Integration of the strain gage onto the APA®*

Qualification campaign

To mitigate the technical risks of this challenging development, two evaluation campaigns were performed first on strain gages mounted on an APA60SM® then on a BreadBoard Model. An electronic allocation (allocation is not the correct word?) was established [6].
At the same time , a qualification campaign was performed to valid the final performances of the mechanism using dedicated Electrical Ground Support Equipment to power the mechanism and a specific Optical Ground Support Equipment to measure the main performances (Fig. 7).

EQM description and associated test benches

An EQM has been manufactured. This qualification model is fully representative of the Flight Models and includes the entire mechanism. (Fig. 2).
A specific Ground Support Equipment (GSE), based on standard products from Cedrat Technologies, is used for, Piezo driving, Strain gages signals conditioning, and Closed loop control (digital controller).

Additionally, an Optical Ground Support Equipment able to valid partially the mechanical performances in thermal environment was initiated including (Fig. 7) Peltier cooler and autocollimator.
The autocollimator is configured in differential mode. It means that the results of the measurement are the difference between the reference mirror angle and the TTM mirror angle. This method minimises the error from the parasite angle from the reference plate and thermo-mechanical influence of the test bench.

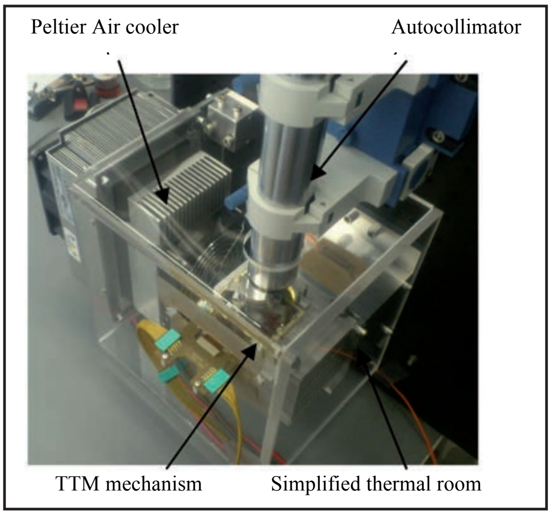


Fig. 7: *OGSE supporting the BSM for the qualification campaign*

Tests sequences

The campaign followed the next steps (Fig.8). A few results are detailed further.

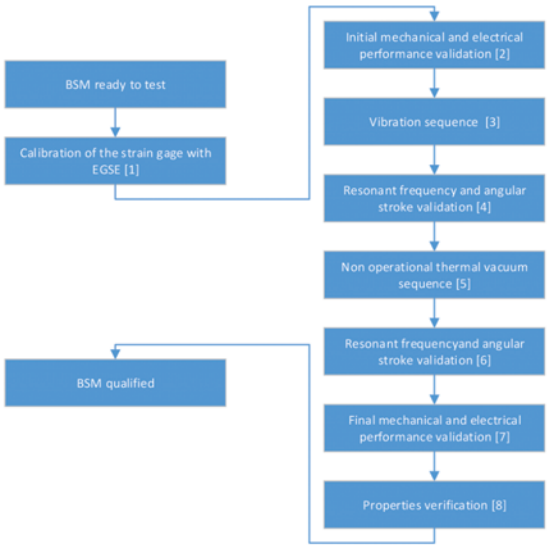


Fig. 8: *Summarise of performed tests on the EQM*

Resonant frequency:
Results on resonant frequency are obtained using a impedance analyser HP4194A. Each rotation axis is analysed separately. At the end of the EQM campaign, a re-tightening process was applied to block the different screws links. This operation and the other ones (vibrations…) don't show any large modification of the mechanical behaviour of the TTM mechanical resonant frequency.

Table 2: *Summarise of measured mechanical resonant frequency on EQM TTM (Hz*

Phase	[2] Initial (reference)	[3] Vibration environment	[5] Non op thermal	Re Tight-ening
Rx	2451.25	2476	2451.25	2500.75
Ry	2822.5	2674	2748.25	2748.25
ΔRx		24.75	0	49.5
ΔRy		148.5	74.25	74.25

Angular stroke:
Full stroke measurements are made after every environment and tightening operation. Open and Closed loop results are given over the entire qualification temperature range [+14°C; +50°C]. There is no major impact of temperature on max stroke on both rotation axes. Minimal stroke on Rx is 2.52µrad and Ry is 1.93µrad, both in closed loop (Fig. 9)

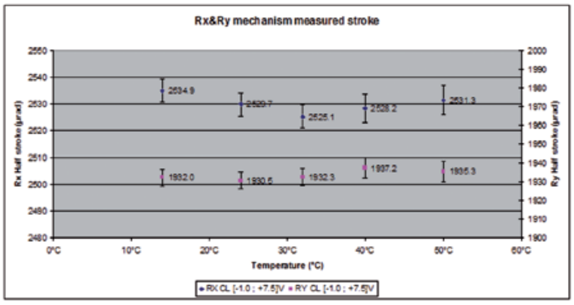


Fig. 9: *Angular range versus temperature Rx &Ry*

Closed-loop displacement:
Very small measurements are something difficult to measure using conventional apparatus. The autocollimator reaches its resolution limitation when sub-mrad motions are required. Full stroke displacement shows linearity below 1.4% for Rx and 1.2% for Ry (Fig. 10).

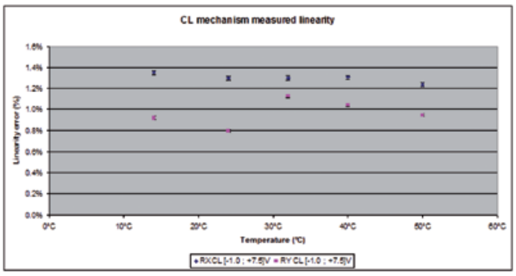
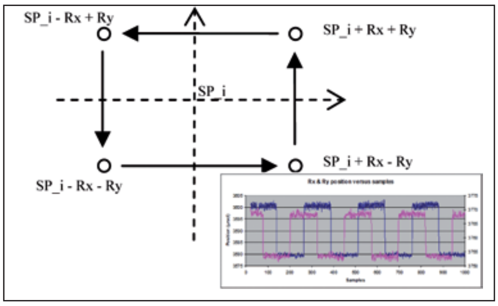


Fig. 10: *Closed-loop linearity of full stroke displacement on Qualification temperature range*

For small displacements, the test consists of a square command around a SetPoint (SP). This square is obtained using two 90°-phased square commands, as presented in Fig. 11. The reached position is then compared with order to compute the Relative Accuracy (Ra). The observed Ra, measured with the Autocollimator, reaches 1.1µrad on Rx and

0.7µrad on Ry.



.Fig. 11: Relative accuracy test philosophy

Repeatability:

Mechanism interest performance is also conditioned by good repeatability. The reached positions after several On-Off sequences are compared and the worst difference is considered on five On-Off cycles.

Results are showing repeatability better than 10µrad on both axes between the qualification temperature range. Repeatability of 0° Mechanical position is always better than 2µrad for temperatures lower than 40°C. These results are presented in Fig. 13.

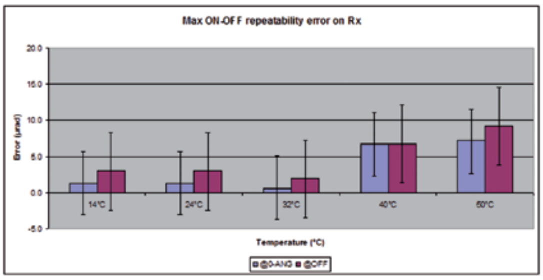


***Fig. 13:** Repeatability results on Rx axes on Qualification temperature range*

Thermal sensitivity:

Position 0° mechanical angle is followed throughout the temperature range. This gives thermal sensitivity of the mechanism around both axes. It is seen that in Closed-loop, thermal sensitivity is below 3.2µrad/K for Rx and 0.8µrad/K for Ry. Results are visible in Fig. 14.

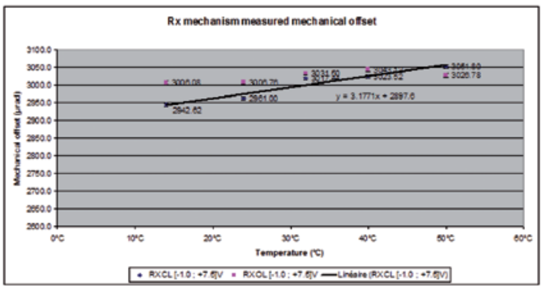


***Fig. 14:** 0°Mechanical angle along temperature range for Rx*

Closed-loop response time

Response time is measured using Strain gages output because the Autocollimator bandwidth is not large enough. Both directions are very similar, showing approximately 20ms response time for full stroke. Bandwidth is shown at 30Hz (Fig. 15).

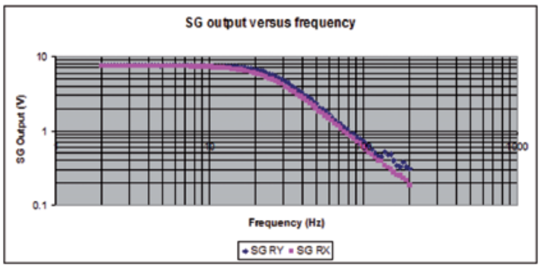


***Fig. 15:** Bandwidth of TTM for Rx&Ry*

Further development and conclusion

The BSM detailed design and associated justification is now over. The theoretical performances are consistent with the requirements. Functional and environmental performances validations were conducted on the EQ Model. The results obtained so far are in line with the expected performances and validated the technical choices and manufacturing processes for the BSM.

The next phases are the coupling with the BSM-FE and the BSME to perform the full qualification of the BSA under Sodern responsibility.

BSM FMs manufacturing and their complete acceptances are launched to be delivered for ATLID instruments.

This new mechanism shows the pertinence of the use of APA® with Strain Gage technology for demanding space applications. The concurrent development between Cedrat Technologies and Sodern allowed the design of a challenging multidisciplinary system.

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