ANTENNA POINTING MECHANISMS FOR SOLAR ORBITER HIGH AND MEDIUM GAIN ANTENNAS

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ABSTRACT

The ESA Solar Orbiter is an interdisciplinary mission to the Sun. It consists of a single spacecraft which will orbit the Sun in a moderately elliptical orbit, using a suite of advanced Remote-Sensing and In-Situ instruments to perform a detailed observation of the Sun and surrounding space. Sener is contractor for the delivery of the Antennas subsystems.

The pointing mechanism from HGAMA is a dual-axes gimbal providing azimuth and elevation steering capability. The azimuth axis is driven by the GHM geared to a rotating bracket which supports the elevation actuator and is linked to the HGAMA boom. Both are based on stepper motors with planetary reducers geared to the corresponding output brackets. An integrated X-band dual axes Rotary Joint Assembly (HGA-RJA) routes the RF energy through the APM in both TX and RX directions. The MGAMA APM is a single-axis gimbal providing elevation steering capability, with one built-in actuator and has been design to share many of the components with the elevation axis from HGAMA APM, including a single axis Rotary Joint Assembly (MGA-RJA).

Based on BEPI-Colombo heritage, some aspects of the design have been developed specifically for the SolO mission and are presented in this paper.

- High temperature ranges in the APM.
- Dedicated output shaft support with dedicated flexible coupling.
- High accuracy required, with a potentiometer as coarse sensor and inductosyn for fine positioning.
- Elevation twist capsule concept based on spiral configuration.
- High solar radiation and contamination requirements.

1. INTRODUCTION

The APM of HGAMA and MGAMA have to deploy antennas and after deployed, they need to point in 2 axes (HGAMA) and one axis (MGAMA) during the lifetime of the mission. The APMs are partially covered by the spacecraft sunshield but during some phases the sun is radiating the mechanisms with up to 17348 w/m2 when spacecraft situated at 0.28 AU. Additionally the APM shall withstand the launch environment and inertial loads generated by the spacecraft manoeuvres. Main requirements of the design are presented below:

- High temperature range, from -55ºC to +120ºC in some components of the APM.
- Angular range of up to 359º in HGAMA azimuth, 210º in MGAMA elevation.
- Accuracy of 0.01º required for RF performance assurance.
- Minimum backlash required to minimize pointing errors.
- Conductivity requirement on any exposed surface, to avoid differential charging

See below two figures with the situation of HGAMA and MGAMA in the spacecraft.

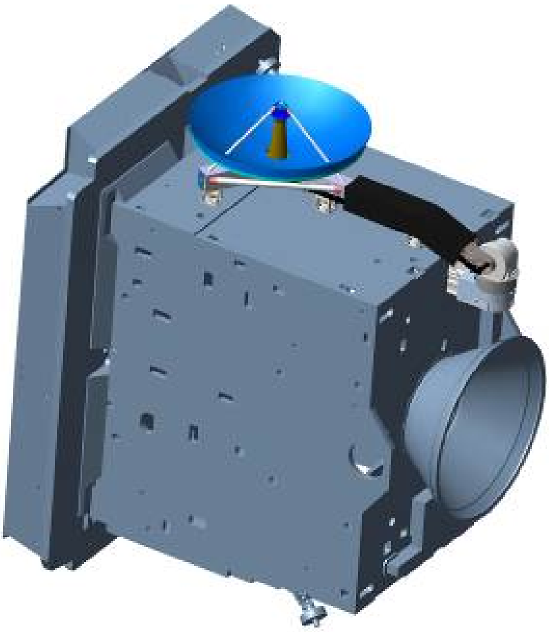

Figure 1. HGAMA in the SC

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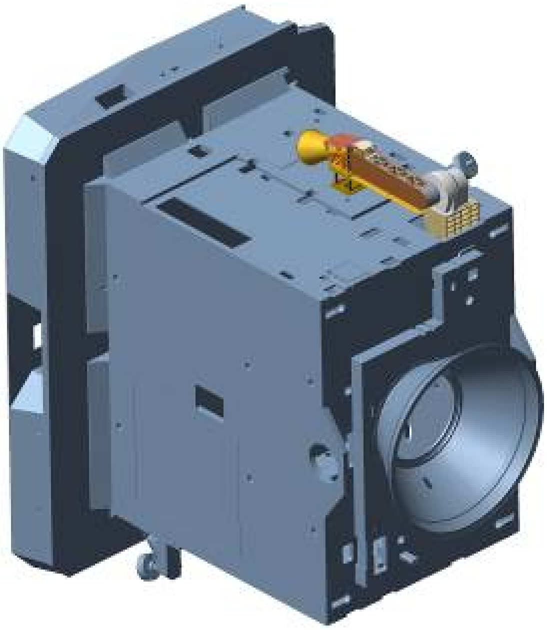

Figure 2. MGAMA in the SC

2. DESIGN DESCRIPTION

Next picture provides an image of current HGA-APM. The MGA-APM is equivalent to the second stage (elevation axis).

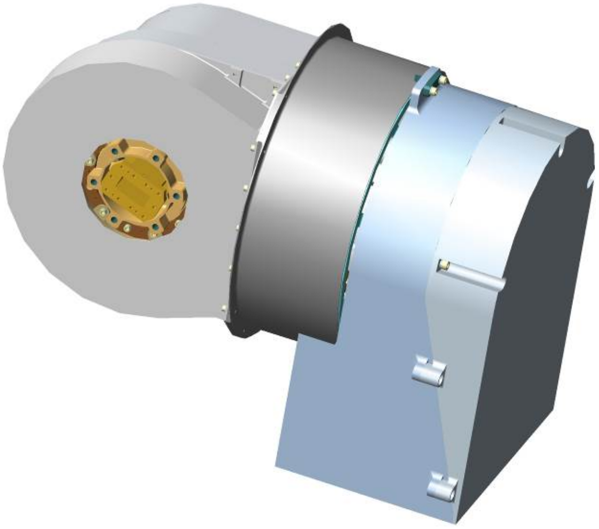

Figure 3. HGAMA APM configuration

The HGA-APM design architecture is based on the following items:

- Azimuth and Elevation actuators
- Main gear including anti-backlash for both azimuth and Elevation actuators
- Azimuth and Elevation potentiometer sensors for absolute position acquisition
- Main bearings supporting the L bracket to the S/C fixed bracket on azimuth axis and supporting the boom output bracket to the L bracket on the Elevation axis.
- HGA Rotary Joint Assembly and interconnecting waveguide connecting the Azimuth and Elevation Rotary Joints.
- L-bracket joining the azimuth actuator output to the elevation actuator and supporting the motor, potentiometers and active thermal control.
- Cable drum for both azimuth and Elevation axes. They include a flexible harness routing to transfer electric lines from Support bracket to the L-bracket and from the L-bracket to the Elevation Inductosyn rotor.
- Thermal hardware including APM thermal covers, survival heaters and associated thermistors for temperature control.
- Support bracket attaching the HGA-APM to the Spacecraft –X panel.
- End-stops to limit the azimuth and elevation range mechanically.

2.1 Gearhead motor

The actuator is based on a motor with redundant windings connected to a planetary gear and a 90º gear.

The output shaft is attached to an elastic coupling to transmit only the torsional moment. This configuration decouples the radial forces originated by the pinion-gear contact from the output of the gearhead.

Figure 4. APM gearhead motor

The gearhead motor actuator includes bearing and gearing systems which require lubrication that will last for the duration of the mission. In order to ensure best coverage fluid lubrication is used. Lubricant loss is mitigated by the use of dedicated seals.

2.2 Gears and bearings

The pinion from the gearhead motor, is directly connected to the main gear of the actuator. The gear is connected to the output of the APM and has an anti-backlash incorporated to avoid play between the teeth of the two gears.
The anti-backlash device is directly connected to the main gear (not pinion).

There are three types of bearings Main Bearing Duplex (one pair per APM axis), Shaft Bearing Duplex (two pairs per APM axis) and Potentiometer Bearing Duplex (one pair per APM axis).

Gears and bearings are all dry-lubricated.

2.3 Position sensors

The APM sensorization has been implemented by the combination of an inductosyn sensor and a potentiometer.

The potentiometer provides a coarse position of the rotation of the azimuth and elevation axis. This coarse positioning (~0.5º), combined with the fine position given by the inductosyn, gives a final absolute and accurate position of the APM rotation axis.

The Inductosyn transducer is a position sensor made of two plates with square wave patterns printed on them, which become the primary (excitation) and secondary (sin/cos patterns) of an electrical transformer. The phase between the input and output varies in the relative movement, resulting in a 180º phase change for a displacement of a coil angular range (360º/Number of poles).

This implementation has the following advantages:

- When the system wakes up, the absolute position is acquired instantaneously, without the need of performing a reference search against an end-stop.

- The potentiometer can work as an absolute sensor with a reduced accuracy to reduce power consumption in some operational modes.

- The resolution and accuracy of the inductosyn sensor is up to 0.01º.

- Both sensors have main and redundant signals.

2.4 Rotary Joint Assembly

A Rotary Joint Assembly (RJA) is fully integrated inside the APM. Its function is to connect the X-band waveguide coming out of the spacecraft panel with the boom, allowing the movement in both axes with minimum RF losses inherent to the rotational function.

The main RF parameters to be optimized are the insertion and return losses, and they must be minimized in both TX and RX bands. The design goal was to design a broadband transition that adequately covers the full 16.74% relative bandwidth. TM01-based transitions cannot reach such relative bandwidth, and the selected RF design provides good transmission in the required frequency band (uplink and downlink) without being too close to cutoff, by using the largest possible diameter. This minimizes insertion loss & reduces heating as a result of the application of high power.

The RJA is made in Titanium, to better withstand the extreme temperature environment, and it is internally gold-plated to increase its electrical conductivity reducing Insertion Loss. The result was an extremely good RF performance.

2.5 Twist Capsule

One of the most complex issues faced during the project has been the cable routing and the twist capsule implementation in a limited space in the mechanism.

In figure below, the HGAMA APM cable and twist capsule routing is presented.

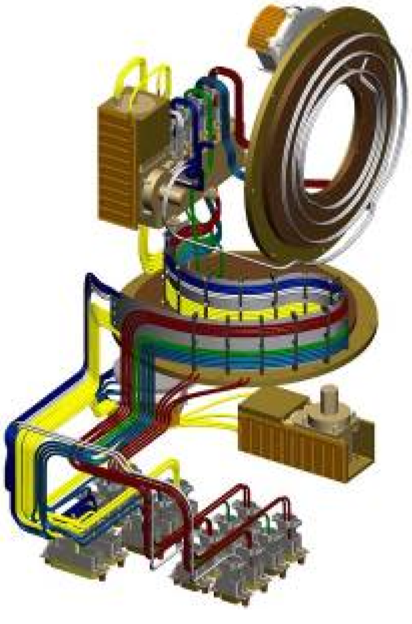

Figure 5. HGAMA APM Harness

For the HGAMA azimuth axis, the concept selected is based on a goose-neck coil supported on a metal foil which meshes between the external fixed part and the cable drum (internal rotating part). The system has to drive cables constrained by the low noise requirements. The foil alternates areas for engaging (meshing) and areas for attachment by dedicated titanium brackets.

The vertical goose-neck configuration uses the transfer of inner drum to external housing by bending. This configuration requires some mean to guarantee that the harness does not slide with respect to the inner drum when unwrapping the harness from the internal drum into the external one. In order to achieve that sliding mitigation in the internal drum and alignment in the external support, meshing teeth and slots were implemented in the current twist capsule and support elements.

In order to guarantee the initial positioning of the twist capsule foil with the teeth pattern the first and last slots of the twist capsules are reduced to match exactly the teeth shape.

The arrangement of the cables in the twist capsule intends to isolate the noisy signals from sensitive ones. In this sense the inductosyn sensor signals from the azimuth stator disk are separated from the excitation ones and the high current motor lines.

For the HGAMA and MGAMA elevation twist capsule, only 2 TSP cables (inductosyn excitation main and redundant) shall travel from stator to rotor.

Due to the number of cables to be routed, for this twist capsule, spiral configuration was selected. Each cable is a long spiral that is wrapped more in the internal drum or the external one, depending on the shaft position. Several turns may be required in order to provide the required motion. It needs soft surface of harness outer envelope in order to allow sliding between coils. The current 210º range of travel is able to be provided with a spiral configuration, depending on the thickness of the wires.

See figure of the concept below:

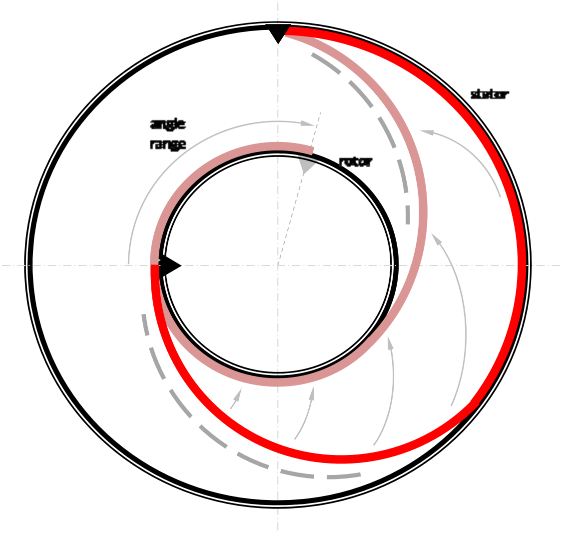

Figure 6. Elevation twist capsule concept

In order to validate this concept for the twist capsule, a breadboard was manufactured and life tested in ambient and TVAC chamber for cold and ambient temperatures. See figures below:

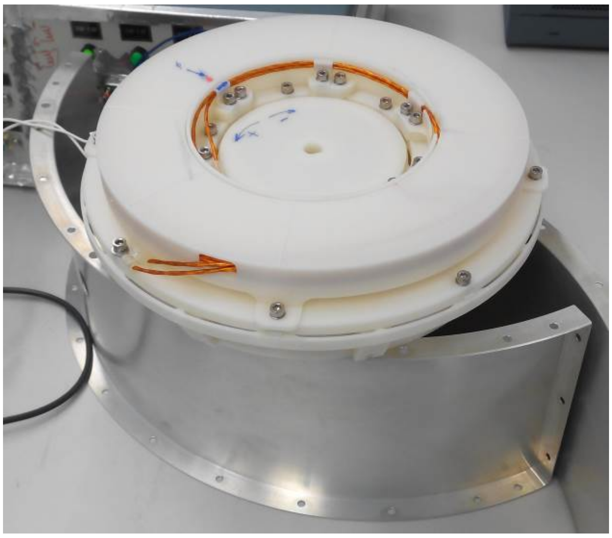

Figure 7. Elevation twist capsule breadboard model.

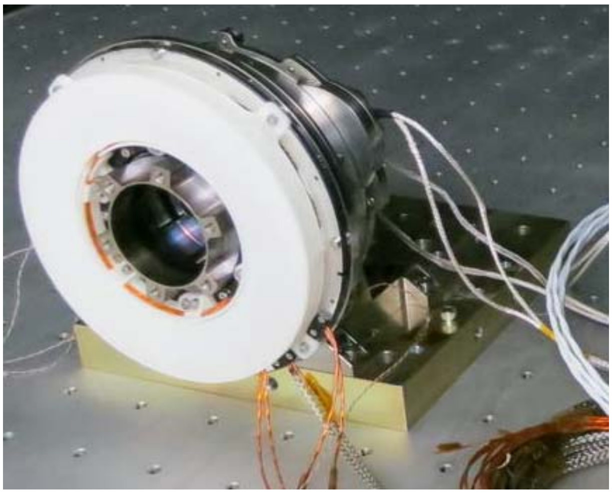

Figure 8. BBM incorporated to the LM.

After life testing, there was no measurable degradation on any of the components.

2.6 Thermal Design

The APM thermal design is pursuing the following performances:

- In hot cases, the HGA-APM should be able to leak the heat dissipated on it and minimize the heat exchanged with the boom and the S/C while not exceeding its maximum and minimum operating temperatures.

- In cold cases, the HGA-APM should be as isolated as possible from the environment in order to reduce the heater power required to maintain its temperatures over operating temperatures.

The thermal subsystem is based on radiation couplings which have the advantage of increasing its performance at high temperatures when more transfer is required and reduce at cold temperature when it would mean higher temperature regulation needs and power consumption. The thermal subsystem is formed by the elements whose function is to protect from heat flux and transfer the heat to maintain the temperature of components and homogenise the temperature map.

The heat power dissipation in the HGA-APM from motors, inductosyns and RJ is radiated to the APM external surfaces and rejected to the environment through radiation.

In addition the APM needs to be decoupled from the S/C due to the additional thermal loads imposed by S/C I/F constraints. This is achieved by the use of an isolating material, titanium, and MLI.

The thermal subsystem is composed by the following components:

- MLI: Provides thermal protection to the APM support. It is required to isolate the APM from the environment, mainly the spacecraft, and, thus, reduce the heat power consumption in cold cases.

- Shield: The shield has two functions. On the one hand, it provides a radiative thermal coupling shroud for the inner elements (housings, rotary joints, harness, connectors) draining their thermal dissipation to maintain their temperature, otherwise these elements would remain isolated and heating up. It is partially coated with PVD treatment inside to maximize thermal sink effect to the internal components.

- On the other hand, the shield dissipates the heat to the environment. Given its good alpha/epsilon ratio, PVD is used in the external surfaces.

- Inductosyn transducer: Its outstanding thermal properties, aluminium thermal conductivity and black anodized non-pattern surface (rotor front and stator back) allow using it as a contactless heat exchanger between mobile and fixed parts. The inductosyn stator couples the housing to the shield.

- Motor radiator: The motor needs a heat drain to maintain its temperature within the acceptable range and its mechanical front interface is to the titanium housing, which is a very isolating element. In addition, the internal coupling from the motor to the mechanical interface through gearhead stages is very poor and there are several housings in between with adhesive stacked threaded interfaces which may perform poorly. Other mechanical interfaces may cause stress and reactions due to thermoelastic differences.

- The coupling between the gearhead motors radiator and the APM shield is only through radiation in order to reduce the heaters power required. As the radiative coupling depends on the temperature and it is higher for high temperatures, the heat exchanged between the shield and the gearhead motor is higher in hot cases, when it is required. In cold cases and taking into account that the heaters are located on the gearhead motor, the heat losses are minimized.

- Drum: The shield is attached to it and it links by radiation azimuth parts with the deep space. It is coated with PVD coating to maximize the coupling by radiation to the elements above, below and mainly of its cylindrical area.

- Twist capsule: This element is surrounded by the drum in its cylindrical heat exchange area. The heat from azimuth is radiated to the twist capsule, from the twist capsule to the drum and from the drum to the deep space.

3. TEST CAMPAIGN

The qualification test campaign of the APM EQM (which is based on the HGAMA azimuth actuator) is composed of the following:

- Functional tests.
- Vibration and shock tests.
- TVAC cycling.
- Life in TVAC.

3.1 Functional testing

The functional test campaign has been performed at Sener facilities and includes physical properties, accuracy, resolution, hysteresis, stiffness and RF performances measurement.

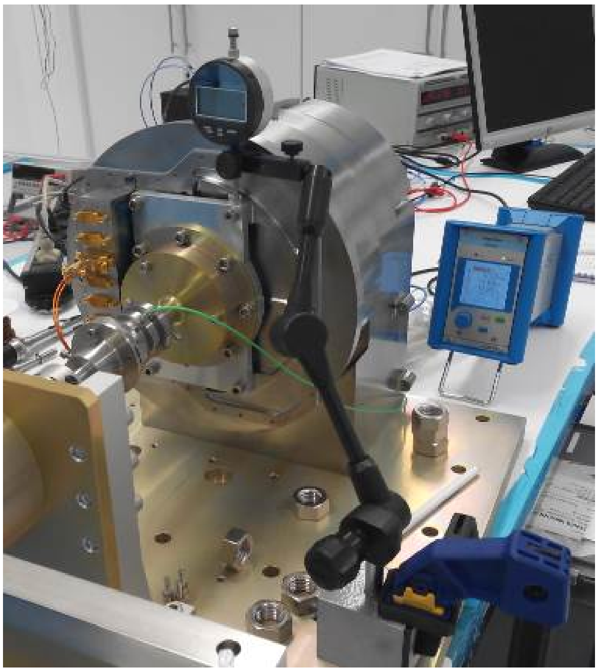

Figure 9. APM Functional testing set-up.

See below some graphs from the accuracy and resolution test:

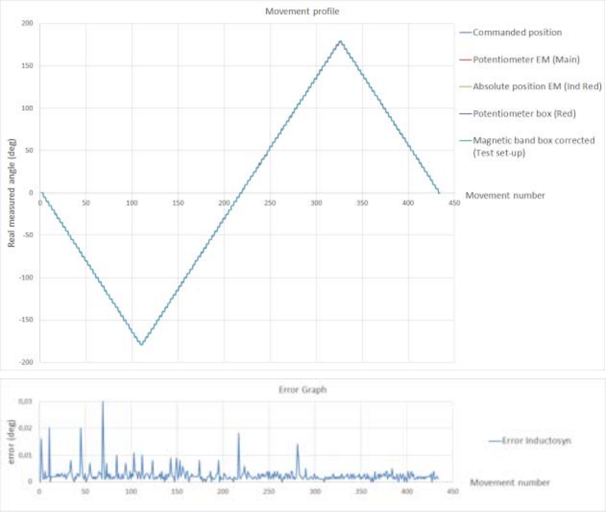

Figure 10. Accuracy test profile (top) and error (bottom)

The accuracy in the mechanism obtained from the tests is high. Most of the positions show differences between the commanded and the measured position lower than 0.01º. There are no measurable non-linearities across the movement range.

RF performances were also checked at several positions, confirming the good figures once the unit was assembled into the APM.

3.2 Vibration and shock testing

The APM EQM will perform a full vibration+shock test campaign according to the following levels.

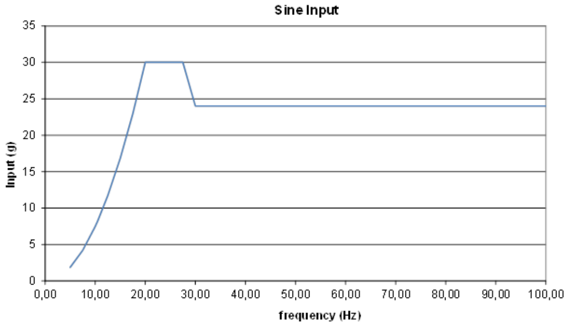

Figure 11. Sine input levels.

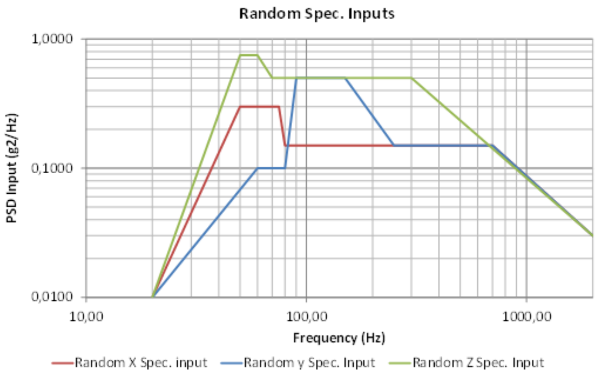

Figure 12. Random input levels.

Vibration and shock test campaign is currently being performed at CTA facilities in Vitoria (Spain). See below a figure of the mechanism on the vibration adapter.

After the test. RF performances health check will be performed.

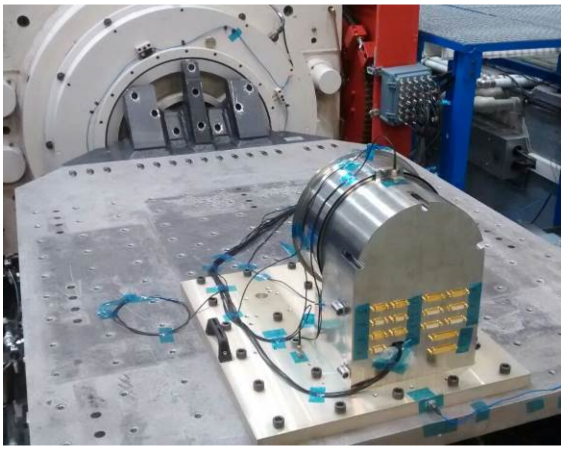

Figure 13. APM EQM on the vibration adapter

3.3 TVAC and Life Testing

After vibration and shock the APM EQM, it will be submitted to a TVAC cycling and a life test in TVAC chamber. RF performances (Return Loss) will be monitored before and after the test.

TVAC cycling and life testing will be performed at SENER TVAC chamber.

The cycling is presented in graph below.

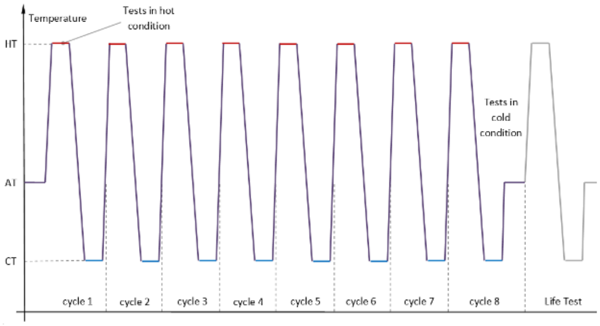

Figure 14. TVAC cycling

The extreme temperatures are -55ºC +105ºC, but the gearhead motor is expected to reach up to 125ºC during hot cycling due to its internal dissipation

For the TVAC and life testing, a test set-up to reproduce inertial loads will be implemented, as shown in figure below.

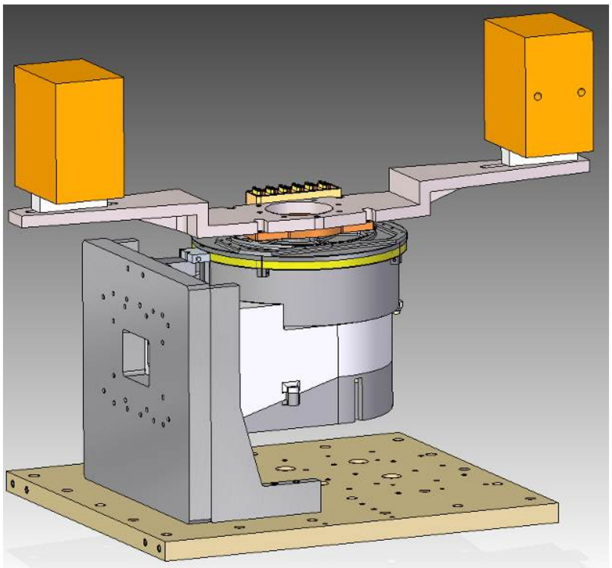

Figure 15. APM EQM TVAC and life test set-up.

The life cycles to be performed are presented in table below.

	Cold Temperature **CT**	Hot Temperature **HT**	Ambient Temperature **AT**	
Angle range	**Number of cycles**	**Number of cycles**	**Number of cycles**	**Total number of cycles**
1º	760	760	380	1900
10º	184	184	92	460
30º	160	160	80	400
60º	72	72	36	180
180º	320	320	160	800
358º	362	362	182	906 (= 900·360/358)

Table 1. Life test cycles.

As a risk mitigation activity, a life model was manufactured and tested prior to the EQM assembly.

See figure below.

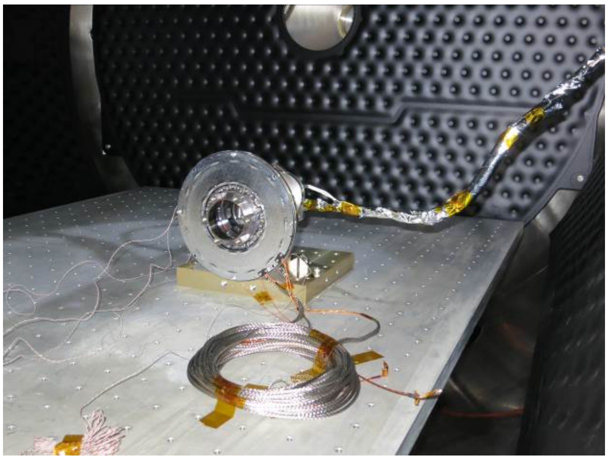

Figure 16. APM LM in Sener TVAC chamber.

The results from this life testing were satisfactory and the mechanism survived the life cycles without any measurable degradation on the performances or in any component. Part of the telemetry obtained during the short cycles is presented in figure below.

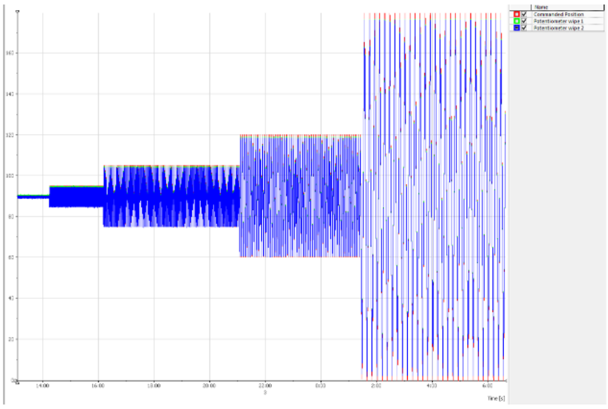

Figure 17. APM LM cycles at the beginning of the test.

4. REFERENCES

1. P. Campo, A. Barrio Development Of A High Temperature Antenna Pointing Mechanisms For Bepi-Colombo Planetary Orbiter. ESMATS 2013.

2. Haslehurst, A., Lewis S. The use of dry lubricated bearings in reaction wheels. ESMATS 2011 p354-362.

3. M. Buttery, E. Roberts ESA-ESTL-TM-0118 Impact of environment on MoS2.

4. B. Wood, D. Musset. SADM Potentiometer Anomaly Investigations