SWIM RMA – HIGH ANTENNA LIFETIME MECHANISM

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ABSTRACT

The Rotary Mechanism Assembly (RMA) is developed in the frame of the CNES/TAS SWIM instrument for the CFOSAT program (CNES/CNSA collaboration - T. AMIOT SWIM Technical Manager, P. CASTILLAN CFOSAT CNES Program Manager). It is a high lifetime mechanism enabling the holding, the release and the rotation of 6 RF beams integrated on an antenna structure at 5,6 rpm continuously during 3 years (qualification needs: 13,6 millions of turns). This mechanism is composed of a rotary for the rotation (with a RF joint and a slip-ring for digital commands in particular), and by 3 HRMs for the holding and the release. Several breadboards (for components submitted to wear as slip-ring and ball bearings) were performed to confirm design choices early in the development plan.
This paper presents the RMA mission, its design, its development and qualification plan, breadboards performed and mains results associated.

1. CONTEXT

SWIM RMA mechanism is developed in the frame of the CFOSAT (Chinese-French Oceanic SATellite) program, a CNES/CNSA collaboration. Its Main objective is the monitoring of the ocean surface wind and wave in order to improve the knowledge and modeling of sea-surface processes: sea-state evolution, role of waves in the atmosphere and ocean...
2 instruments are then implemented on the CFOSAT Chinese plate-form :

- The SWIM (Surface Waves Investigation and Monitoring) scatterometer spectrometer dedicated to waves measurement and provided by CNES
- The SCAT scatterometer dedicated to wind measurement and provided by CNSA.

Both are microwave active instruments (radars) at Ku-band (13,2 to 13,6 GHz) scanning around the vertical axis.

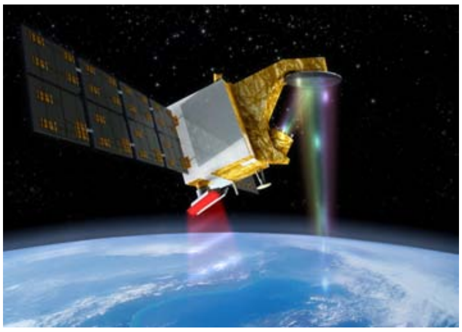

Figure 1. CFOSAT with the SWIM (right) and SCAT (under) instruments

Developed by the CNES and Thales Alenia Space, SWIM instrument is the first ever space radar concept that is mainly dedicated to the measurement of ocean waves directional spectra and surface wind velocities through multi-azimuth and multi-incidence observations. Orbiting on a 500 km sun-synchronous orbit, its multiple Ku-band (13,575 GHz) beams illuminating from nadir to 10° incidence and scanning the whole azimuth angles (0-360°) provide with a 180 km wide swath and a quasi global coverage of the planet between the latitude of - 80 and 80°.
Multi-azimuth multi-incidence observations requirements have led to design an ambitious antenna subsystem that rotates continuously at 5,6 rounds per minute while transmitting high power RF signals towards tunable directions.

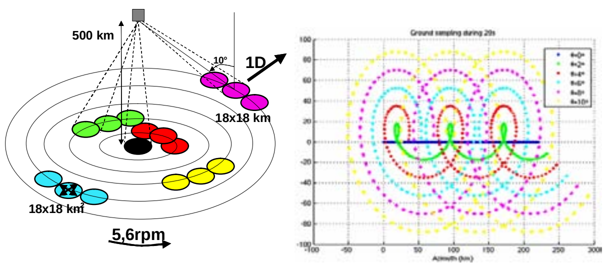

Figure 2. Geometry of observations of SWIM and surface patterns described by the SWIM antenna beams

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This antenna is composed by

- A carbon reflector and structure
- A Rotary Feed Assemby (RFA) itself composed by:
  - The 6 beams oriented from Nadir to 10°
  - A RF switch matrix (1 entry / 6 exits)
  - A Rotating Mechanism Assembly (RMA)
  - Harness and active thermal control components.

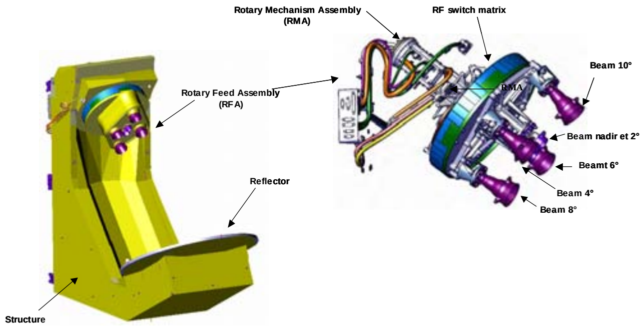


Figure 3. Antenna Description

2. RMA DESCRIPTION

2.1. RMA Mission

Hearth of the RFA and integrated directly on the little antenna baseplate, the RMA mechanism provides many and major services to the antenna mission, having gone beyond standard heritage.

Its main requirements are:

- To hold on ground and during launch the antenna RFA (about 9 kg)
- To release the RFA once in orbit to allow the feed rotation
- To provide to beams a stabilized pointing through the reflector
- To rotate the RFA at 5,6 rpm continuously during 3 years (about 9 millions of turns) added to 1,7 millions of turns on ground.
- To stop and keep a particular feed angular position (step of 1°).
- To transfer Ku RF signal to the RF switch matrix
- To transfer digital commands and DC power to the RF switch matrix
- To transfer analogical electrical signals to RFA active thermal control
- To provide a precise reference angular position once per turn.

In particular, continous rotation and lifetime associated, digital command transfer and RF joint integration are the main challenges of the RMA design.

2.2. RMA technical description

Developed by Thales Alenia Space Cannes, the RMA is composed by a central rotary mechanism with 3 hold down and release mechanisms. Fig.4 shows the RMA design.

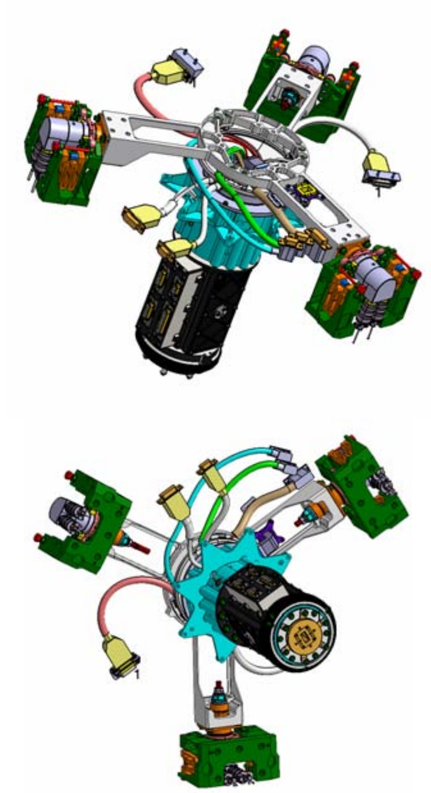
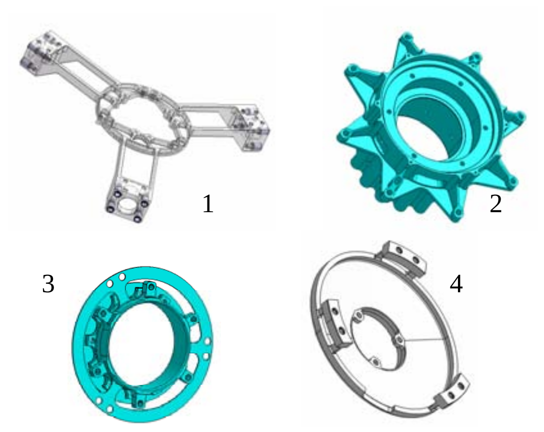


Figure 4. Up and bottom views of RMA

Rotary is principally composed by of:

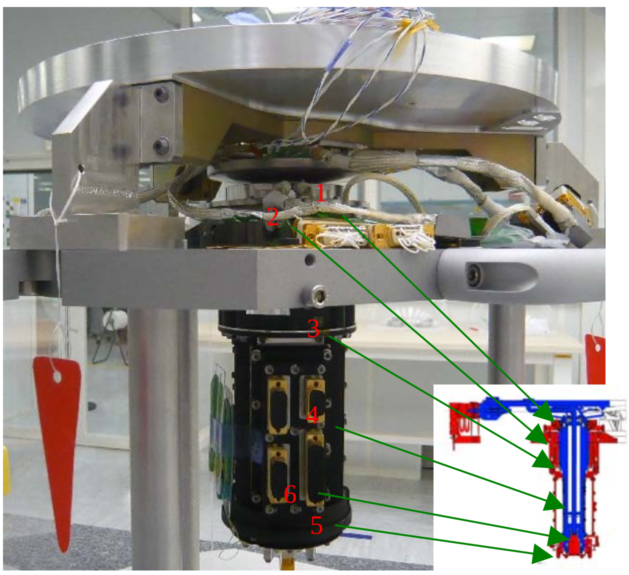
- A stepper motor 4 stacks 35PP commanded by microstep sinus/cosinus current.
- 2 dry lubrificated ball bearings to lead the rotor in rotation with lower friction and lower unbalance
- 1 RF joint and wave-guide to transfer RF Ku signal through the mechanism.
- 1 structural 38 tracks slip ring to transfer digital and analogical electrical command.
- 1 optical switch to provide the reference position
- Several complex interfaces brackets to link mechanically component and interfaces.

Fig. 5 and Fig. 6 present different brackets and components localization into the mechanism.



1 : Support RFA Bracket – Interface between RMA and RFA
2 : Stator RMA – Interface between Rotary and Antenna, mounting of motor, front ball bearing, optical switch and stator slip ring interface
3 : - Thermal blade – mounting of rear ball bearing, stator slip ring interface, stator RF interface and thermal blades
4 : Decoupling bracket – For thermal and mechanical decoupling between Rotary and Support RFA bracket

Figure 5. Exemples of RMA parts



On the sketch, red components are stator, blue ones are rotor

From up to bottom
1 : Optical switch
2 : Front ball bearings
3 : Stepper motor
4 : Slip ring
5 : Rear ball bearing
6 : RF joint

Figure 6. RMA Rotary and components

The 3 (every 120°) HRM RMA hold and release the rotary and are composed by:

- A feet part (HRM Blades and preloaded beam)
- A release cartridge with a low shock European Pyronut provided by Lacroix

Fig. 7 shows the HRM pictures.

Figure 7. RMA HRM and cartridges

Fig. 8 shows how HRM works: In stowed configuration, preloaded beams are bended and HRM blades are right, held by the stowed cartridge. Once release, preloaded beams move away the HRM blades to free about 3mm air gap between fixed and releases part of the cartridge for mechanism rotation. Released, a preload in the preloaded beams is kept.
Cartridge concept is based on a high friction treatment at the release plan interface and can be restowed.

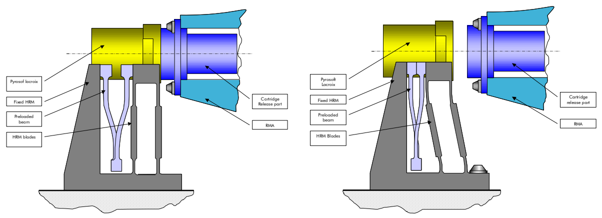


Figure 8. Functional sketches of RMA HRM

2.3. Design orientation

The design of the RMA takes into account several constraints. Mains drivers are:

- The continously rotation and the high lifetime associated,
- The 5 Antenna interfaces (imposed baseplate, RFA, RF interfaces and little closed volume dedicated to the mechanism),
- The mass (< 11 kg)
- The use of component without content subject to any dedicated export license (as for the pyronut),
- The Ku RF joint and wave-guide dimensions,
- The programmatic schedule.

At the beginning of the mechanism design, a complete technology trade off had been performed on components sensitive to wear (slip-ring and ball bearings in particular). Conclusions are:

- For slip-ring, use gold/gold contact based on previous TAS heritage

- For ball bearings, the need of an accelerating life test (schedule constraints) and a hot temperature local environment limit for fluid lubrication (due to dissipation from RF guide and motor and antenna facing space environment), a dry lubrication based on MoS2 was chosen.

While MoS2 is robust to high temperature and speed acceleration, the high lifetime required presents a challenge for this kind of lubrication. It imposes to design the mechanism with a low Hertzian stress and reduced defaults into ball bearings and to demonstrate early the capacity of slip-ring and ball bearings by breadboard to reach the lifetime requirement

To reduce defaults, loads and torques into ball bearings, particular attention had been taken on mechanism quotation and to limit number of centering and internal interfaces. That drives to structural pancakes components, as for example the slip ring whose rotor and stator are directly the mechanism ones and to choose two ball bearings (front and rear) with low angular stiffness.

Slip-ring design is optimized for the lifetime. It is double isolated. Its internal barriers (width and height) have been increased with regard to standard heritage The slip ring features a closed volume thanks two chicanes.

The choice of an optical switch was based on the non-contact technology. The antenna precision requirement of the reference position (inferior to 0,1°) is not severe for this kind of sensor but eliminates other simple concept. Drift on components at the hot temperature and radiation are compliant to the need.

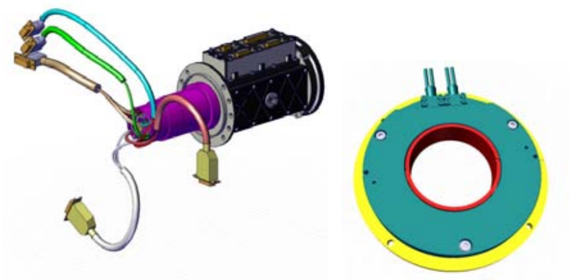


Figure 9. RMA Slip-ring and optical switch

The stepper motor was choosen as a non-contact technology and taken into account the requirement to stop and keep a particular feed angular position with a step of 1°. Commands by microstep sinus/cosinus enable to have a regular speed and avoid having dynamic effect on RFA. Command in current enables to control torque motorization and dissipation in hot temperature.

Endly, the RF joint and wave-guide, provided by TAS antenna team, are directly integrated into the mechanism rotor and imposed its dimension to all RMA components (Phi 27mm). A S flexible guide is mounted on rotor part for misalignment interface absorption.

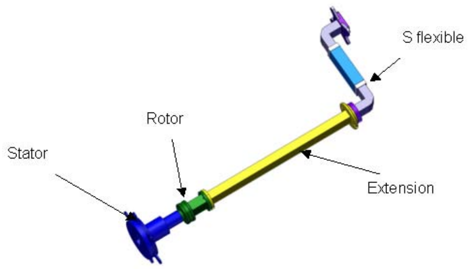


Figure 10. RMA RF joint and wave-guide

3. MECHANISM DEVELOPMENT AND TEST PLAN

Complete qualification of the RMA requires a long lifetest, despite of accelerating possibilities. Began with the participation of the Preliminary Design Review (PDR) at instrument level, the mechanism development and qualification plan will end after the flight model delivery and with the completion of the QM lifetime qualification.

Lifetime duration have a major impact on the mechanism development, requiring a design and a QM assembly early in the global instrument development plan. Thus, several breadboards had been assembled and tested to check and validate as soon as possible design choices. In addition, PDR and CDR mechanism had been anticipated with regard to antenna and instrument reviews.

At the end of the first semester 2013 (writing date), the two first models (QM, EM) are assembled and qualification is in progress.

3.1. RMA models produced

3 RMA at flight quality level have been manufactured and are dedicated to:

- The QM RMA, a complete mechanism for all mechanism and components qualification.
- The EM RMA, only a rotary, used for a coupled functional test at Antenna level and back up for PFM if necessary.
- The PFM RMA, a complete mechanism

3.2. Qualification test sequence

QM RMA qualification test sequence is composed of:

- Initial characterization and functional test
    - Rotation dynamic behavior and motorization margin
    - Digital transfer (Bit Error Rate and transfer quality up to 100 MHz)
    - Analogical transfer (dynamic resistance)
    - RF transfer
    - Reference switch position
    - HRM release and verification of release air gap
- HRM Cartridge lifetime
- Vibration test
    - Sinus up to 100Hz at 16g
    - Equivalent acoustic Antenna level random at 10g RMS
    - Equivalent random Antenna level random at 26g RMS
- Shock test at 2000g / 1000Hz
- Cartridge release and exported shock measurement during release.
- Intermediate functional test
- Thermal and Vacuum Test [-35°C; +75°C]
    - Balance Test
    - HRM Release in worst thermoelastic case
    - Functional test in cold, ambient and hot case.
- Intermediate functional test
- Accelerated lifetime test (9 months).
    - 1200 turns in clean room condition
    - 2,2 Millions of turns under nitrogen
    - 11,4 Millions of turns under thermal and vacuum.
- Long time HRM stowed test.
- Final characterization and functional test
- Disassembly and expertise.

Figure 11. RMA in functional test configuration

4. BREADBOARDS DESCRIPTION AND MAIN RESULTS

4.1. Slip Ring breadboard

To demonstrate the capability of the slip-ring technology (Supplier: Ruag Space Switzerland Nyon) to reach the RMA lifetime requirement and to allow the choice of the best compromise between number of brushes per tracks and preload versus wear and electrical quality end of life, a slip-ring breadboard was performed.
Several configurations were tested on the same model: from 1 to 4 brushes by track (1 for information) and different preloads.
Accelerated speed lifetest was performed under ultra vacuum condition with the help of CNES facility with a constant current of 0,5A for 24 millions of turns and more than 2000km covered by brushes (diameter of breadboard smaller than RMA one).
Every 2 millions of turns, static, dynamic resistance and bit error rate measurement were performed at the same brushes linear speed as for the RMA.

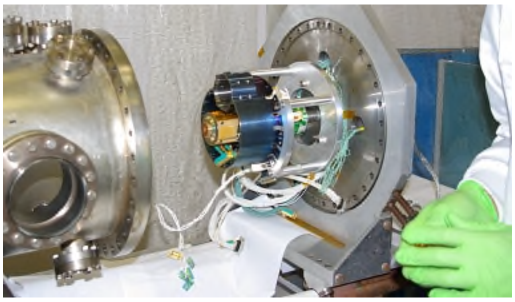


Figure 12. Slip-ring breadboard at CNES facilities

Functional results (electrical)
After 24 millions of turns, all functional results are compliant to mechanism needs:

- Static resistance: increase of about 30% between begin and end of life
- Noise dynamic resistance: Compliant at RMA functional speed end of life
- Bit Error Rate at 100 KHz: 10^{-6} at RMA functional speed end of life

Tribologic results
A complete expertise of the slip-ring had been performed.

- A torque resistance variation of 20% between begin and end of life.
- Brushes and tracks expertise shows significant wear and enable to determine a configuration for which the wear is acceptable.

This slip-ring breadboard test was successful and reaches the RMA needs.

4.2. Ball bearing breadboard

As a dry lubrificated ball bearing had been chosen for ball bearings, a breadboard was performed to demonstrate the capacity of this kind of lubrication (molykote PVD) to reach the RMA lifetime requirement. 2 representative ball bearings with 2 different low internal constraints were tested under representative clean room, nitrogen and ultra vacuum conditions with the help of the CNES facility during the first semester of 2012 at an accelerated rotation speed.
Resistive torque was supervised continuously and measured at 5,6 rpm every each million of turns thanks to 2 torque meters.

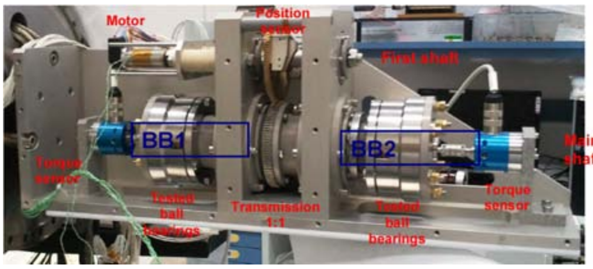


Figure 13. Ball Bearings breadboard

Fig. 14 shows the torque evolution of both ball bearings under ultra vacuum condition (after clean room and nitrogen conditions turns) and shows that the lifetime limits are not reached.

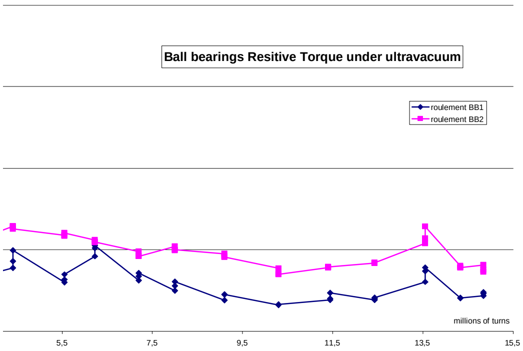


Figure 14. Ball bearings resistive torque under ultravacuum

At the end of the test, about 14,7 millions of turns were performed with success and without significant resistive torque variation. Expertise shows no major degradation and no significant difference between both ball bearings (principally wear of separators).

4.3. HRM breadboard

According to the development plan, HRM breadboard objectives were to verify early:

- The good correlation stiffness complex parts and assembly between FEM (Finite Element Model) analysis and real model.
- The good removal movement with sufficient margin
- To characterize the preloaded beam loss tension during a long duration (screeping).

Component stiffness is measured directly by applied displacement and measuring loads. This measurement shows globally a good FEM correlation despite of a light overvaluation of the FEM (about 15 to 20%).

The good removal movement and margin associated were checked by applying a load at HRM interface, as presented in fig. 15. This load and displacements were measured. Test shows that functional displacement was reached and with significant margin.

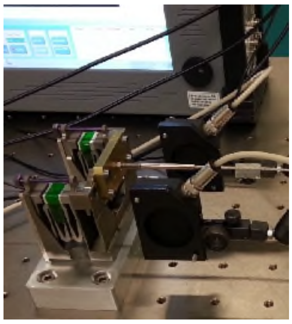


Figure 15. RMA Breadboard HRM during functional test

To end, the preloaded beam screeping was checked by measuring the load in stowed configuration (and eventual displacement) during 3 months, as presented in fig. 16.

Figure 16. RMA Breadboard HRM during long duration in stowed position

Fig.17 shows loads results during these 3 months (3 loads measurements).

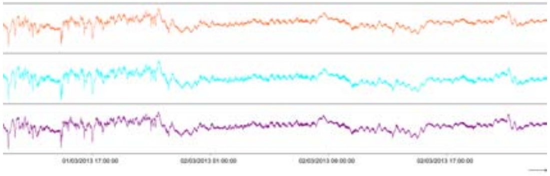


Figure17. Loads to maintain the stowed position during the long duration test

No significant variation was observed (noise measurement due to clean room thermal cycling). Then, there is no screeping on titanium part at ambient condition even if under high stress).

4.4. Others breadboards

Two others breadboards were performed in the frame of RMA development:

- the breadboard RF joint checks its compliance to RF requirements and determine acceptable misalignment between stator and rotor parts. This breadboard was tested by TAS Antenna team with success.
- the breadboard stepper motor, adapted to the specific needs for the RMA application, to check theirs performances impacts. Based on a 27PP, this breadboard was tested directly by Sagem and shows acceptable perturbations on motor behavior.

5. DEVELOPMENT LESSONS

Major lessons learned during RMA development are:

Early BBM versus representativeness: First results are targeting needed PDR RMA. Due to test duration, there were many RMA design unknowns when the breadboard had to be defined and launch. Some long time was taken to find the best compromise between early results and a better flight representativeness.

PDR and CDR mechanism anticipated with regard to antenna and instrument reviews:
While mechanism was near to CDR maturity, Antenna PDR shows a complete different mechanism dynamical behavior integrated on antenna with regard to "on clamped interfaces on mechanism frame" specified (several mechanism interfaces on the same baseplate). Major improvements on RMA design were then performed to reach the mechanism compliance not at RMA level alone but at coupled level, with delays on schedule.
Consequently, sinus and random test at RMA level will be performed in antenna frame (angle of about 40° with regard to mechanism frame) to be compliant with the antenna dynamic behavior.

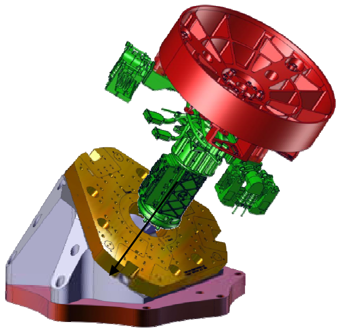


Figure. 18. RMA and vibration tools (representative RFA in red and prism for angle to 40°)

Mechanism quotation: particular attention was taken on RMA quotation in order to master internal defaults to reach lifetime requirement. This careful work took an important time in the definition phase and shall not be missed.

Coupling of command/mechanism: early quick coupling of the RMA with its command/control electronics was planned early in the development. But, due to reuse constraints, available command law of the electronics led endly to overconstraints the mechanism. The trade-off should have been more into details at the time when the reuse decision was taken.

6. CONCLUSION

The RMA mechanism is designed and developed for a high lifetime. The challenging choice of dry lubrication is proven correct. Breadboards performed on components submitted to wear (slip-ring and ball bearings) and on low heritage components enable to validate concept and technology choices.
The RMA mechanism qualification is in progress. Thanks to these precious results, obtained through the breadboards, the team is confident in qualification success of the mechanism foreseen after 9 months of a lifetest of 13,6 millions of turns.