CALIBRATION MECHANISM FOR INFRARED SPACE TELESCOPE

Patrice Kerhousse

Alcatel space industries

100 Boulevard du Midi, BP 99 - 06156 Cannes la Bocca Cedex

Telephone : 33-(0)4-92-92-72-38 / Fax : 33-(0)4-92-92-60-20

E-mail : Patrice.Kerhousse@space.alcatel.fr

ABSTRACT

In order to achieve high infrared optical performances of the HELIOS2 telescope, a Calibration Mechanism, called MECALIB, is developed by ALCATEL.

The specific kinematic architecture of MECALIB is based on an eccentric shaft, driven by a stepper motor, linked to a push rod that drives the rotative mirror mounting. This architecture presents the following main advantages:

- as the two pointing positions are close to the upper dead point of the mechanism, the reduction ratio is high enough to achieve the positioning accuracy during on ground tests (no need of zero G tools).
- the reduction ratio is highly non-linear so, even if the stepper motor is driven with full steps, the specified angle between the two pointing positions can be accurately adjusted by rotation of the motor housing.
- only preloaded ball bearings are used in the mechanism to achieve the function without any backlash.

The development tests demonstrated that the MECALIB design meets all the requirements but a failure occurred during lifetime tests : the resistive torque increased drastically at the third of the specified lifetime.

It has been investigated that the failure was due to the ball bearings MoS2 degradation. The design was modified to use fluid lubricated ball bearings.

The qualification tests are in progress.

1. INTRODUCTION

Because of unstability of usual space infrared detectors used in infrared telescopes, a periodic calibration of them is necessary to achieve high optical performances. ALCATEL is in charge of the development, qualification and delivery of two flight models of a Calibration Mechanism (MECALIB). The main function of the MECALIB is to allow the in-orbit calibration of the detectors by pointing a mirror at 2 black bodies. This mechanism is to be used on the HELIOS2 telescope.

The paper will present the design of the MECALIB, its development test results, and its performances and will point out the ball bearings failure that occurred during development life test. The novelty feature of the mechanism will be highlighted : the kinematic architecture that allows high positioning accuracy on the two pointing positions, with very simple mechanism design and drive electronics.

2. MAIN SPECIFICATIONS

The main specifications which were the basis of the MECALIB design are detailed in the following table :

REQUIREMENT	SPECIFICATION
Pointing accuracy :	
Δx, Δy, Δz	< 2 mm
$\Delta\theta x$, $\Delta\theta y$, $\Delta\theta z$	< 5’
Pointing reproducibility :	
Δx, Δy, Δz	< 0,1 mm
$\Delta\theta x$, $\Delta\theta y$, $\Delta\theta z$	< 2,5’
Cycles duration :	
ATT -> CN1	< 5 s
CN1 -> CN2	< 0,7 s
CN2 -> ATT	< 1,3 s
Launch loads :	
quasi-static	150 g
sine vibrations	30 g
random vibrations	200 g (on internal parts)
Stiffness :	
launch	> 300 Hz
in orbit	> 10 Hz
Mass :	< 4 kg

3. MECHANISM DESCRIPTION

MECALIB is mainly composed of:

- a structure made of titanium
- a calibrating mirror
- a mirror mounting with two pairs of ball bearings
- an actuator with a stepper motor
- a speed reduction unit
- a detection system by magneto-resistors
- a hold-down and release device

The drawing thereafter shows the overall architecture of the MECALIB.

Actuator

The actuator is based on a stepper motor (200 steps) whose rotor is directly mounted on the shaft that drives the speed reducer. The shaft is guided by a pair of preloaded ball bearings. The speed reducer is made of an eccentric located on the motor shaft that drives a push rod. The push rod is linked to the mirror mounting.

Detection system

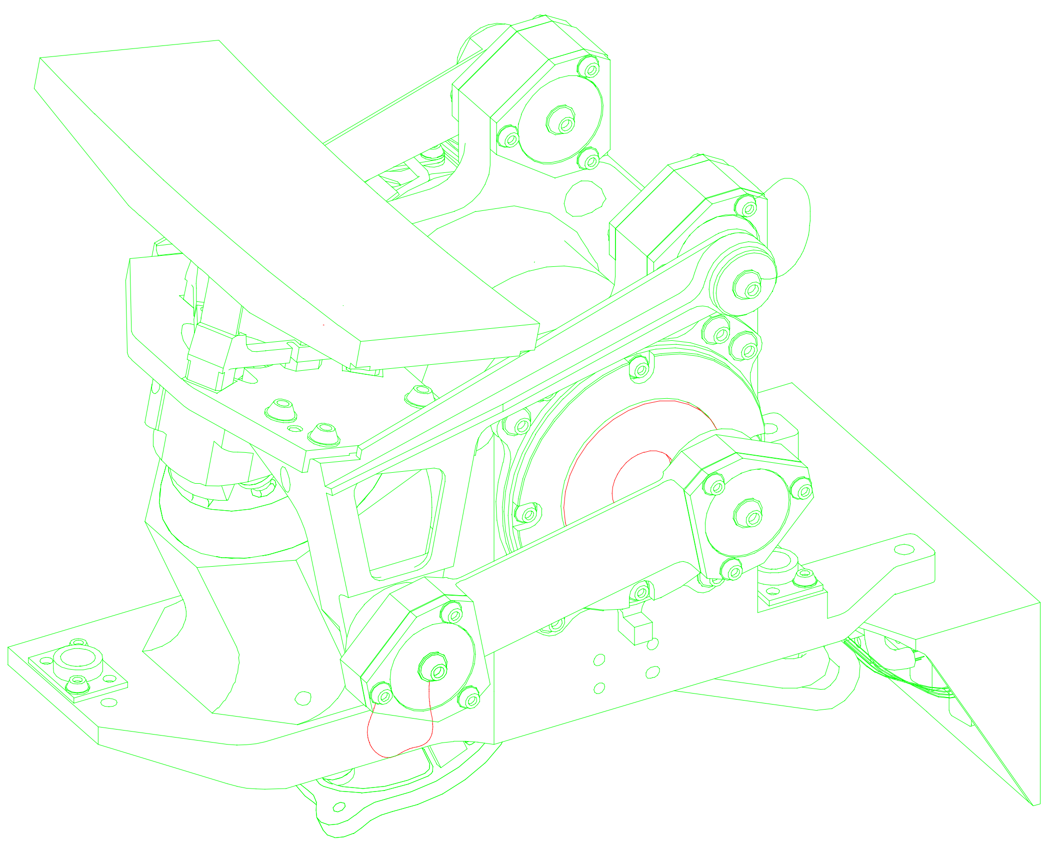
A position status is sent for each in-orbit functional position (ATT, CN1, CN2) in order to validate the good execution of each command . The detection device is based on 6 magneto-resistors (MR), 3 nominal and 3 redundant, which resistance changes when a steel tooth, mounted on the motor shaft approaches the MR.

Hold-on and release device

This device is based on a Shape Memory Alloy (SMA) component that breaks the tightening rod. To minimise the development costs, the SMA component is fully recurrent of the Refocusing Mechanism one, that explains the large size of the component compared to the mechanism. The SMA component has a 90.000 N capability when the rod breaking force is 13.000 N.

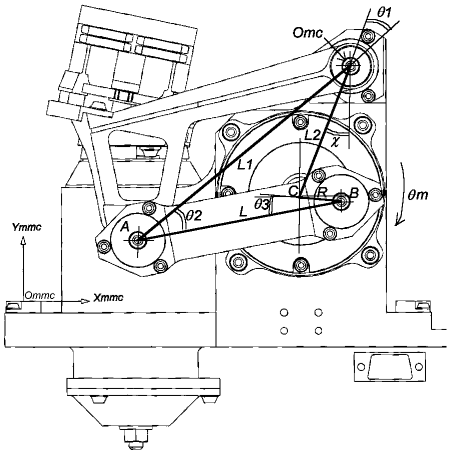
The main advantage of this technology are :

- high reliability due to the use of a physic behaviour
- multi-working possibility.



4. KINEMATIC ARCHITECTURE

The main kinematic parameters are presented in the scheme hereunder :



θm = motor angle
θ1 = mirror mounting angle
θ2 = angle between mirror mounting and push rod
θ3 = angle between shaft axis and push rod

This architecture (location of the different rotation axes, eccentric radius, push rod length) is optimised in order to fulfil the following criteria :

- the angular stroke must be sufficient to hold the mirror out of the field of view during the sleeping mode.
- in the stowed position, the motor shaft must be stiffly held.
- the reduction ratio in the pointing positions must be sufficient to provide the specified pointing accuracy without a zero G device.
- all positions of the MECALIB must coincide with a full step of the motor to simplify the drive electronics.

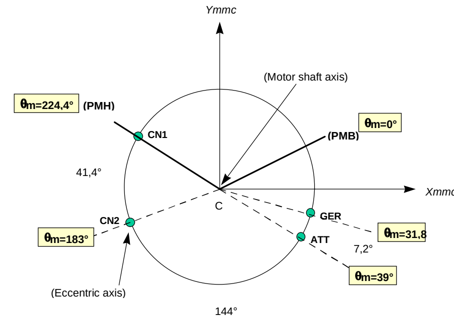
The main positions of the MECALIB are the two pointing positions (CN1) and (CN2), the sleeping position (ATT), the stowing position (GER), the upper dead point (PMH) and the lower dead point (PMB).

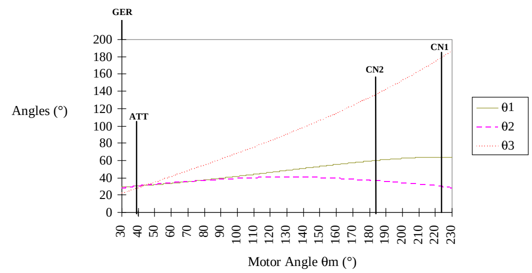
The complete stroke of MECALIB is from (GER) to (CN1) located near (PMH) and needs 107 of the 200 steps of the stepper motor.

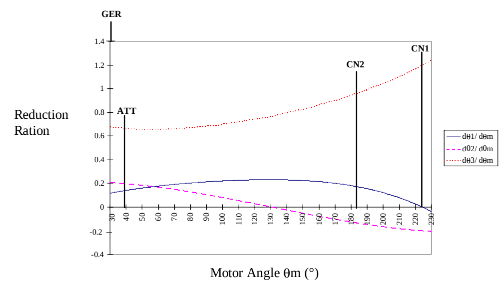
The location of the different MECALIB positions is detailed in the following figure.

The stowing position (GER) was chosen at a motor angle of 31.8° to provide enough stiffness during launch.

Taking into account this geometric architecture, the following graphs show the evolution of the different angles and reduction ratios function of the motor angle.







The MECALIB kinematic architecture presents the following advantages :

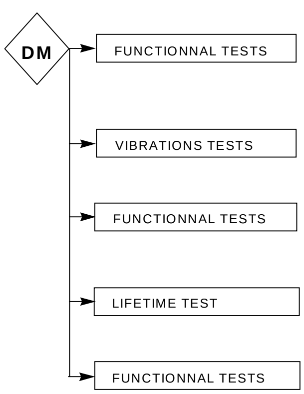
- as the pointing position (CN1) is located at the upper dead point, the angle between the two pointing position (4°10’) can be easily adjusted by rotation of the motor housing. This rotation has a negligible effect on the (CN1) position because of the very high reduction ratio, but it is the opposite for the (CN2) position that has a reduction ratio of 1:6. After this adjustment, the absolute pointing accuracy is achieved by adjustment of the three shims located at MECALIB structure interface plane.
- all positions (GER, ATT, CN1, CN2) are reached with the specified accuracy on full steps of the motor in open loop. With this configuration, the pointing accuracy does not depend on the motor coils voltage and current stability, that allows a very simple drive electronics.
- only preloaded ball bearings are used in the mechanism to achieve the function without any backlash (widely flight proven technology).

5. MECALIB KEY PERFORMANCE DATA

Pointing accuracy : Δx, Δy, Δz Δθx, Δθy, Δθz	 < 0.7 mm < 4,4' (worst case 1 g) <1.5'
Pointing reproducibility : Δx, Δy, Δz Δθx, Δθy, Δθz	 < 0,04 mm < 2,5' (worst case 1 g) < 1'
Cycles duration : ATT -> CN1 CN1 -> CN2 CN2 -> ATT	 < 5 s < 0,7 s < 1,3 s
Stiffness : launch in orbit	 > 291 Hz > 20 Hz
Mass :	= 4.020kg max

6. DEVELOPMENTS TESTS

These tests have been performed on a development model fully representative of a flight model except for the mirror (replaced by a dummy mass) and the cleanliness class (class 100.000 instead of class 100). The test sequence was the following :



Main results

The specifications in terms of accuracy, reproducibility, release of the mirror, duration of the cycle, motorization margin have been verified in the initial functional test. The vibration tests and the functional tests after vibrations have been performed also nominaly.

Nonetheless, a very high degradation of the motorization margin appeared during the lifetime test after 40.000 cycles (112.000 specified). After inspection, it was found that this degradation was caused by the same kind of damages on all the ball bearings. All the ball bearings were of the same TiC/MoS2 technology.

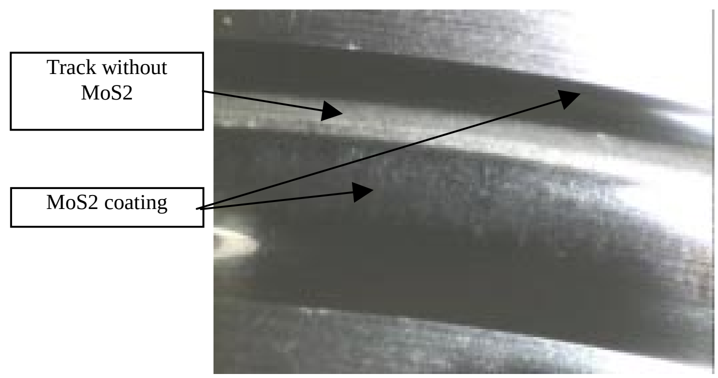
7. BALL BEARINGS FAILURE

After visual inspection in ALCATEL, some ball bearings were sent back to the supplier and to the French National Space Agency (CNES) in order to proceed to fine measurements and Electronic Scanning Microscope analyses.

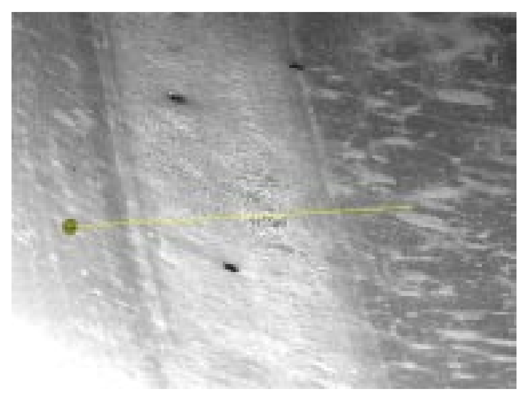
The measurements and analyses showed that all the ball bearings had the same damages :

- the inner and outer rings present a large track without MoS2 in the area of balls contacts.
- a high quantity of titanium particle were found on the tracks

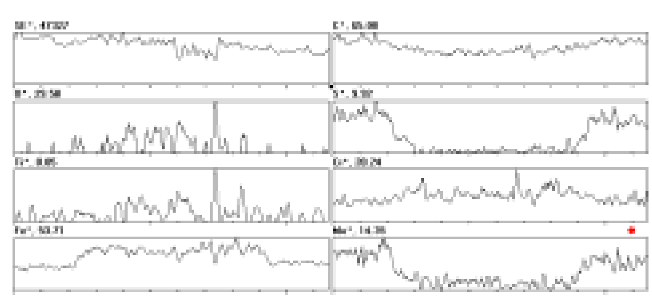
The following figures present the ball bearings tracks observations and their microscope analyses.



Inner ring view (CNES photograph)



Microscope track view(CNES photograph)



Track elements analysis (CNES data)

These measurements demonstrate that the MoS_2 coating had completely disappeared from the area of balls contact.

A series of two lifetime tests were performed on new ball bearings in order to determine if the degradation was initiated by vibrations damages or because of humidity during the DM lifetime tests.

The two additive lifetime tests (one under Nitrogen and the other one under 10^{-8} Torr vacuum) gave nearly the same results : the ball bearings were not able to achieve even the half specified lifetime. But as the vacuum test was stopped when the resistive torque just began to increase, it has been identified that the MoS_2 was responsible for the degradation :

- the same large track without MoS_2 as in the previous ball bearings was found.
- there was no titanium particles (that were coming from the balls TiC coating in the previous ball bearings) on the track.

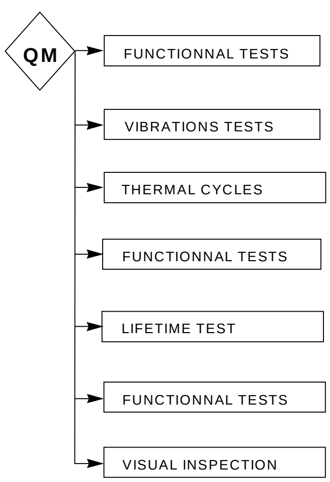
As no anomaly was found in the MoS_2 coating process and on the ball bearings coatings, and because of the MECALIB schedule criticality, it has been decided to replace the TiC/MoS_2 technology by the MAPLUB fluid lubrication developed by CNES for Qualification and Flight models.

In parallel investigations are still in progress to understand the reason why the MoS_2 coating failed so early compared to demonstrated capabilities on previous programmes.

7. QUALIFICATION TESTS

These tests will be performed on a fully representative flight model of the MECALIB.

The test sequence is the following:



The qualification tests will be achieved by October 1999.

8. CONCLUSION

The development tests performed on MECALIB demonstrate that the design meets all the functional requirements and withstands the mechanical loads.

In particular, the novelty of the kinematic architecture and its associated pointing adjustment philosophy was fully validated, with a pointing accuracy less than 1’ in the orbital configuration.

However, the failure that occurred during the MECALIB life test demonstrates that, even if the design is very simple and only uses widely flight proven technologies, it is necessary to verify all the requirements on a Development Model as early as possible during the studies.