3POD: A HIGH PERFORMANCE PARALLEL ANTENNA POINTING MECHANISM

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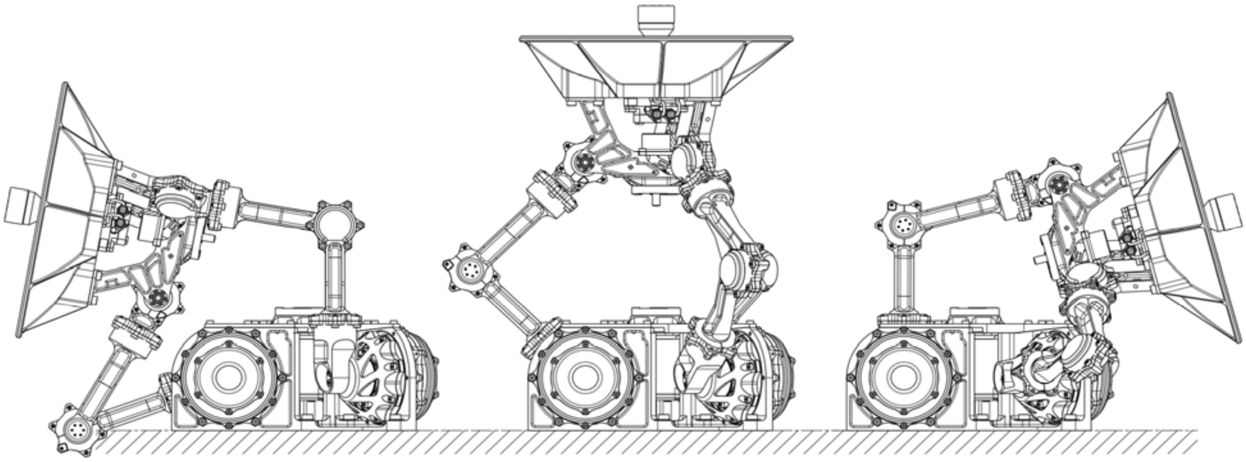

Figure 1. The antenna pointing system 3POD

ABSTRACT

This paper presents the 3POD Antenna Pointing System (APS) developed in collaboration between CNES and COMAT. The development is performed for the OTOS (formally CXCI) technological program dedicated to the preparation of future optical very high resolution satellite missions.

The role of the APS is to maintain the communication with ground stations independently of the satellite's agile attitude (Pléiades-like satellite) and without affecting the line of sight stability. In order to ensure the proper antenna gain and axial ratio, a +/-74° pointing domain with a worst case precision of +/-1° at pointing speed of 5°/s for elevation is achieved using the specific kinematic linkage of the 3POD.

The preliminary study phase of this APS concluded to the feasibility of the system. It has successfully provided precise analysis results and testing results that are presented in this paper.

1 INTRODUCTION

This paper is dedicated to the mechanical APS developed for CNES High Data Rate Telemetry (HDRT) activities in the framework of the 'OTOS' technological program. OTOS program is dedicated to the preparation of future optical very high resolution satellite missions (post-Pléiades missions).

Figure 2. Artist view of OTOS satellite

X-band Earth Exploration Satellite Service (EESS), 8.025-8.4 GHz, is chosen in order to limit costs and reuse parts of current X-band stations. A 2 Gbps (average) data rate is targeted with an available bandwidth of 375 MHz on two polarizations [1].

The technological program 'OTOS' began in 2011. The program is expected to be completed in 2016. The first post-Pléiades satellite using OTOS technological developments is planned to be launched before 2020/2021.

The APS secures the downlink between the OTOS satellite and X-band ground stations. It is composed of:

- A 3POD Antenna Pointing Mechanism (APM)
- 2 Radio Frequency (RF) subsystems (X-band antenna and a 2-channel RF flexible harness)
- Controls and Commands electronics

This paper describes both the design phase up to the Preliminary Design Review (PDR) state, and the test campaign performed on the kinematical breadboard model (BBM) of the APM at the CNES.

The main characteristics and performances of the APS are presented in the first part, followed by a description of the 3POD's kinematic principle and its key design features. The paper then describes in more precise detail the various analyses, performed on the APM, which allowed us to have a strong understanding of the 3POD's kinematic and dynamic specificities. Furthermore, a presentation of the various tests performed on breadboards at CNES complete the description of the development. Finally a dedicated short paragraph recapitulates the "lessons learned" and the paper concludes by assessing questions about the 3POD modularity and the possible adaptations to fit other specifications.

Table 1. Main APS Performances

Function	APS Characteristics and performances	
Interfaces	APS Mass (with thermal protection)	5,6kg
	Volume (with antenna)	Ø391mm – h255
Kinematics	Azimuth / Elevation rotation range	Unlimited (>360°) / +/- 74°
	Pointing resolution	< 0.02° (excluding piloting simplification)
	Pointing Accuracy incl. electronics	<+/-1°
	Angular velocity	5°/s (elevation with ECSS margins)
	Reliability to actuator failure	Up to 40% of pointing domain in case of actuator failure
Mechanical and thermal environments	Vibrations (ECCS-E-D10-03)	17grms (Z-axis) / 11grms (transverse axes) First eigenmode > 150Hz
	Thermal (with thermal control)	[-150°C ; +150°C] (on deployable mast)
	Jitter (PLEÏADES app.)	Mz, Mt=0.01Nm / Fz= 0.015N / Ft = 0.03N *(measured on BBM)*
Power	Power consumption	18W (APM) + 15W (thermal control)
Lifetime	Mission lifetime	7 years
	APM Lifetime	~100.000 tracking cycles
RF (for X-band application)	Data rate (for 2 polarizations)	Up to more than 2 Gbps
	Total insertion loss	< 1.35 dB
	APS overall gain	~ 19 dBi @+/-3°
	Maximum input RF Power	10 W / polarization
	Antenna gain	> 20.3 dBi @+/-3°
	RF antenna mass	Reflector < 350 gr

2 APS CHARACTERISTICS

Targeting an average data-rate up to 2 Gbps implies new challenges on the associated APS, particularly in terms of agility and pointing range. Maintaining the communication coverage with the ground station independently of the agile satellite's attitude and without affecting the line of sight stability (low mechanical jitter) is indeed decisive. For OTOS application, a 74° pointing domain with a worst case pointing precision of +/-1° at pointing speed of about 5°/s (for elevation) is targeted.

The 3POD parallel manipulator concept, patented in collaboration between COMAT and CNES was chosen by CNES for the APM. It has several advantages compared to classical gimbal assemblies [2]. The main performances of 3POD APS for OTOS technological program are gathered in Tab. 1.

3 KEY DESIGN FEATURES AND ADVANTAGES OF THE 3POD APM

The main design challenge, in this new development, is to propose an APM :

- ✓ With low induced jitter.
- ✓ With bi-polarization of the RF cables.
- ✓ Including its unique integrated HDRM device.
- ✓ Ensuring sufficient motor ECSS factors.
- ✓ Minimizing the overall dimensions and mass.
- ✓ Compliant with space thermal environment (3POD mounted on a deployed mast).
- ✓ Robust to an actuator failure (reduced range).

The challenges are addressed by a combination of 7 sub-systems that each perform a specific function and come together in a complex mechanism assembly, the 3POD APM (see Fig. 4):

- ✓ The moving plate (Antenna interface).
- ✓ An RF cable routing structure (or Slinky).
- ✓ 3 Legs (or Arms), (upper and lower links).
- ✓ The fixed base plate, (Satellite mast interface).
- ✓ 3 Actuators (I/F btw the base plate and legs).
- ✓ The Hold Down and Release Mechanism (HDRM).
- ✓ A passive thermal control system.

4 3POD KINEMATIC PRINCIPLE

The 3POD APM is a parallel architecture robot; it controls a moving plate's orientation and plunge (height on the elevation axis) by the three fixed rotative actuators at the base joints.

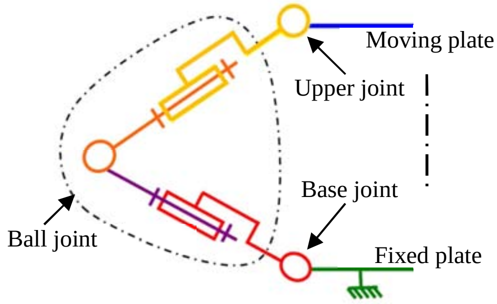

Figure 3. 3POD schematics and Mechanical linkage of one 3POD leg

The fixed base plate satellite interface (I/F) is linked to three sets of legs via the motorized revolute joint (the base joints). The lower link of each leg is connected to the upper link via a ball joint (an association of three revolute joints). The upper link is in turn connected to the payload I/F plate using revolute joints. This linkage allows for three degrees of freedom (DoF) of the moving plate (Azimuth, elevation and plunge).

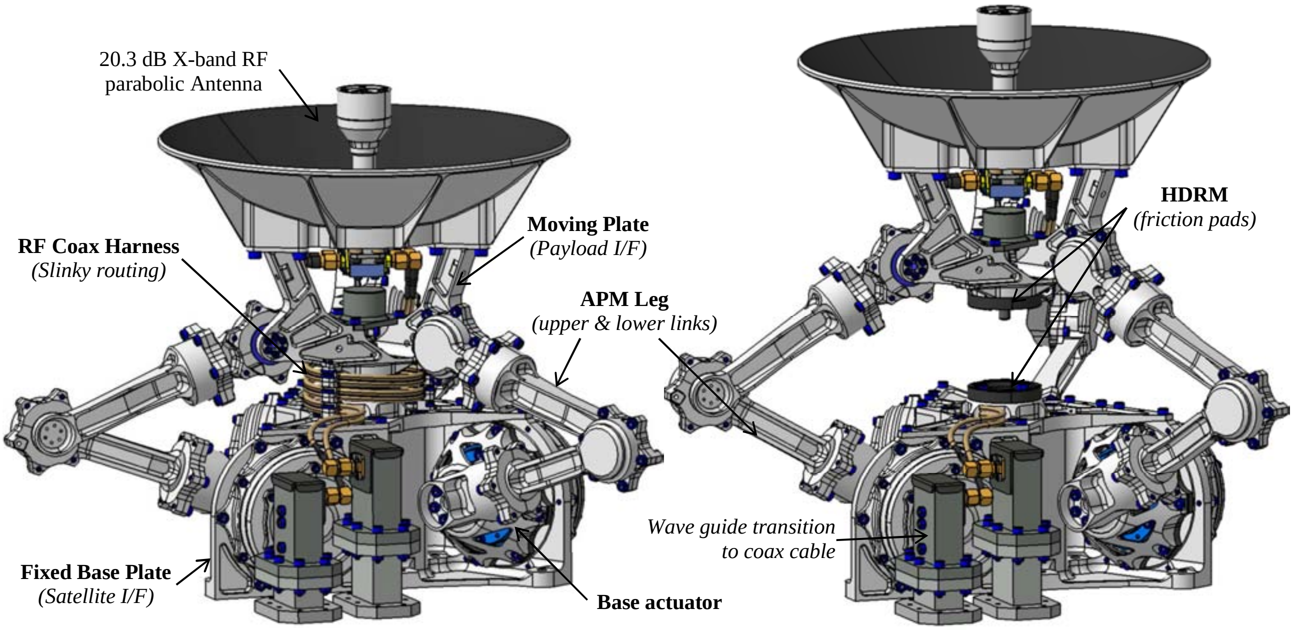

Figure 4. APS 3POD for OTOS application

5 DESIGN DESCRIPTION

5.1 General description

This section presents the main design principles that drive the global mechanism's design architectures.

First of all, the primary objective of the 3POD APM is a general pointing requirement to orient an antenna within a wide domain (+/- 74°), following a high tracking speed (5°/s in elevation), and with a specified precision of 1°. It remains the primary criteria analyzed and verified throughout the design evolutions of the 3POD.

Secondly, the overall dimensions in folded and deployed states limit the parameters of the robot. The geometry proposes the legs' length of L=125mm for a base radius of R=55mm. It is the optimum geometry considering the required pointing domain, the allowable space for the integrated HDRM and for the RF cable routing system. In parallel, an important effort in mass reduction steered the design evolution. The number of parts and of assemblies is minimized and all parts are optimized in shape.

Finally, the design is driven in part by integration and maintainability requirements. This is addressed by ensuring every sub-system remains relatively "standalone" to be assembled onto the 3POD as a whole.

5.2 The moving Plate and X-band Antenna

The moving plate is designed to minimize the Center of Gravity (CoG) height of the antenna and to ensure accessibility in the center for access to the RF coupler and to the HDRM locking screw. The plate proposes three structural arms that reach toward the antenna.

The APS antenna is a parabolic reflector antenna. The source is designed as two crossed dipoles surrounded by a subreflector. To generate the dual circular polarization, the crossed dipoles are fed by a 3dB hybrid coupler which is made using a full-metal bar-line technology. The source is protected by a radome in PEEK material attached to the source core. The overall dimensions of the antenna are Ø212mm by 100mm, the mass is below 350 grams.

5.3 The RF coax routing system

Due to its sensitivity to cumulated lifetime and space environment, specific attention was paid to the RF coax harness development. Several coax cable routing solutions were tested at CNES (including direct link with or without relaxation loop). An innovative helical routing in the center of the APM was chosen. It allows unlimited turns in the azimuth angle without requiring the use of RF rotary joints while minimizing mechanical stresses in the coax cables.

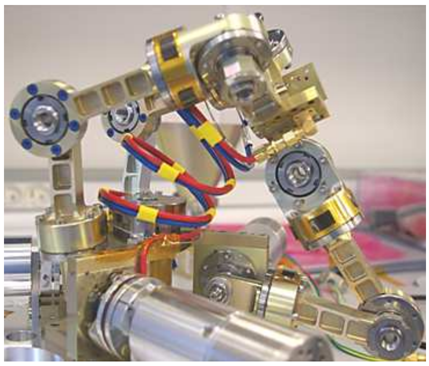

Figure 5. Breadboard of RF cable routing

For OTOS application, the routing structure resembles a helical "slinky" toy, with two RF cables linked to it using clamps. The movement of the cables (predicted by analyses) is maintained within the central part of the 3POD free of interference. It is controlled in part by the axial rigidity of the slinky. Furthermore, on the clamps holding the RF cables is added a feature to maintain in position the entire routing structure during launch.

Concerning the coax cable itself, the baseline is a 4mm coax cable manufactured by AXON specifically for this application. This cable is inspired from Axowave AX4US cables. Special precautions were taken during design phases of both the external and the internal elements, in order to undergo the aggressive cumulated environments (vacuum [3], lifetime, thermal, oxygen atomic and radiations). The total insertion loss of the harness is about 1.2dB including SMA connectors in worst case.

5.4 The leg sub-system

The legs are an essential element to the kinematic linkage of the 3POD. To limit the use of MLI on mobile parts, they are not under any thermal protection. They are in titanium painted in white. Each leg is equipped with 4 identical Superduplex ADR ball-bearings, solid preloaded and dry lubricated by PVD MoS2. The design and accommodation on the legs take into account the thermal gradient provided by the thermal analyses.

5.5 The actuator

The three identical actuators (6N.m @ 18°/s) have been highly optimized for reduced mass and high compactness. They are composed of a stepper motor 27pp from SAGEM, a Harmonic Drive HFUC 14 with a reduction ratio of 30 (50 in backup solution), a double preloaded inclined ball bearing, and finally an absolute encoder measuring the actuator output position.

The double bearing guides the motor and the Harmonic Drive output shafts. This bearing also serves as the base joint of the kinematic robot and its rotation directly drives the legs in movement. All components within the actuator are wet lubricated with grease based on Penzanne SHFX2000 oil. The main actuator performances are listed in Tab. 2.

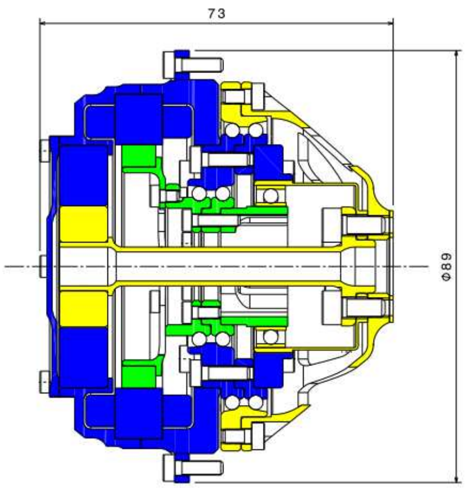

Figure 6. Actuator cross section

Table 2. Actuator Performances

Characteristics	Data	Comments
Motor step angle	1 °	
Harmonic drive ratio	30	50 (backup)
Output shaft speed	18 °/s	
Output torque	6 Nm	@ 18°/s
Holding torque	13.5 Nm	max
Detente torque	1.05 Nm	max
Axial stiffness	60 N/µm	
Radial stiffness	260 N/µm	
Bending angular stiffness	34 N/mrad	
Torsional stiffness	1900 N/mrad 3400 N/mrad	Min Max
Operating temp.	-20 / 80 °C	Min / Max
Non-operating temp.	-40 / 80 °C	Min / Max
Power consumption	6 W	under 0.5A
Total mass	0.8 Kg	
Outer volume	Ø89 x 73 mm	

5.6 The HDRM unit

The trade-off realized on APM HDRM led to the choice of a unique point of attach, in the center of the APM. It holds down the moving plate and the antenna onto the base plate during launch and uses a standard separation nut system (Pyrosoft (Lacroix) as the baseline and Rulsa (Soterem) as back-up. The locking screw is ejected into a bolt-catcher feature on the moving plate. The plane to plane contact between the moving plate and the base plate is controlled with the use of specific removable friction pads. One is in Titanium with Tungsten Carbide and the second is Stainless Steel, this contact is calibrated to the required axial load for the application.

5.7 The Base Plate

The base plate is the direct interface of the 3POD APS onto the satellite. It also houses the 3 actuators, the separation nut of the HDRM and all the connectors both to the electronics and to the RF feeders. Onto this base plate is also attached the thermal protection. For ease of maintainability, the 3POD fully equipped with its RF payload and the thermal protection can be mounted “as is” onto the Satellite without having to remove the thermal protection. All interfaces are regrouped and accessible from under the base plate.

6 THERMAL DESIGN

6.1 Thermal environment

Due to its location on top of a deployable mast (cf. Fig. 2), the thermal environment is particularly constraining on the APS subsystems. It is considered as a worst case scenario for the APS and its subsystems in comparison to any other accommodation on the spacecraft structure. The APS is sized for an environment of [-150°C; +150°C], the mast implies a thermal interface of [-100°C; +80°C] with a coupling of 0.05W/K. Finally, the thermal control power budget is about 15W.

6.2 Thermal analyses

Early in the preliminary design phase, the APS was analyzed thermally as a whole, considering the RF systems' thermal effects on the mechanism and vice versa. All thermal analyses include thermal dissipation due to RF power.

One of the difficulties behind the thermal analysis performed by EPSILON is to estimate the worst case scenarios for both the mechanism with its actuators and for the RF sub-systems. The methodology used is based on the position in orbit but also on the mission specific 3POD APS movements coupled or not with effects of RF power dissipation.

Three different thermal concepts were evaluated, the one selected for the OTOS application relies on simple and well controlled methods (heaters, painting, radiator, MLI,…). In this design, the RF subsystem and the mechanism propose their individual thermal protection and avoid using any MLI on mobile parts especially on the legs of the APM (see Fig. 7).

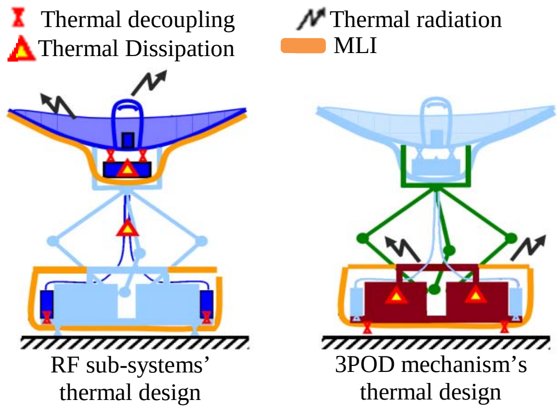

Figure 7. Thermal design schematic

6.3 The mechanism's thermal design

The APM's moving parts (plate and legs) are painted in white and do not require thermal protection. The fixed base plate, and all the components or sub-systems regrouped onto it, are protected under a thermal MLI cover (described below). Each actuator is equipped with a heater, they can provide up to 3.9W in the cold cases (survival). Finally, in the hot case scenarios, the power dissipated by the actuators is evacuated through the top plaque of the 3POD base used as a radiator. Since the top plaque is oriented toward the earth it is a thermally stable surface, appropriate for its radiator function.

The challenge in the design of the base plate's thermal MLI protection lies in the area between the moving legs (the base joint) and the fixed plate. The area in the back of the actuators is protected by a fairly simple MLI tent. On the other hand, the base joint, rotating close to the base plate, is protected by boxing it under an isolation thermal shutter that rotates under a fixed isolation structure on the base plate (see Fig. 8).

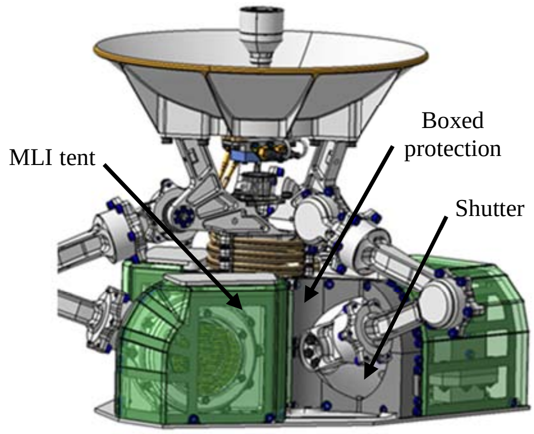

Figure 8. Thermal protection on the base plate.

6.4 The RF subsystem's thermal design

An MLI protection is located on the rear of the antenna; it also covers the RF coupler and the SMA connectors toward the RF cables. The active face of the antenna is painted in white. No active thermal regulation is needed on the antenna.

The transitions to wave guide are thermally decoupled from the 3POD's base plate but remain covered under the same MLI protection as the remainder of the base plate. Under worst cold case scenario (or survival), they require heating provided by heaters of 1.4W each.

Finally, the main challenge behind the RF sub-system thermal design resides in the heaters enlaced around the RF cables. Indeed the RF cables are not covered by any passive thermal protection since they would reach too high temperatures in operating mode. Therefore under certain conditions (worst case cold or survival) the cables require small heating power (about 0.75W each). This technology is currently being developed by AXON and is undergoing tests.

7 CONTROLS AND COMMANDS

7.1 3POD Piloting Modes

The APS functional modes can be separated as follow:

- Folded mode/configuration: during launch, the APS is folded and held by the HDRM, the actuators are not powered (see. Fig. 4, left).
- Stand-by mode/configuration: the APS is deployed into its reference state called the standby mode (see Fig. 4, right). It consists of the position pointing toward the nadir direction. The APS is stable in this position and all actuators can be turned off.
- Nominal tracking modes: within the movement modes we can differentiate the tracking or continuous pointing mode (RF power on) from the ground station transition mode (RF power off).

7.2 Piloting by pointing tables

The actuators of the 3POD are controlled in open loop. To reach a position the electronics "translates" the pointing order into three angle values at the base joint actuator. The equations linking the pointing vector to the base angles are well known but using simple driving tables avoids requiring intelligent electronics to calculate in board the complex relations.

The embarked memory regroups in three independent tables every pointing position of the domain. Each table is composed of an actuator angle value per azimuth and elevation coordinates (0.1° resolution).

The electronic architecture is based on a FPGA receiving the data at 8Hz from the Attitude Determination and Control Subsystem (ADCS); it then selects the appropriate position in each look-up table to translate the position into actuator angles. Finally it commands the stepper motors through classical drivers.

For nominal tracking in "continuous pointing", the APS follows the command at the required speed and selects an acceleration profile to minimize the induced jitter. For the transition mode, the 3POD APS is piloted at maximum speed and is able to reach two opposite positions in less than 30 seconds. Finally the electronics system accounts for a degraded mode control used in case of failure in one of the actuators.

8 3POD ANALYSIS METHODOLOGY

8.1 3POD specificity

The 3POD linkage allows for three degrees of freedom, controlled by three base joints rotation actuation. This complex linkage on a parallel robot architecture requires specific analyses to comprehend not only its kinematics but also the associated dynamic effects and reaction of RF harness, to properly size the elements of the mechanism. These analyses presented in detail here after are central to the development since the agility (ability to move at 5°/s) is a critical and essential feature of the APS.

8.2 Kinematic Analysis

The kinematic analysis addresses the study of the complex movement of the 3POD in detail, to evaluate the pointing domain. All throughout the design phase the global architecture was optimized for maximum domain of reach. The final design, assures a secured APM since every possible collision with moving parts is identified and sized mechanically; furthermore the possible singularities are controlled and eliminated by design. The final domain is +/-74° elevation and 360° azimuth (see Fig. 9).

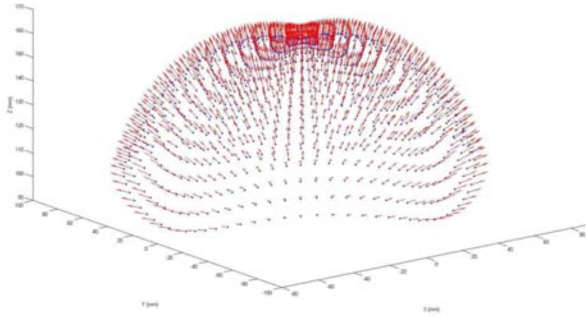

Figure 9 : 3POD reachable positions

The 3POD being a parallel architecture robot, the singularity phenomenon needs to be excluded by design. This was a major part of the kinematic analysis. The two types of singularities are characterized by tests on the 3POD Breadboard Model (BBM) and by simulation. The design proposes mechanical stops to exclude them from the pointing domain.

Another aspect of the kinematic analysis was to estimate the pointing precision of the APM. It includes the error due to the 3POD's mechanical characteristics (bearing default, flexibility, actuator precision, thermo-mechanical deformation, and manufacturing), but also the error induced by simplifying the controls through indexed tables. The precision of 1° is guaranteed.

Finally, the 3POD as a parallel architecture robot offers robustness to an actuator or bearing failure. In fact in this degraded mode, the pointing degrees of freedom (azimuth and elevation) are maintained but on a reduced pointing domain. The remaining domain after failure is dependent on the angle at which the motor or bearing is blocked. The final part of the kinematic analysis was to evaluate the degraded mode and its detection. As an example we can describe the case where a motor is blocked at 50°; in this case, 35% of the pointing domain is still useable.

8.3 Dynamic Analysis

The aim of the dynamic analysis is to provide a reliable torque budget calculation at actuator level to verify the ECCS motorization factors. It takes into account efforts applied on the 3POD (friction, RF harness, dynamic, S/L agility), using multi-body simulation on MSC ADAMS [4]. The model used is a fully configurable 3POD model, where only the bearings are flexible elements.

Special care was taken to implement on the model the effect of the RF harness on the 3POD. The harness was modeled with nonlinear finite element (FE) simulation by IMPETUS AFEA (see Fig. 10). IMPETUS Solver® calculates the kinematic behavior of the harness (used in the Kinematic analysis) and the efforts transmitted to the 3POD by the movement (used in the dynamic analysis). The efforts are translated into analytical equations that also account for the effect of temperature and that are then implemented in the ADAMS model of the 3POD.

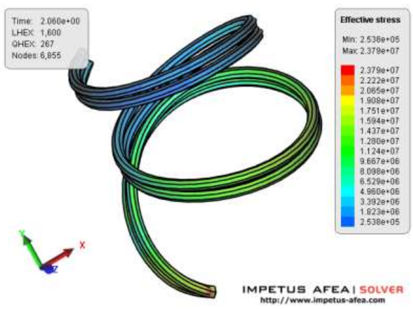

Figure 10 : RF harness Simulation

A sizing cycle, passing by every critical positions of the domain, was developed. The cycle was simulated on ADAMS without gravity, to size the motors in worst case mission use and with gravity to evaluate the behavior during ground testing. The simulation revealed that the RF harness is the sizing elements for the motor torque in orbit use.

To finish the dynamic analysis, the torque requirement obtained by the ADAMS simulation, is used in an actuator model under MATLAB/SIMULINK. It predicts and evaluates the precision of the actuator and the ECSS motorization factor. The model includes all the resistive torques seen by the motor (HD starting torque and friction, bearing friction, 3POD payload inertia and torque, motor detent torque…).

9 ANTENNA POINTING SYSTEM BBMS

During preliminary development phases several tests were performed on the APM and RF subsystems in order to consolidate the APS' Technology Readiness Level (TRL). The benefits of the APM architecture for agile low jitter are confirmed and AXON coax cables show satisfying performances.

9.1 APM Breadboard model

The BBM of the APM was integrated in 2010 at CNES laboratory by COMAT and CNES teams (see Fig.11) and was submitted to the following tests:

- **Kinematic characterization / ground operations:** the APM BBM (see Fig.11) validated the kinematic principle and supported the development activities particularly to characterize the APM's singularities. In addition, operating activities of the BBM helped identify the difficulties / risk linked to the APM operation under gravity for future AIT activities.
- **RF harness routing (**see §5.3 & Fig 5).
- **Vibration test**: the BBM without the antenna (see Fig.11) was submitted to a vibration test at flight levels (ECSS standards). It characterized the APM's dynamic behavior and validated the FE models' capability to reproduce the complex architecture.
- **Jitter measurements**: the torques and forces induced onto the spacecraft by actuating the APS were measured on the BBM equipped with a dummy parabolic antenna. The dynamic loads exported seem low compared to other mechanisms normally used on satellites even for agile tracking cycles (Pléiade application). The results are: Mz / Mt = 0.01N.m Fz = 0.015N & Ft = 0.03N. In addition to jitter measurements, these tests were used to support the development of the commands. They confirmed that the simplification of piloting through look-up tables has a negligible effect on the exported loads.

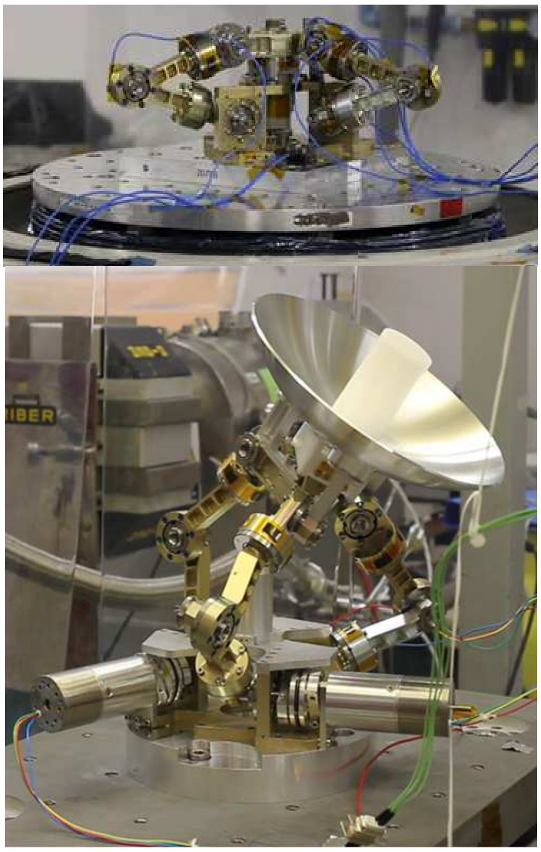

Figure 11. APM BBM in test configurations

9.2 RF coaxial cable elementary tests

Thermal elementary life tests (@ -70°C/+40°C) were performed on several AXON Axowave coaxial cables. Test specimens consist of coaxial cables mounted on a test bench with a relaxation loop. The minimal bending radius reached during a cycle is about 25mm (smaller than the APS RF harness needs. A total of 70.000 bending cycles were performed at CNES laboratory. No Axowave coaxial cables tested showed any sensitive degradation (neither mechanical stiffness nor RF TOS, phase shifting, insertion loss, etc).

In addition, power handling tests of Axowave cables were performed under vacuum at room temperature, with a 12,5W RF power for 360min without any degradation of the RF properties of cables.

9.3 Foreseen additional testing on RF harness

The coaxial cables and as RF harness are identified as critical for the APS development, additional tests campaigns are planned/being performed and results are not available for the present paper :

- **Thermal life-tests in cumulative environments for coaxial cable**: the aim is to assess the capability of AXON coaxial cables to undergo the entire environment of OTOS mission, including the cumulative effects of radiations, atomic oxygen, bending, thermal environment and vacuum. For obvious cost and test facility capacity, it will be performed at elementary scale.

- **Thermal life tests at harness level**: these tests are currently being performed by AXON on Engineering Models (EM) for temperatures [-70°C; +180°C].
- **RF Harness Power handling** in OTOS thermal environment: it will validate capabilities of the cables and connectors to undergo worst hot cases scenarios.
- **Precise RF harness mechanical characterization**: the aim is to validate / readjust the nonlinear FE simulations performed by IMPETUS AFEA using various configurations and thermal environments.

10 LESSONS LEARNED

Throughout the development phase many lessons learnt were set aside.

- ✓ All technical teams should be implicated early in the development for complex systems including mechanisms, electronics and RF subsystems. They can propose design modifications based on their own heritage/field of competence. Activities led on OTOS APS illustrate the benefit of the close collaboration between CNES, COMAT, AXON, COBHAM Antenna and EREMS.
- ✓ Planning early in the development phase for breadboards and elementary testing. In the case of the 3POD, the singularities testing on the BBM was essential to complete the kinematic analysis. The use of simulation tools is well adapted to evaluate known and controlled phenomena, but singularities or nonlinear movements, found for example on the RF harness, are by definition difficult to predict.
- ✓ When sizing a mechanism it is important to keep in mind the end use mission but also the testing on ground phase, this part of the mechanism's life time may propose other design challenges. For example, the main driver for the 3POD's motor torque is none other than the dynamic movement under gravity. The first step in the detailed design phase is to further assess the use of the 3POD on ground, by designing specific compensation tools and/or limiting the deployment.
- ✓ Controls and commands: despite the apparent kinematic complexity of the APM, driving laws can be highly simplified by close collaboration between mechanisms and electronics. The definition of the look-up table illustrates the interest of a close collaboration (CNES/COMAT with EREMS).
- ✓ The use of redundant components (e.g. 12 identical bearings and 3 identical actuators) simplifies the complex mechanism. This is necessary in an effort to maintain high reliability and for the system's industrialization in a competitive approach.

11 CONCLUSION AND DEVELOPMENT PLAN

The preliminary phase of the development is successful; it enables the detail comprehension of the 3POD specificities. The design is optimized to fit the OTOS application especially for thermal and agility requirements and proposes an APS with a large pointing domain free of singularities (+/-74° in elevation).

OTOS technological program plans a CDR of the APS before end of 2015 then to fully qualify the APS by the end of 2016. The qualification program includes the manufacturing and tests of an APS Engineering and Qualification Model (EQM) with an Engineering Model (EM) of the controls electronics.

The qualification plan includes:

- ✓ Qualification of the APS (incl. antenna and harness) and RF harness standalone, for mechanical environment and for lifetime under TVAC environment,
- ✓ Measurements of the RF signal on the APS.

Finally, it is important to add that the 3POD as an APM can be adapted to similar applications on other missions but also for other applications all together. For instance, a Ka-band Antenna payload is feasible; given some component modifications (the RF cables and actuators designs will most likely be revised). For example, the FE analysis has shown that the payload mass of 350g can be increased up to 750g without having to modify the structural design.

Furthermore, the 3 rotary actuators located on APM are specifically developed for this application, but can also be considered as a standalone mechanism. It can be used to motorize other systems or can also be replaced on the 3POD by off the shelf actuators if required.

12 ACKNOWLEDGEMENTS

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