MTG SCAN MECHANISM PREDEVELOPMENT: DESIGN & PERFORMANCE

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ABSTRACT

The MTG instruments are located on a new generation of GEO SC, 3 axes stabilized. The scanning of the Earth along the E/W and the S/N directions shall be ensured by the Scan Mechanisms located ahead the Instruments, corresponding to challenging pointing requirements. Key requirements are: scan angular velocity stability (accurate slope and low jitter), angular pointing restitution accuracy (angular pointing knowledge) and overall pointing position accuracy with respect to the commanded position. All these performances are in the µrad – or even sub µrad - range over a wide angular stroke, corresponding to challenging capabilities.

In order to secure the MTG development on these topics, pre-development activities were initiated under ESA funding, one development was being completed by SENER under ASTRIUM prime contractor ship (France and finally Germany). SENER subcontracted CEDRAT for motor development and TNO as interferometer and optical consultant, meanwhile ASTRIUM subcontracted the encoder activity to CODECHAMP.

The performances finally demonstrated by the Breadboard indicate how the target performances are achieved, together with the lessons learnt which are of paramount importance to further secure the development of the MTG mission.

1. MTG BACKGROUND WITH RESPECT TO THE SCAN MECHANISM

During the MTG Phase A, FCI & IRS instruments designs were progressively worked out. The (bi axis) Scan Mechanism specifications were refined and candidate concepts proposed – in line with the instrument concepts - different from TAS and ASTRIUM.

Based on limited relevant heritage, the Scan Mechanism low TRL was considered as a possible risk for the overall MTG development. Preliminary activities were decided by ESTEC, aiming at developing breadboards consistent with both instrument activities (TAS & ASTRIUM).

The BB design was focused to be representative of the most critical FM aspects, in particular E/W performances. BB detailed design was started only after having settled the major representativity aspects with respect to FM

The BB industrial activities were initiated reflecting the baseline industrial organization. For the FCI Scan Mechanism, SENER is the ASTRIUM key partner

2. STUDY OBJECTIVES AND OVERALL LOGIC

For the study and overall logic, two parallel flows were followed, one as a reference design (the FM concept focused on the BB development), and the other one substantiated by key technologies consolidation.

Some novel verification aspects required early preparation as the metrology, needed for the BB but also suitable for the FM development.

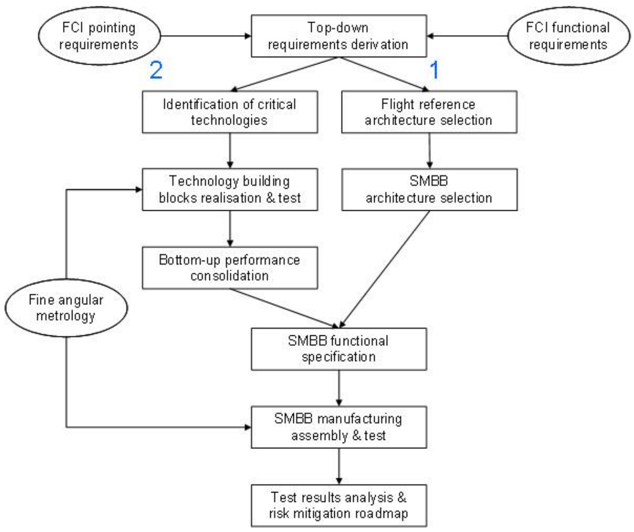


Figure 1. Top-down requirements derivation.

'14th European Space Mechanisms & Tribology Symposium – ESMATS 2011'
Constance, Germany, 28–30 September 2011

3. MECHANISM FLIGHT DESIGN CONCEPT

The driving technical requirements derived from instrument specification are:

- Scanning accuracy (stability): "The E/W scanning accuracy shall be such that 68,3% (1 σ) of the PTV errors are lower than 1.6 µrad (target 0.58 µrad) over 203 ms."
- Pointing Restitution: "For each scanned line, the E/W scanning angle knowledge / restitution accuracy shall be better than:
  - Bias < 0.5 µrad. Error average over the scan range.
  - Jitter < 0.5 µrad (1 σ).

  This is the error between the actual pointing angle and the associated measurement / restitution. This accuracy can include proper processing to be specified and/or applied by the Scan Mechanism responsible based on the knowledge of the Scan Mechanism components performances (encoder characterization, filtering, calibration & mapping as necessary)"
- Overall position accuracy ("achieved" versus commanded): "the maximum absolute angular error within the whole scan range shall be lower or equal to 100 µrad"

The development priority was to rely on existing heritage and further re-enforce European technologies:

- Using results of previous technology pre-developments (GSTP)
- Taking benefit of European capabilities in critical aspects (sensors, flexures)

The major components that have been developed during the BB phase are:

- Guiding: Flexural pivots designed and manufactured by SENER (HAFHA heritage)
- Actuator: Resulting from previous GSTP development with encouraging results that were further optimised and associated hardware implemented:
  - Selection of a LAT design as reference design – for FM & BB
  - Intensive trade off and optimisation of alternatives solutions studied to consolidate the selection for FM
- Angular position sensor: CODECHAMP high resolution/high accuracy optical encoder (24-bits).

4. REALIZED ELEGANT BREADBOARD MECHANISM DESIGN

The EBB mechanism design was derived from FM concept and focused on E/W performances. The key design requirements are the E/W pointing performances, and the mechanical environment - frequency response (mechanical), including mechanical design verification through vibration tests.
The EBB representativity is limited concerning the following aspects:

- S/N axis functions. Limited to structure (locking & ball bearings) for mechanical vibrations.
- E/W anti-rotation device: manually operated
- Electronics front end & control = industrial rated drivers + DSpace
- Materials not necessarily fully representative for non-critical components

The mirror is represented by a dummy– IFs (mounting principle), mass and stiffness representative.

In the next figure it is described the main features of the EBB design. The first step was the accommodation analysis of two main mechanism architectures that were valuable and be compared:

- localised: both the motor and the encoder on the same side
- delocalised: motor on one side, encoder on the other side

The delocalised option was selected due to the following many/major advantages:

- Simpler, safer design, manufacturing, assembly and modularity
- More compact and quite symmetrical configuration
- Better E/W mass balance, avoiding unbalanced, with masses on the both sides of the mirror

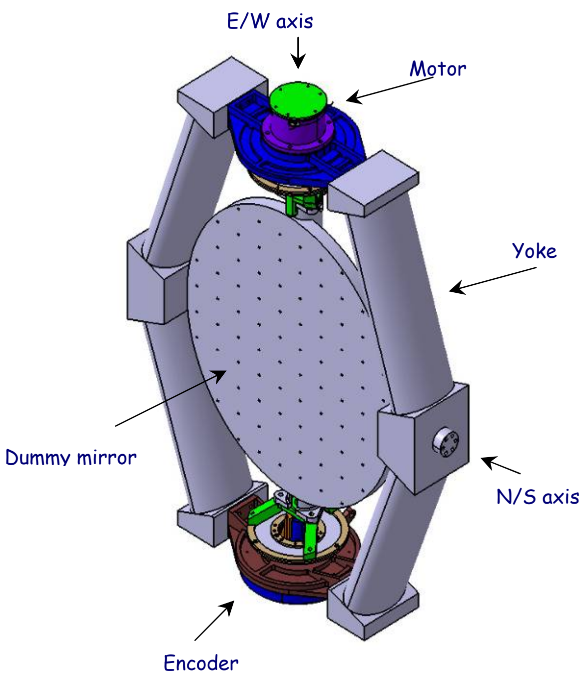


Figure 2. EBB E/W design.

4.1. Flexural pivots

The flexural pivot developed is based on HAFHA design, mainly, including some new features as higher load case (supports the whole load range) or three blades configuration that prevents the pivot from suffering an additional stress generated by a bending moment when loading it radially. One important advantage is the manufacturing in one piece that implies no welding between parts.

The design of the FP is focused on the following features:
- supporting high loads
- mechanical IF efficiency and robustness
- trade off supported by early vibration tests
- FEM iterations and refinement
- component-level characterisation: stiffness & hysteresis, mechanical allowables (axial, radial traction, radial buckling) and life test (> 20 million cycles demonstrated)

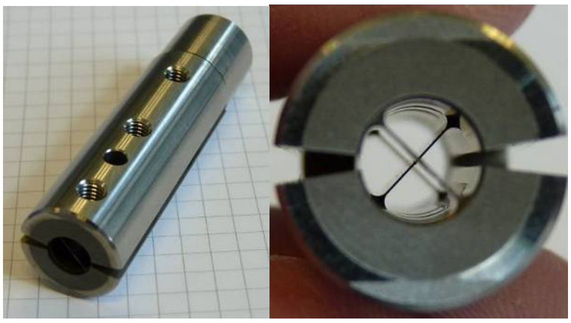


Figure 3. Flexural pivot (left) and section view showing the 3 blades crossing (right).

4.2. Angular position sensing

The angular position sensing has very stringent requirements applicable. The baseline is a European source with high in-orbit heritage experienced: CODECHAMP Encoder including embedded electronics whose communication interface is a protocol based on RS422.

Early characterization has been performed at encoder level, in various configurations to ensure full traceability of guiding properties effects. The main characterized parameters have been the harmonics which are related to the sensor knowledge / restitution.

5. TEST PLAN OVERVIEW

The objective of the EBB test plan was to mitigate prior to Phase B E/W scan development technological risks, as the mechanical design verification through vibration tests or the E/W scan performance assessment:
- Verification of pointing performances using an independent metrology system – not relying only on the encoder data:
    - Early validation of the metrology system (tuning, sensitivities) with several toolings
    - Demonstrate suitability for BB, DM, EM & FM – starting with 1 axis for BB
- E/W scan performance assessment by incremental validations:
    - Individual assessment of each key technology building block
    - Components assembled into a representative breadboard (SMBB)
    - Closed-loop tests to validate E/W scan performance
- Mechanical design verification through vibration tests

The BB integration was performed by incremental models in terms of representativity:
- BBM1: Structural model representative of launch configuration
- BBM2: Encoder and actuator open-loop characterisation with motor drive electronics (torque shape versus current, noise, quantification, harmonics)
- SMBB: Full E/W scan breadboard, for closed-loop tests

The encoder guiding and mechanical coupling with fine angular metrology system has been performed by steps:
- Step 0: Encoder foot print measured at CODECHAMP on ball bearings
- Step 1: Encoder mounted with ball bearings (idem) + motor + metrology for first check of encoder & metrology. Comparison with Step 0.
- Step 2: Encoder on SMBB to check effect of flex pivots

Open-loop characterization has been tested on encoder & motor: Encoder bench mounted on ball bearings. LAT motor prototype + laboratory-grade electronics to command different positions and ramp or sine profiles to allow full encoder characterization.

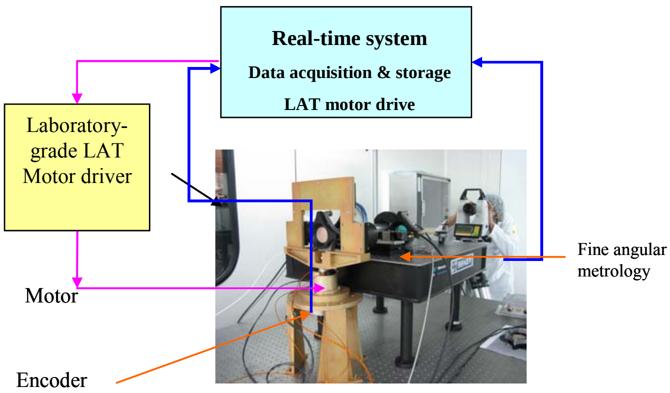


Figure 4. Open-loop characterization

A synchronous acquisition of encoder & metrology was performed, first version of real-time electronics.

5.1. Realized Test and Hardware Models

The test plan rationale was as follows:
- OGSE set up & tuning
- BBM2: Building blocks for elementary characterisation / testing (pivots properties & life),

isostatic mounts, encoder, actuator (torque defects & thermal), motor driver electronics (proto)

- SMBB: Open loop tests. Correlation with predictions (Simulink). Models refinement and real time controllers comparison
- SMBB: Closed loop tests (FCI profile & IRS profile ("step & stare"))
- BBM1: Vibration tests, specific instrumentation for the critical items (allowables oriented)

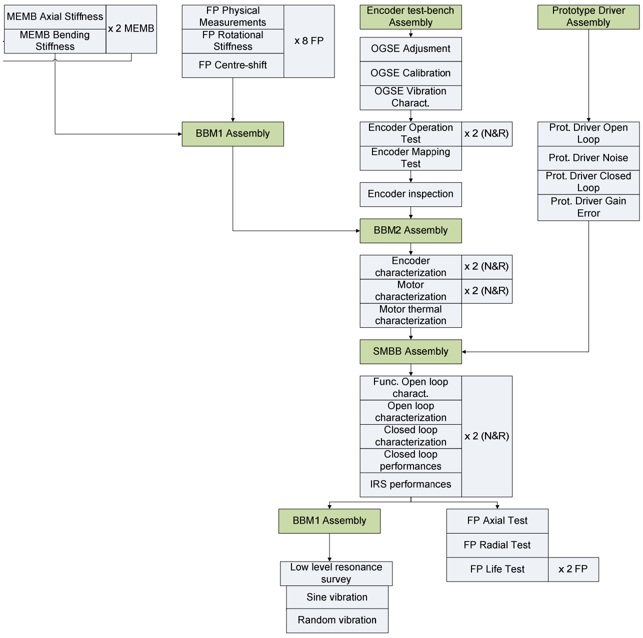


Figure 5. Test plan rationale

Figure 6. EBB MTG FCI SM in vibration test

5.2. OGSE set-up

The metrology equipment used (and available at SENER facilities) in the EBB MTG FCI optical characterization was:

- Interferometers (resolution 0.77nm)
- Retroreflectors
- Autocollimator (resolution 0.2 µrad)
- Theodolite (accuracy 0.5´´)
- Others: laser dielectric mirrors, optical mounts and active isolators

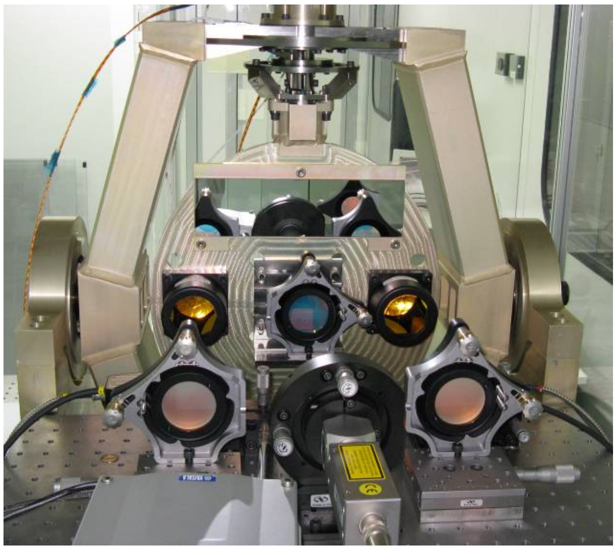


Figure 7. EBB functional assembly in the OGSE set-up.

The measurement results fully confirm that IFM system may be considered the adequate metrology system for the analysis of the EBB E/W movement. The obtained data show the system accuracy strongly depends on the setup which was applied during the measurement.

Metrology system is introducing some errors in large angle measurements and errors are increasing in function of measured angular range. Try to distinguish the origin and estimate its individual value post processing the final data is very difficult, and the tests made specifically for this reason were not conclusive.

5.3. Electromechanical actuator

An exhaustive trade-off was performed between actuator technologies as LAT, BDLC and Voice Coil. The selected actuator has been a LAT motor related to a GSTP development (ESA program). The profits of this technology are the high torque stability and the low mass.

The actuator tests, which are detailed in the next paragraph, was focused on calculating the actuator parameters like torque stability, Kt variability along the scanning, hysteresis and torque saturation (maximum torque). Resulting, the torque stability of the actuator is a good property in the scanning process.

6. MAJOR TEST RESULTS ACHIEVED

6.1. Stability

The stability of realized movement meets the 1.6µrad (red line) stability spec over 203 ms. the stability error has been calculated as:

$$Angle\ Error(t) = Actual\ Angle(t) - Commanded\ Angle(t)$$
$$dAngle\ Error(t) = [\max(Angle\ Error(t1)) - \min(Angle\ Error(t1))]$$
$$\neg \quad t1\ is\ between\ t\ and\ t+203\,ms$$

The following figure represents the stability error during an individual scanning with the requirements: the limit (in red) and the goal (in orange).

Good repeatability observed in different scannings.

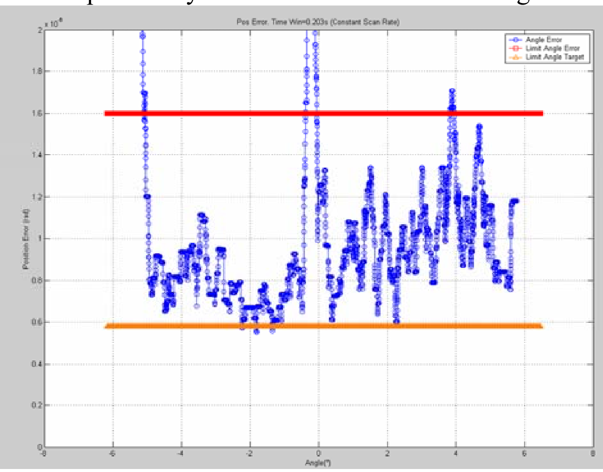
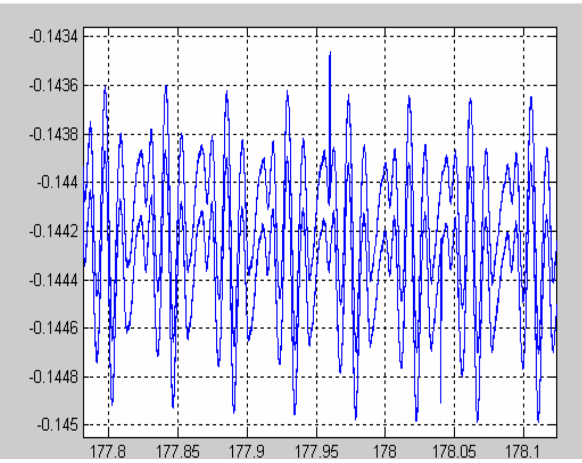


Figure 8. Stability

6.2. Restitution

The encoder includes some high frequency contents that correspond to spatial errors ("foot print") of the encoder. Spatial errors translated into time-frequency, following the scan rate.



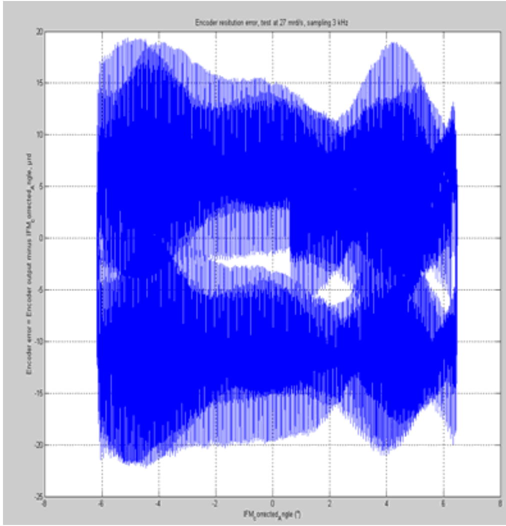


Figure 9. Encoder error versus reference metrology. 27 mrd/s – 3 kHz

6.3. Accuracy

The 100 µrd overall accuracy requirement is achieved with margins.

In the figures, the scanning is plotted in blue line (Left Y-Scale) and the error is in green line (Right Y-Scale). Each figure is set with different control laws (course on top and optimized on bottom).

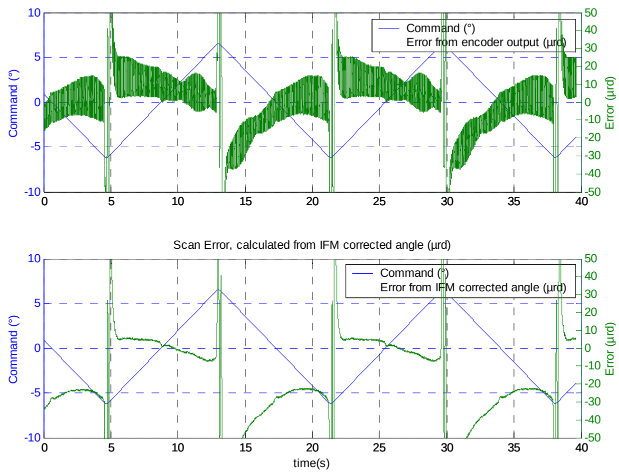


Figure 10. Accuracy

7. LESSONS LEARNT

External metrology is mandatory to assess "achieved" performances - independently of the encoder data. Real time aspects shall be carefully controlled (sampling rate, delay effects = velocity dependent).

Some improvements were identified and justified in terms of alignment – to minimize the magnitude of the correction. However, current misalignment effects are observable and are corrected in the metrology processing by calibration

No jitter observed on the mirror achieved position @27 mrad/s; sensitivity to be assessed by prediction for different rates.

Encoder processing to be optimized for the restitution purpose.

8. ABBREVIATIONS AND ACRONYMS

BB	BreadBoard
BDLC	Brushless Direct Current
DM	Development Model
E/W	East / West
EBB	Elegant BreadBoard
EM	Engineering Model
FCI	Flexible Combined Imager
FEM	Finite Element model
FM	Flight Model
FP	Flexural Pivot
GSTP	General Support Technology Programme
HAFHA	High Accuracy Flexural Hinge Assembly
IF	Interface
IFM	Interferometer
IRS	Infrared Sounding Mission
Kt	Motor constant
LAT	Limited angle torque
MTG	Meteosat Third Generation
N/S	North / South
OGSE	Optical Ground Support Equipment
PTV	Peak To Valley
SM	Scan Mechanism
SMBB	Structural Model Breadboard
TAS	Thales Alenia Space
TRL	Technology Readiness Level

9. REFERENCES

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