GOCI (GEOSTATIONARY OCEAN COLOUR IMAGER) MECHANISMS

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ABSTRACT

The Geostationary Ocean Color Imager (GOCI) instrument was developed by ASTRIUM SAS in the frame a commercial programme. It is the first ocean colour imager operating from geostationary orbit and providing an enhanced regional monitoring due to the high repeatability of the measurements. In the frame of this programme, three different mechanisms have been developed: a Shutter and Calibration Mechanism (SCM), a Filter Wheel Mechanism (FWM), and a two-axis high accuracy POinting Mechanism (POM). Each mechanism supports different payloads (Shutter, Filter Wheel and Mirror) and fulfils different functional and performances requirements. Typical pointing accuracy for SCM and FWM are in the range of 3.4 mrad, while POM is a high accuracy pointing system with accuracy in the range of 1.5 mrad and pointing stability better than 0.030mrd.

In order to cope with the stringent schedule requirements and to minimize the technical and industrial risk, ASTRIUM optimized the development of these 3 mechanisms by implementing a robust industrial approach and a co-engineering scheme with the system team.

Despite the quite different requirements to be fulfilled by each mechanism, they have been designed from a common building block based on mature technologies: the "Common Elements for Actuators" (CEA). This common module is composed of a well known stepper motor, with a large space heritage, duplex preloaded ball bearings for guidance and a mechanical structure. All the CEA mechanical components have been, as far as possible, selected on the basis of existing qualified hardware – "design to parts" approach, taking great care not to modify in any extend such existing and qualified elements. Telemetry devices are specific to the functional requirement and are not part of the CEA. The CEA building block is suitable for POM and SCM, and a little bit over-sized for the FWM. But the associated extra-mass has been largely compensated by the cost savings obtained in developing only one building block.

The SCM and FWM use one CEA while the POM is composed of 2 CEA, with a suitable mechanical arrangement. The performances have been optimized by using the same mini-stepping command format for all mechanisms, reducing also electronics development.

The paper presents the major features of those mechanisms design and development, with focus on the particularities of this project in terms of development, by detailing the advantages of a "system" approach at the beginning of the project, leading to embedded mechanisms design, and common generic mechanism module for the whole functions. Key validation and test aspects will be also presented.

1. CONTEXT

1.1. The COMS mission

The Communication, Ocean, and Meteorological Satellite (COMS) is being developed for the Korea Aerospace Research Institute (KARI) to provide to South-Korea 3 services from geostationary orbit:

- A Meteo Imager
- An ocean color imager mission
- An experimental Ka band telecommunication mission

The ocean color imager mission is relying on the GOCI to provide classical ocean color information: chlorophyll, alga blooming…for monitoring of long-term and short-term change of marine ecosystem.
COMS is a unique experience in Europe to develop 3-axis stabilized Earth Remote Sensing from GEO orbit, thus setting up in Astrium a unique and valuable heritage of such missions.

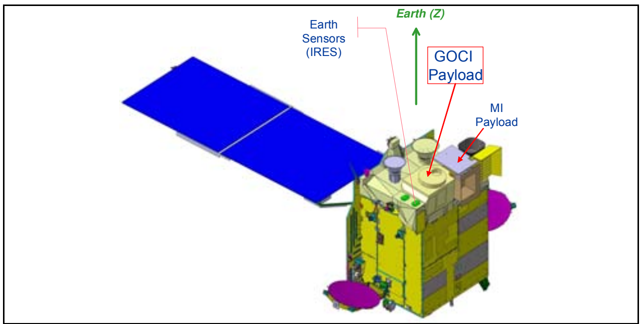

Figure 1 - COMS geostationary satellite with GOCI payload

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1.2. GOCI mission overview

The GOCI is designed to provide multi-spectral data to detect, monitor, quantify, and predict short-term changes of coastal ocean environment for marine science research and application purpose.
Images are provided in 8 spectral bands selected for ocean color monitoring in a 2500*2500 km² area centered on the Korean peninsula.
The GOCI spectral bands have been selected for their adequacy to the ocean color observation.

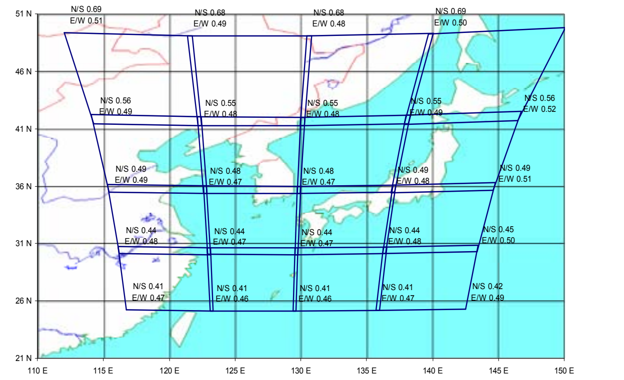


Figure 2 - GOCI target area around Korea

1.3. GOCI design overview

The GOCI instrument is split into a Main "Optical" Unit and an Electronic Unit.
Total GOCI mass is below 78 kg. Power needed is about 40 W for the electronics plus about 60 W for Main Unit thermal control.
A Payload Interface Plate (PIP) is part of the Main Unit. It supports a highly stable full SiC telescope, 3 mechanisms and proximity electronics and it interfaces with the satellite structure. The Main Unit layout overall dimensions are 1.00*0.80*0.80 m^3. The PIP is larger than the instrument to carry the satellite Earth position sensor, providing an accurate Line Of Sight (LoS) restitution. The Electronic Unit is remotely located on a satellite wall about 1.5 m from the instrument.

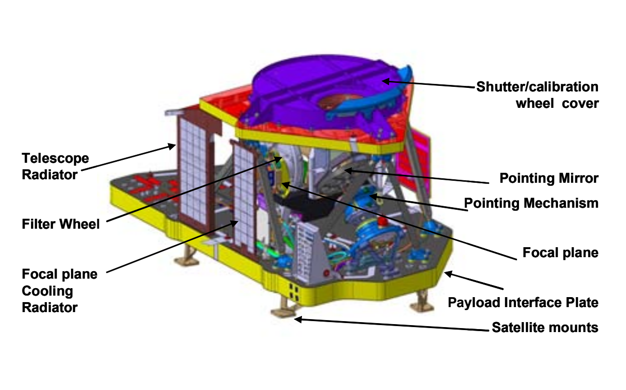


Figure 3 - GOCI Main Unit, without MLI protection

2. THE THREE MECHANISMS

2.1. Main requirements

Three mechanisms are needed to implement the three following functions :
- SCM : Shutter/Calibration Mechanism
- FWM : Filter Wheel Mechanism
- POM : Pointing Mechanism (2 axis with a skew angle)

For each function, the Mechanism shall be able :
- to rotate an inertia with a specified profile (speed),
- to stop the motion when the command is switched off, with the required angular stability and accuracy

Shutter Calibration Mechanism (SCM)	Filter Wheel Mechanism (FWM)	POinting Mechanism (POM)

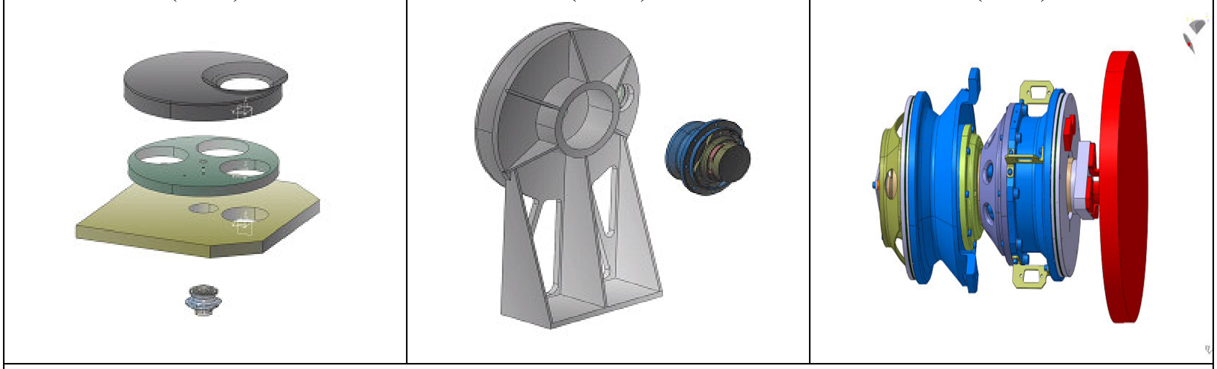


Figure 4 - the 3 required functions

	SCM	FWM	POM
appendage supported	2.5kg, Izz= 0.080m²kg	1.1kg, Izz= 0.015m²kg	1.1kg, Izz= 0.011m²kg
Speed	6.°/s (90.° in 15.s)	20.°/s (40.° in 2.s)	1st stage : 12.°/s 2nd stage : 20.°/s
Stability	<0.2° after 1.s	<0.1° after 1.s	<30.µrad after 8.s
Accuracy	<0.2°	<0.2°	<0.086°
Wobble	<0.1°	<0.1°	<5.µrad (a)
Mass	<3.5kg	<3.5kg	<9.5kg
Stiffness	>150.Hz	>150.Hz	>100.Hz on its support
QS load	35.g	30.g	20.g
Cycles	48,000 rev. 192,000 stops	730,000 rev. 6,570,000 stops	172,000 rev. 688,000 stops for each stage
Motorisation ratio	> 3. (ECSS)		
non-op T°	[-40., +65.°C]		
operational T°	[+5., +62.°C]		

Figure 5 - the main requirements

(a) or < 100.µrad and mapping of the wobble

2.2. Development aspects

The development of the GOCI Mechanism was identified from the beginning as a challenge, both in term of performance, cost and schedule. Therefore, the following guidelines were decided at the early beginning:

- minimization of the technological risks by using recurring building blocks. The design is based on "off the shelf" building blocks without modification. Thus, the building block interfaces are considered as design drivers in order to keep the qualification status of the components (cf §2.3)
- maximisation of the common design for the 3 mechanisms. The key development drivers were to find the adequate balance between the specific needs fulfilment for each function and the maximisation of the commonalities.
- choice of the number of items for each building block in order to maximise the interchangeability and minimize planning risks in case of anomaly
- sorting out the critical components and allocation of the most suitable items with respect to the performance requirements. A specific risk was the ball bearing wobbles because the manufacturing cannot control in a deterministic way the final wobble (the friction torque and the wobble are antagonist criteria). The wobble has been characterised on each ball bearing. The ball bearings with the best lowest wobble have been selected for the POM, because it is the mechanism with most critical pointing performances

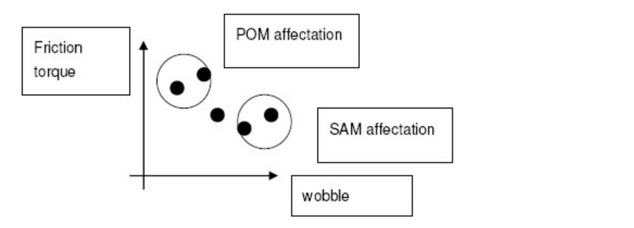


Figure 6 – Sorting out and allocation of the ball bearings

2.3. Heritage

The design is based on well known components.

Item / Supplier	Heritage
Ball Bearing ADR	- custom design - long experience with ADR on other projects (CMG)
Stepper Motor SAGEM	- product from catalogue - fully recurrent design (SEVERI)
Optical Switch CODECHAMP	- adaptation from existing product : . no modification of the principle . mechanical modifications (to adapt to the mechanism I/F) . addition of a radiation shield
Optical Encoder CODECHAMP	- almost fully recurrent product (PLEIADES). The minor modifications are : . redundant channel . radiation shield . electronic optimisation with respect to radiation aspects
Slip Ring MECANEX	- fully recurrent product (PLEIADES)
Mech. parts COMAT	- specific design
EGSE SOTEREM	- specific design

2.4. Design overview

The Common Elements for Actuators (CEA)
The CEA is composed of:

- a pair of angular contact preloaded Ball Bearings
- the Stepper Motor with a step angle of 1°

By design these items are common for the three Mechanisms.

The SAM (Single Axis Mechanism)
The SAM is composed of the following main elements:
- a CEA
- a housing (stator)
- a hollow shaft
- a reference position sensor (Optical Switch)

It is used for two functions : FWM and SCM.

SAM Main features:

Materials	Titanium
Mass	2.5 kg
Size	length ~ 110.mm, diameter ~ 110.mm (without the I/F flange)
Electrical I/F	- Stepper Motor 28.V - Optical Switch 5.V
Power dissipation	Holding mode : 0.48W Moving mode : 4.56W
Frequency	170.Hz (when an appendage of 2.kg is mounted)

Figure 7-1 – The SAM

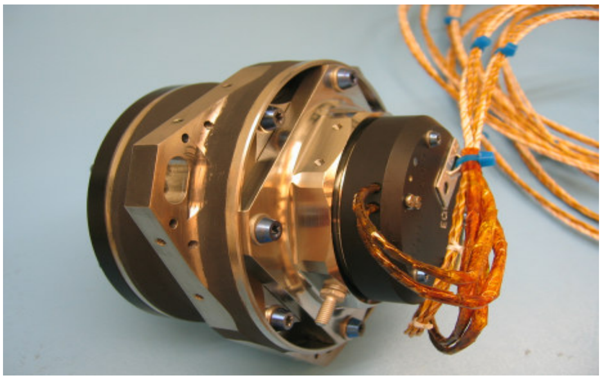


Figure 7-2 – The SAM

The POM
The POM includes 2 stages, assembled in a "stacked" configuration. The first stage interfaces with the GOCI structure, the second stage interfaces with the mirror frame. A coupling flange links mechanically the rotor of the first stage to the stator of the second stage. A slip-ring provides signal and power transmission for the down stream axis

Each Stage is similar to the SAM, and composed of.:
- a CEA
- a housing (stator)
- a hollow shaft
- an accurate position sensor (high accuracy Optical Encoder). This point is different from the SAM

The 2 mechanisms corresponding to the 2 stages are aimed at being as similar as possible and are mounted up-side down.
The combination of the 2 skewed parts provides finally the 2-direction pointing capability.

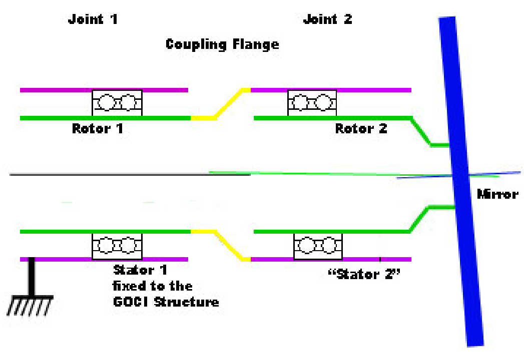


Figure 8 – Principle of the POM

POM Main features :

Materials	Titanium
Mass	8.8 kg (POM alone) 1.3 kg (Support-POM)
Size	length ~ 240.mm, diameter ~ 180.mm (without the I/F flange)
Electrical I/F	- Step Motor 28.V - Optical Switch 5.V
Power dissipation	Holding mode : 2.86W Moving mode : 11.02W
Frequency	100.Hz (when mounted on Support-POM)

Figure 9 – The POM (mounted on its Support)

2.5. Development

Industrial organization

Astrium Mechanism Project team has been working in close co-engineering scheme with Astrium GOCI instrument team, in order to optimize and streamline the development. This allowed increasing project flexibility, to optimize performance allocation, and to optimize the whole GOCI architecture.
Moreover, schedule has been secured via the procurement of additional building blocks (not strictly necessary in terms of industrial development), which allowed early characterization tests on engineering models for risk mitigation.

Developed models

The following models are developed :
- SAM : 1 QM + 2 FM (1 for the SCM function and 1 for FWM function)
- POM : 1 QM + 1 FM (for the Mirror)

Based on the commonalities, a spare policy was elaborated in order to have a maximum flexibility in case of anomaly and to avoid shortage of HW (with respect to NRB for instance). This aspect is of paramount importance with respect to schedule issues.

Development Logic

The development of the 2 mechanisms is linked.
The 2 following points are taken into account :
- the Integration is performed first on SAM because it is less complex than POM to minimise risk, and to take benefit from "lessons learnt"
- the Integration is performed first on QM in order to debug before integration of the FMs (as usual)

It leads to the following sequence :

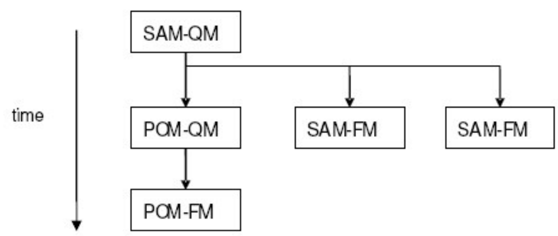


Figure 10 – Logic of development

AIT logic

The preliminary assembly has been performed by the Mechanism assembly team with reduced pass/fail criteria (friction torque, simple functional tests).
The final assembly and the performance tests have been performed by the Instrument AIT team with whole criteria and thanks to the development of optical and performance-critical GSE.

Qualification logic

The Qualification logic has been optimised by minimising the number of tests, but ensuring that all flight configurations are covered and qualified.

Aspect	Qualification performed on	Configuration
Performance	- SAM-QM - POM-QM	- with Shutter Dummy and with FW Dummy (b) (a) - with Mirror Dummy (a)
Mechanical	- SAM-QM - POM-QM	- with Shutter Dummy (ç) - with Mirror Dummy
Thermal	- SAM-QM - POM-QM	- with FW Dummy (d) - with Mirror Dummy
Life Test	- POM-QM	- with the 3 Dummy (Shutter, FW, Mirror) - in order to cover the 3 functions
Radiation	- at Component level	

(a) : or with an Optical Dummy for some tests
(b) : in order to qualify the 2 configurations
(ç) : because it is worst case for mechanical aspect
(d) : FW Dummy chosen because there is not enough space for Shutter Dummy. It has no impact on the validity of the qualification for the 2 configurations.

Development specificities

To summarise development aspects, one can say that the Project has merged the best business practises between Earth Observation / Instrumentation Business Unit : (design customisation and optimisation) and Telecom Business Unit (stringent performance requirements and recurring cost control).

A small series of seven basic actuators has been produced. The design could have been even more optimised on several aspects (mass, volume…), but such over-design leading necessarily to new developments has been discarded to implement a secured approach allowing efficient risk management mitigation policy under severe planning constraints. This approach has been followed in full visibility and negotiation with the final customer. :

3. SIMULATIONS AND ANALYSES

Simulation tools have been developed since the beginning of the project, and even before, during the GOCI instrument architecture trade-off, in order to:

- optimise the mechanisms common design, with respect of the key requirements
- define the most suitable command profile, to achieve better performance, and the highest torque margin
- Assess and secure performances, prior EQM development.

EQM (and FM) tests confirmed the validity of the approach.

4. EARLY BREADBOARDING

Early Breadboarding was the approach to minimise risks and secure design choices, before GOCI mechanisms PDR. The two following technical risks were thus eliminated:

- Electrical interface of optical encoder signals through a slip-ring: a Pleiades "EM" encoder (identical to GOCI one) was connected to a Pleiades slip-ring (identical to GOCI one) and encoder acquisition was successfully performed, at various rotation speed.
- A Generic Actuator breadboard was built, with fully representative stepper motor and commercial ball bearings, and its performances were successfully compared to simulation model prediction. This gave full confidence on validity of GOCI mechanisms performances prediction performed by simulation, far before the mechanisms test campaign.

Figure 11 – The Generic Actuator Breadboard

5. TEST

All the performances for all the mechanisms and configurations were satisfactory. Some details are given for the key performances of the POM.

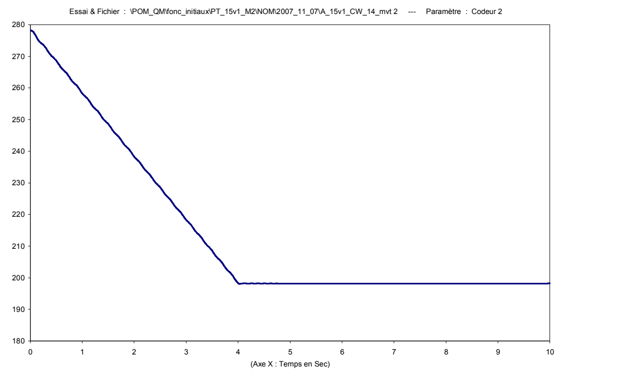
5.1. Torque margin

The POM has been equipped with dummy inertia representative of mirror. The motion (maximum rotation speed) has been commanded on the 2 stages by dedicated EGSE.

The command is performed at nominal motor voltage of 28V. The test is repeated, with decreasing 1V of the supply voltage each time, until there is a loss of synchronism. As the motor voltage is a direct image of motor torque, this allows to demonstrate that the motorisation ratio is higher than 3.

Test results:

POM2: nominal functioning (8.V)



POM2: loss of synchronism (7.V)

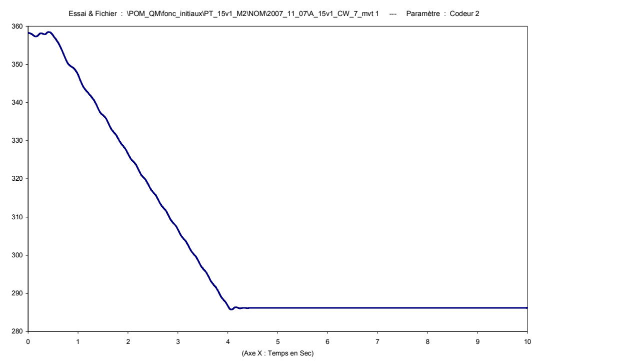


Figure 12 - POM Stage 2 ; motorisation ratio

Conclusion : the specification (POM shall function for voltage > 9.5V) is achieved : the test shows that the POM functions even at 8.V.

5.2. Stability and Accuracy

The POM has been equipped with dummy inertia representative of mirror. The motion has been commanded (specified speed, nominal voltage during the motion, holding voltage at the end of the movement) on the 2 stages by dedicated EGSE.

Test results for Stability :

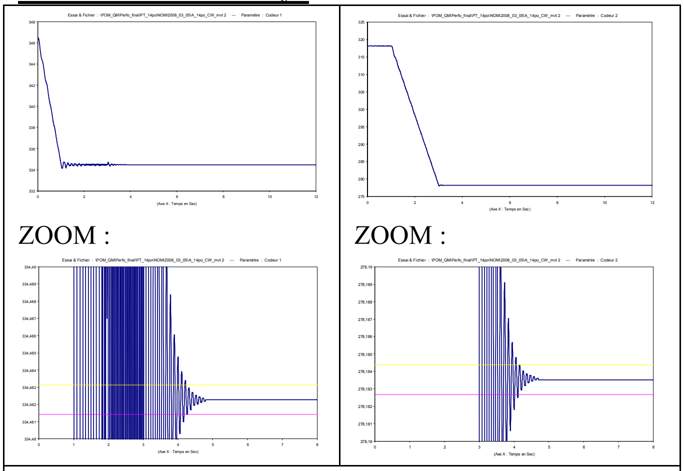


Figure 13 – POM Stages 1 and 2 ; stability

Conclusion: the specification (angle < 30.µrd after 8.sec) is achieved : the residual oscillation after the end of the motion for each encoder is < 3.µrad after 2.s.

Test results for Accuracy :

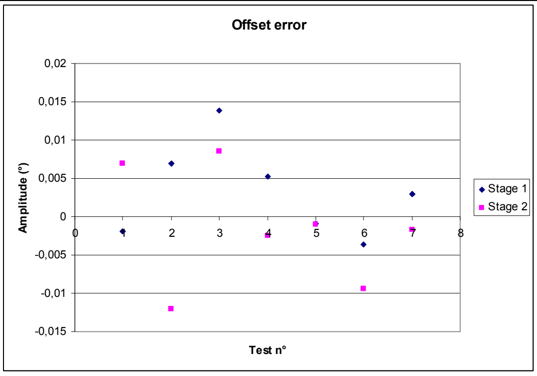


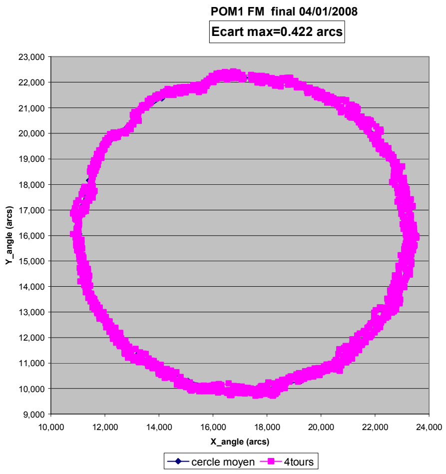
Figure 14 – POM Stages 1 and 2 ; accuracy

Conclusion : the Specification (< 0.086° for each Stage) is achieved : the Pointing error is < 0.020°.

Wobble

The POM has been equipped with dummy mirror allowing optical measurements.

Test results :



Maximum gap to the circle is 2.0arcsec (Stage 1)

Figure 15 – Wobble

Conclusion :

the results are satisfactory, consequently, the wobble characterisation was not necessary because the specification (5.µrad) is reached.

5.3. Life Test

POM QM accelerated Life Test duty cycle was optimised to cover the three mechanisms functions (SCM, FWM and POM) in order that one life test was sufficient to qualify the mechanism. Life Test lasted 6 months, and was carried out in parallel with GOCI AIT (thus after GOCI mechanisms FM delivery). Life-test demonstrated that the performance of the mechanism (accuracy, stability, friction torque, etc….) does not degrade during the lifetest

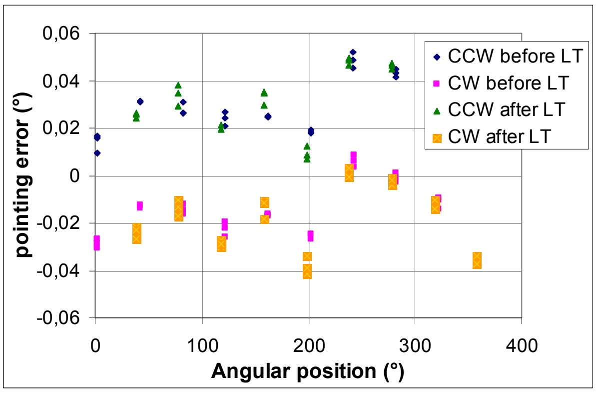


Figure 16 Pointing error before and after life-test

6. LESSONS LEARNT

Lessons were learnt on different domains of the project:

- Industrial :
  - a close co-engineering scheme between mechanism team and GOCI instrument team allowed to optimise GOCI and Mechanisms design and development, and was a key factor to deliver on time with respect to instrument needs
  - Design-to-cost by using qualified "building blocks" was another key factor of the success,
  - The third cornerstone is the use of a common actuator module, instead of tailoring each mechanism function, despite the slight overmass impact.

- Technical: comparing the performances with respect to analysis, resulting in some iterations on ball bearings and motor detailed implementation was of paramount interest, and contributed to increase the designers' expertise, and the accuracy of our analysis tools and methods.

7. CONCLUSION

GOCI mechanisms development was based on a building block approach, avoiding as far as possible new developments at acceptable over-cost for the system. A pre-requisite for the feasibility and success of such an approach was the availability of the required building blocks in their fully qualified version and their re-use without any modification ("design-to-reuse" approach). GOCI mechanism development took benefits from the availability of the main building blocks already qualified in the frame of past Institutional programmes (Pleiades, MSG SEVIRI,…) supported by Space Agencies (ESA, CNES). This demonstrates once more the paramount importance for European Prime Contractors and Space Mechanism industrials, to have ready-to-use " off the shelf" qualified elementary building blocks (Space Actuators, Sensors, Ball Bearing, etc….) to efficiently develop new solutions.

COMS Communication, Ocean, and Meteorological Satellite
KARI Korea Aerospace Research Institute
GOCI Geostationary Ocean Color Imager
PIP Payload Interface Plate
LoS Line of Sight
SCM Shutter/Calibration Mechanism
FWM Filter Wheel Mechanism
SAM Simple Actuator Mechanism
POM POinting Mechanism
CEA Common Elements for Actuators
AIT Assembly, Integration and Tests
GSE Ground Support Equipment