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Coarse Pointing Mechanism Assembly for Satellite Interlink Experiment

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Abstract

Since 1975, MECANEX S.A. has been manufacturing components for solar array drives and mechanisms used in space applications [1]. In 1991, work was started in an early phase C (Engineering Model) on a Coarse Pointing Mechanism Assembly (CPMA) for the Semiconductor-laser Inter-satellite Link EXperiment (SILEX).

This paper deals with the history, the evolution, and the lessons learned from taking over a pre-design in 1991 to the delivery of last flight models (FM 5 & 6) in 1995.

Introduction

The objective of the SILEX project is to establish an optical link between a low earth orbit satellite (LEO) and a geostationary satellite (GEO), or two GEO satellites. The core of this system, developed by MATRA MARCONI SPACE (MMS) in Toulouse, France, is a very narrow laser beam (±4 μrad divergence) mounted in a 250-mm-diameter telescope [2].

The pointing, acquisition & tracking sub-systems, having extreme accuracy, are integrated close to the telescope in the terminal. For the purpose of the present paper, the terminal shall be called the payload. The payload characteristics have been presented earlier [1] and will not be addressed in this paper.

The payload is supported by a two-axis mechanism, the Coarse Pointing Assembly (CPA). The articulations allowing movement about the elevation and the azimuth axis are the Coarse Pointing Mechanism Assembly (CPMA), developed, manufactured, assembled and tested by MECANEX. These two articulations of very high structural stiffness, are bound together with an L-shaped bracket represented on Figure 1.

The global coarse pointing performances are as follows:

Kinematics	-	Angular coverage up to 200°
	-	Angular velocity < 2°/s (< 0.2°/s for full performance)
	-	Angular acceleration < $0.02°/s^2$
Pointing	-	Two axis bias < 0.03°
	-	Two axis random < 0.01° (1 σ)
	-	Stability over 60 s (one axis) < 0.007° (p.p.)
Torque	-	Noise < 6.10^{-3} N•m (1 σ)

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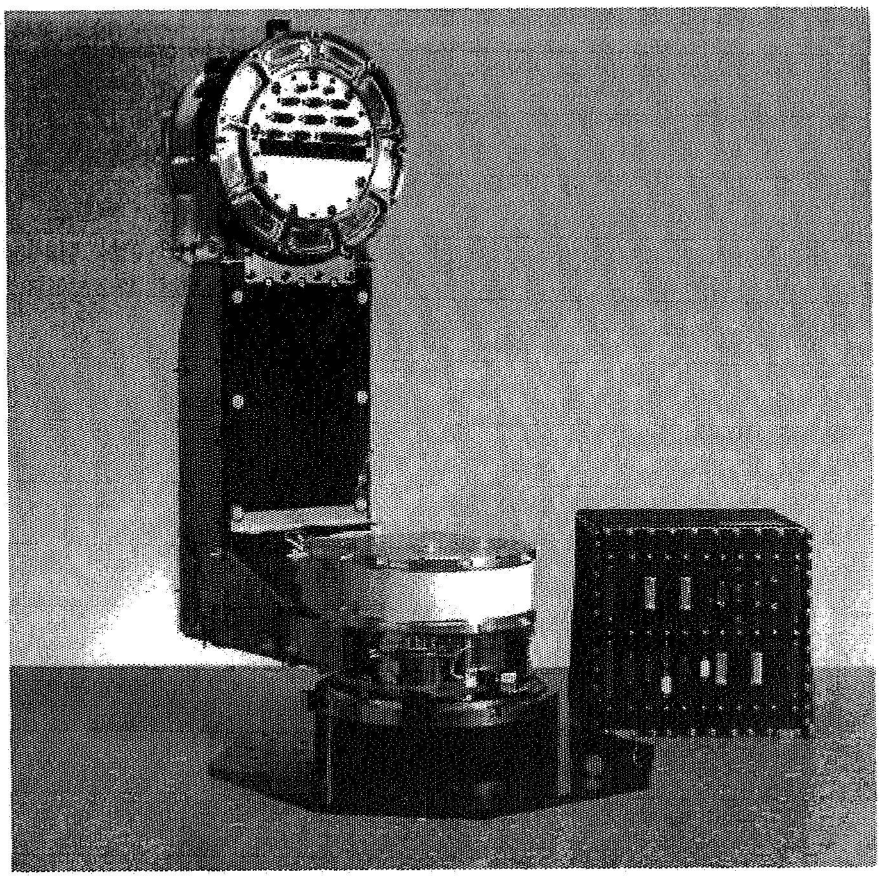

Figure 1: CPA: The two articulations (CPMA) are supported by the L-Bracket.

This paper presents details of the CPMA designed by MECANEX S.A. under a collaboration contract from MMS. The CPM Assembly is shown in Figure 2.

The characteristics listed above can only be achieved with a compact, rigid design. The torque and electrical stiffness of the motors must be high enough to guarantee not only the static stability in the satellite micro-vibration environment, but also the angular position reproducibility of an open-loop tracking, in spite of the torque disturbances generated by the ball bearing and the cable-wrap.

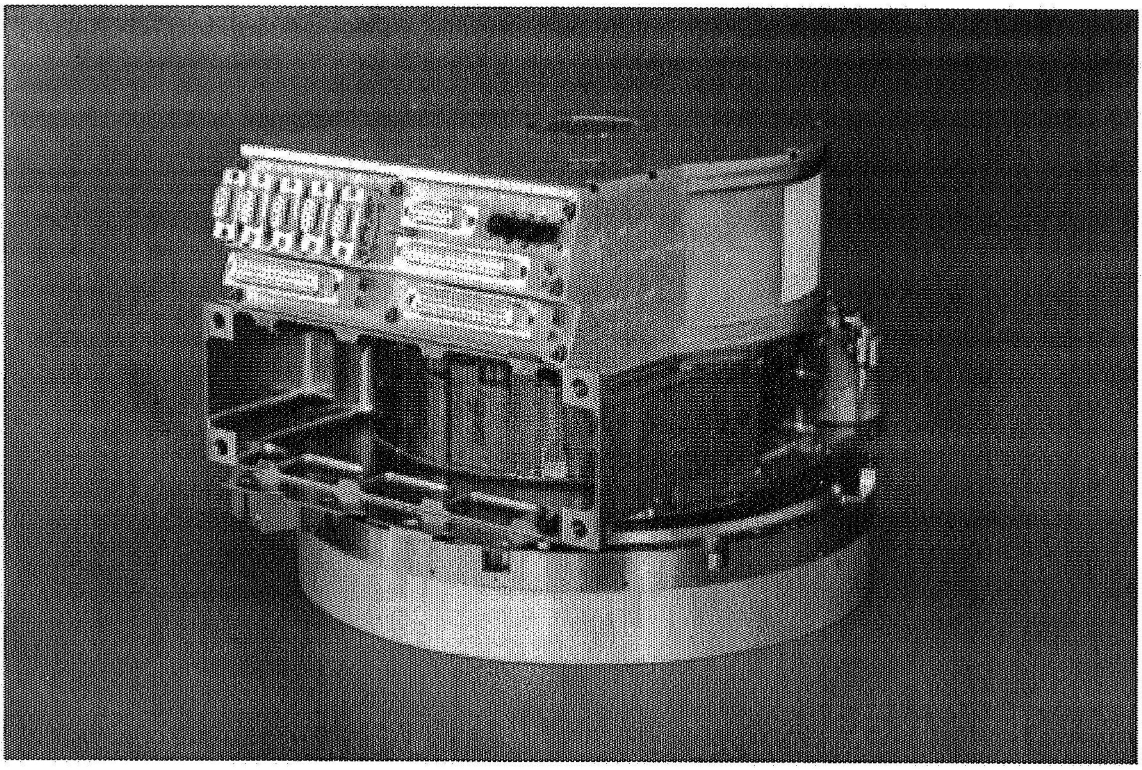

Figure 2: Assembled CPMA (Azimuth type): The connectors on the Overshielding box next to the Cable-Wrap are placed on the Housing structure. The Base-Plate is visible below.

The functions required for each CPMA unit are:

- Rotation actuation (motor)
- Blocking device braking capability
- Angular position sensing (encoder)
- Electrical status (position sensitive switches, thermistors, thermoswitches)
- End stops
- Electrical transfer to the terminal (Cable-Wrap)
- Temperature control (heaters).

Historical Evolution of the CPMA Design

The CPA concept is based on the IOC (Inter Orbit Communication) mechanism flown on EURECA, developed by MMS for an RF antenna pointing system. The direct application of the IOC device to SILEX requirements proved to be unsatisfactory. Important design modification had to be brought in the early C/D phase to take into account the new specifications. These are much more demanding with respect to pointing accuracy, electrical connection capacity, mass handling capability, mechanism mass and volume allowance, mechanical noise generation allowance, and thermal insulation with payload allowance.

The basic IOC architecture was preserved. An increase in the dimensions was necessary, however, with the corollary that the IOC concept, with respect to ball-bearing and Cable-Wrap torque, thermal behavior, mass, and volume had to follow this evolution. A complete analysis of the performance had to be undertaken, leading firstly to the complete re-design of the structure, secondly to the introduction of an improved thermal control, thirdly to the design of a new Blocking device concept, and finally deep re-work of the Cable-Wrap with all the connection scheme. The development of a representative bread-board model was decided late in phase C/D. This proved to be extremely beneficial to the overall model refinements. Numerous performance and model verifications, as well as design adjustments could therefore be done before the final design was frozen.

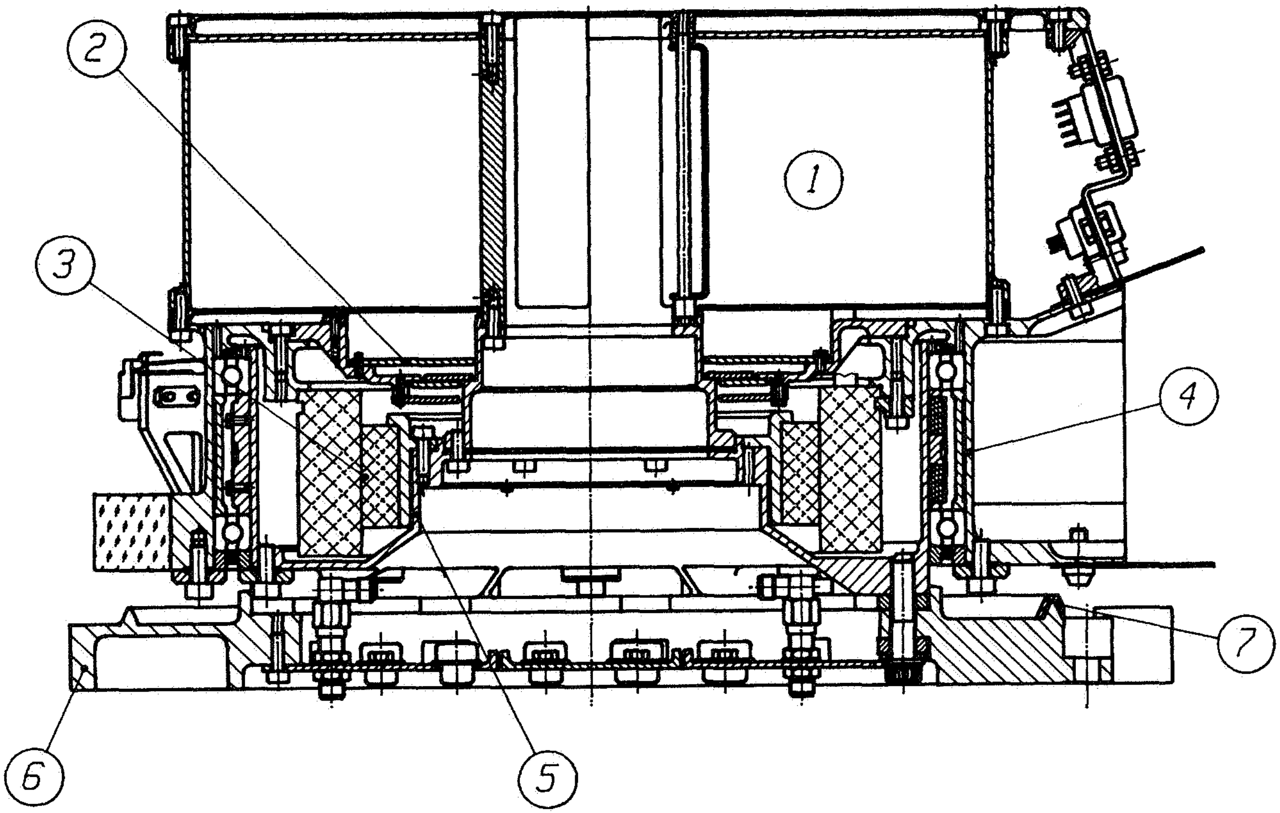

Figure 3: CPMA cross-section:

1: Cable-Wrap Housing
2: Encoder
3: Motor
4: Housing
5: Body
6: Base-Plate
7: Blocking-Device Castellated track

The carved walls (1.5-mm thickness) of the adapter are visible on the photograph.

A number of specific difficulties had to be overcome during the design and manufacturing of the parts. The most relevant aspects are discussed below.

Figure 3 shows a cross-section of the articulation. The main body, called Housing, is mounted on a Base-Plate with a pair of preloaded thin section ball bearings. The hollow shaft, called Body, allows the electrical wiring between connectors situated on the Base-Plate and connectors on the Housing side, through the Cable-Wrap. The wire connections and distribution to the connectors are in an Overshielding box. The motor and encoder are mounted inside the Housing. A lateral Housing adapter provides for the articulation fixation capability to the L-Bracket.

The main structural parts are made of beryllium, secondary parts of titanium alloy (Grade 5), while the non-structural elements are essentially aluminum alloy.

The mechanical design is particularly compact, thus favoring a stiff structure. The direct drive (without gear) imposes that an extremely accurate angular positioning is achievable by the motor. The coupling to the L-Bracket is also a point of concern with respect to the global stability of the CPA [2].

The compactness of the design leaves little room for additional features like the Blocking-Device, End Stops and Micro-switches. These elements are fixed on the lateral external part of the Housing, in the narrow groove between the fixed and rotating parts. The heaters surround the Housing at the level of the bearing. A white-painted radiator allows heat evacuation from the Cable-Wrap shield box.

Structure

The necessity for a very low weight imposed the use of beryllium for the structural parts. The high Young's modulus of this material is also favorable with respect to the stiffness requirements. These two advantages, though essential, cannot override the many disadvantages attached to the practical application of this metal in complex structures, i.e.:

- The metal although innocuous in simple handling, presents toxicity when inhaled in small particle or vapor form; this prevents all possibility of in-house machining. Very few equipped workshops with the capacity to produce complex accurate mechanics are available. In this project, the company SAGEM (France) was selected. The sub-contracting of machining implies complete definition of the design, which is not necessarily possible at a prototype level. The procedure for modification is complex.

- The metal production is based on sintered powder technology. The raw material quality is strongly process dependent, and irregular machinability has been encountered in different material batches, even though the material mechanical properties were within the specification.

- Most of the Housing and body structure was carved to leave walls of only 1.5 mm in thickness as can be seen on a detail photograph of the Housing on Figure 3. The brittleness of the material associated to such dimensions makes the structures sensitive to local shocks. Fractures of the walls may likely happen, leading to the discarding of the piece as reparation is not recommended on structural area.

Some difficulties have also been encountered in adhesive application on beryllium. Though excellent adhesion may be achieved when the surface is properly treated followed by quick application of the adhesive, inappropriate bonding was also obtained when the application was done on freshly cleaned surfaces having formerly experienced several months of exposition to air. The type of adhesive may also be a sensitive element for bonding on beryllium.

The above drawbacks of this material makes its use extremely expensive and penalizing with respect to planning. We would recommend to use it only when its unequaled mechanical and physical properties are unavoidable; simple shapes with as little machining as possible should be a design driver.

The Aluminum-Lithium alloy could be an interesting alternative to light structural materials. The scarcity of application in space applications makes its availability somewhat problematic, however, more interest should be given to this material of high technological potential.

Ball Bearing assembly

A very sensitive element with respect to stiffness lies in the ball bearing assembly. A large diameter (o.d. about 200 mm) and separation (about 30 mm) was adopted here. The two spacers' relative lengths should be adjusted with an accuracy better than 1 µm to control the rigid preload within 10 %. The thermal constraints implies that the spacers, Housing and shaft must be of the same material, i.e. beryllium. The preload adjustment was thus realized by the manufacturer (ADR, France) on a tool on which the bearings were assembled with the dedicated spacers. Integration in the CPMA was later done at MECANEX.

The pointing performance is particularly sensitive to torque noise. Very special care had to be given to the track grinding finish and to the dust control. A dedicated tooling had to be devised to record torque noise under nominal preload in production, before integration.

Fluid lubrication was adopted here to help achieve the low mechanical noise requirement. Oil impregnated reservoirs placed on the spacer between the two ball bearings assure that the lubricant will last over the full life of the articulation. Anti-creep barriers was also applied to prevent oil depletion and pollution towards the optics of the terminal.

The handling of lubricated parts implied the participation of 5 contractors, which made the cleanliness control of the bearing a perilous task.

Motor

The CPMA is equipped with a SAGEM motor of the series 57 PPP. The record of micro-step angular deviation was recorded over a full revolution to allow the necessary pointing compensations.

The rotor and stator were assembled by MECANEX at the same time as the ball bearing. No particular difficulty was encountered during this integration thanks to an adequate tooling providing a rigid guidance to the concentric elements.

Encoder

The 10-bit optical encoder was developed and produced by CODECHAMP (France). It includes the optical masks, the opto-electronic elements, and the drive electronics all mounted within the CPMA. The criticality of parts alignment and availability of tooling imposed that the mounting, adjustment and control be done at the producer's site. Although this procedure was technically the best suited, it was cumbersome administratively (custom, transports).

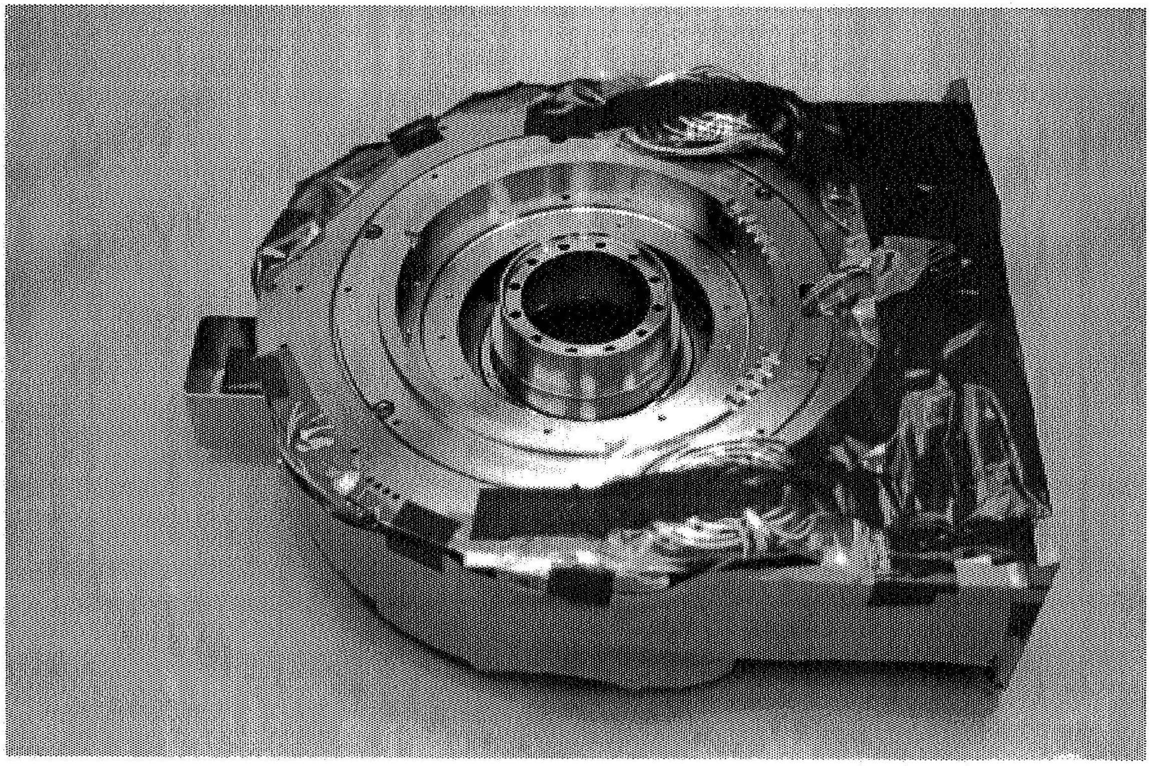

Figure 4: Top view of the Housing sub-assembly prior to encoder integration

Figure 5 shows a top view of the Housing sub-assembly prior to encoder integration. The motor and encoder wires, routed to the Housing adapter (lower part of the picture), become completely covered by the Cable-Wrap in further assembling steps. The high integration level of this design prevents any easy access to internal parts after integration. Servicing being generally not part of space requirements, this configuration is acceptable here; preference has been given to compactness.

The main difficulty of a totally integrated concept arises on sub-system control level as wire routings cannot be traced from beginning to end. A special testing procedure of the encoder at first power-up following final integration has to be set-up to make sure that no overload would be applied on the electronic parts, should a wiring mistake be present.

Cable-Wrap

Over 60 twisted pairs of wires (shielded and unshielded), two coax and 1 bonding strap were concerned in one Cable-Wrap execution. An angular coverage of nearly 200° was necessary (Figure 5).

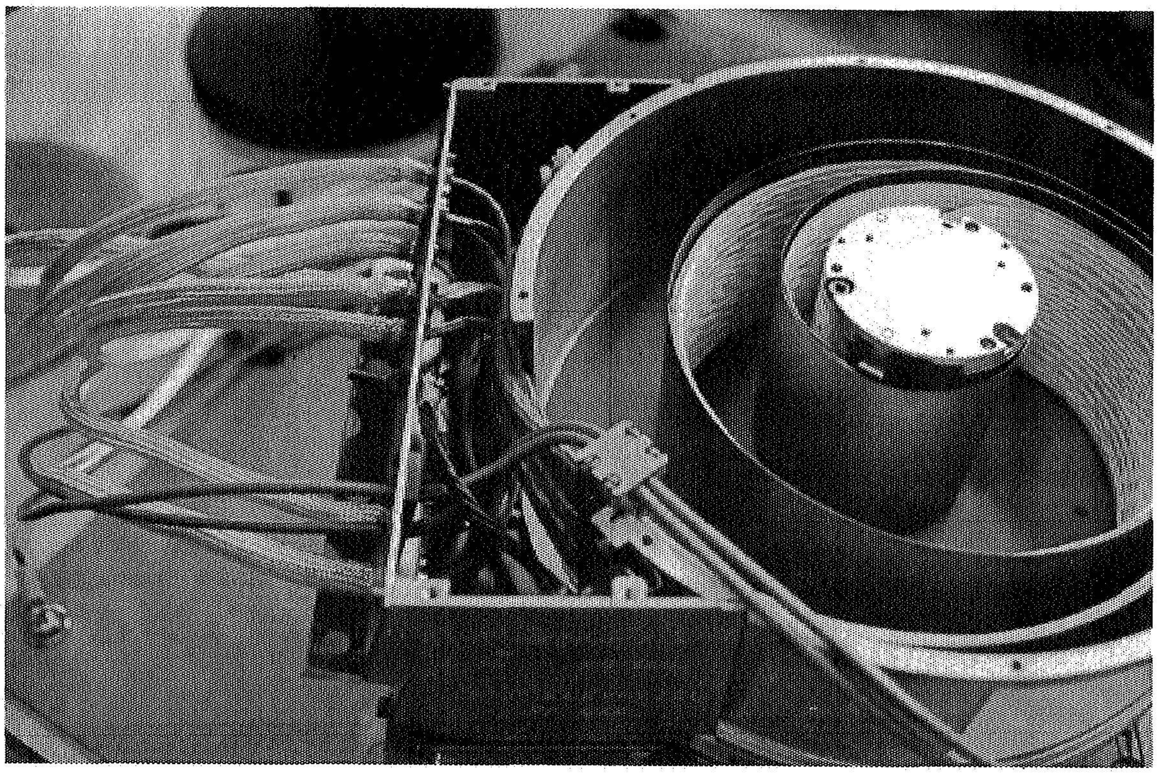

Figure 5: Top view of the CPMA without its cover. The flex cable and bonding sheets fixed on the central rotating drum are visible.

The action of a torque on the rotor generates de-pointing. The maximum acceptable resistive torque from the Cable-Wrap, ball bearings and motor resistance is of the order of ±0.25 N•m. The soft nature of the Cable-Wrap does not allow rotation without generating friction under 1-"g" conditions. A special low-friction coating was applied for this reason on the upper and lower plates imprisoning the cables.

Furthermore, the presence of insulation material around the wires also favors friction losses. The development of a multi-layered spiral made of flat cable and bonding metal sheet assembly enabled meeting the requirements of minimum absolute torque (i.e., to control the zero-torque equilibrium position within a range of ±10°) and to limit the hysteresis under 1-"g" to an acceptable value. Careful cable and cable sheet stiffness evaluation gave inputs to a model we developed from a theory of springs in watches, and implemented it to take into account the specific nature of the "soft" elastic element. A careful choice of the cable sheet length in the definition phase, and the adjustment of the spiral tension was done for each model (Figure 6).

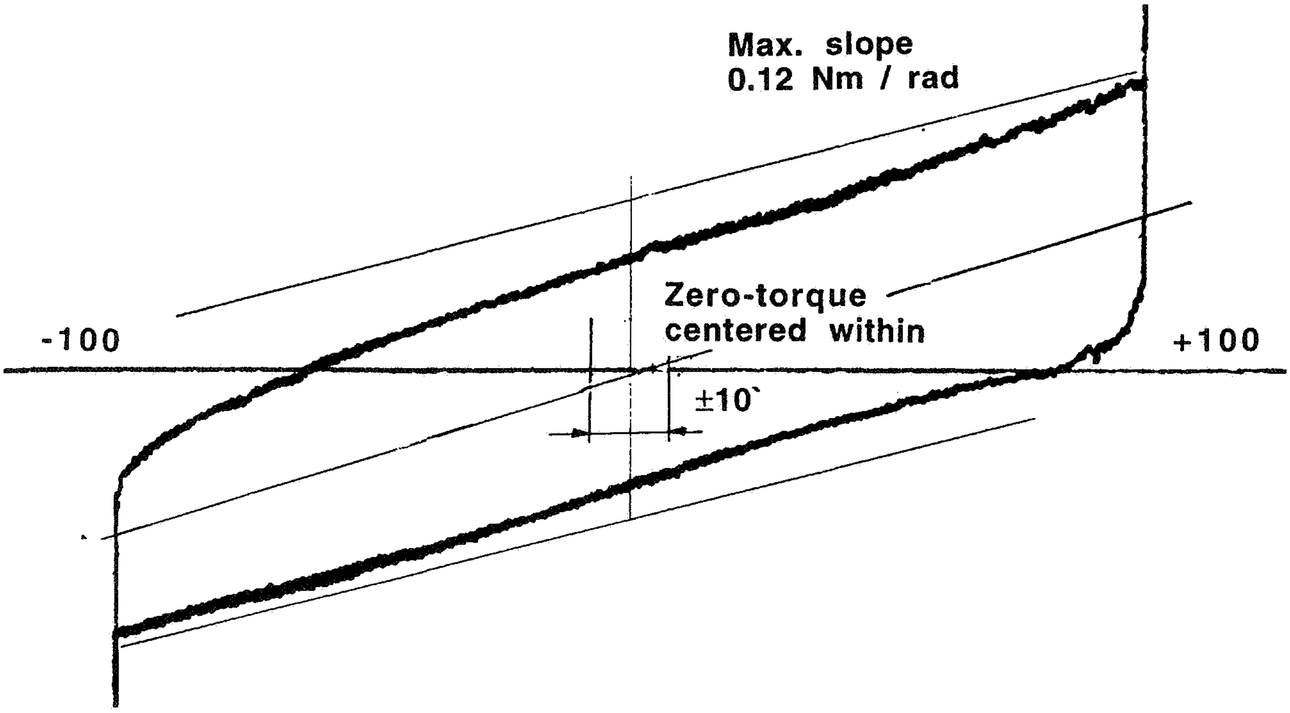

Figure 6: **Record of a full articulation cycle over the maximum range of 200°.**

Blocking Device

Immobilization of the payload in case of power interruption is guaranteed by a Blocking Device which has to provide a braking torque of at least 1.35 N•m. A reluctant electromagnetic actuator, developed and produced by ETEL, Switzerland, is used to hold a brake block against its counterpart without energy consumption, and to release the movement when powered (Figure 7).

Initially, the blocked position had to be achieved at any angular position; it is also in this state during the launch vibration period.

The first proposition to solve this question was to wind a belt around the mobile part; the brake action was done with an actuator pulling the belt. This solution was ruled out in the initial trade-off for lack of available room, difficulty to avoid any friction contact in the released state, and finally because of the relative low reliability figure of this solution which is a potential single point failure.

The first brake was designed as a VESPEL friction pad pressed on a toroidal track of beryllium with a triangular cross-section as shown by Figure 8a. Very satisfactory results were obtained in air where sufficient braking capacity was obtained and no jamming was observed. High vacuum tests however, showed a deficiency in braking capacity due to the collapse of the friction coefficient under vacuum. This material pair had to be rejected; the replacement of VESPEL by a harder material (hard anodic oxidation of aluminum) tended to jam in micro-vibration in spite of the increase of the triangular cross-section angle (formerly adapted to VESPEL friction coefficient); it was caused by the generation of beryllium dust in the friction zone (beryllium is not adapted to friction!).

The requirement of continuous blocking position was relaxed to a discrete one later in the project, allowing the replacement of the friction brake by a castellated track of titanium alloy, the blocking action being assured by a VESPEL diving core driven between the teeth; this last design has been successfully qualified. Figure 8b shows the principle.

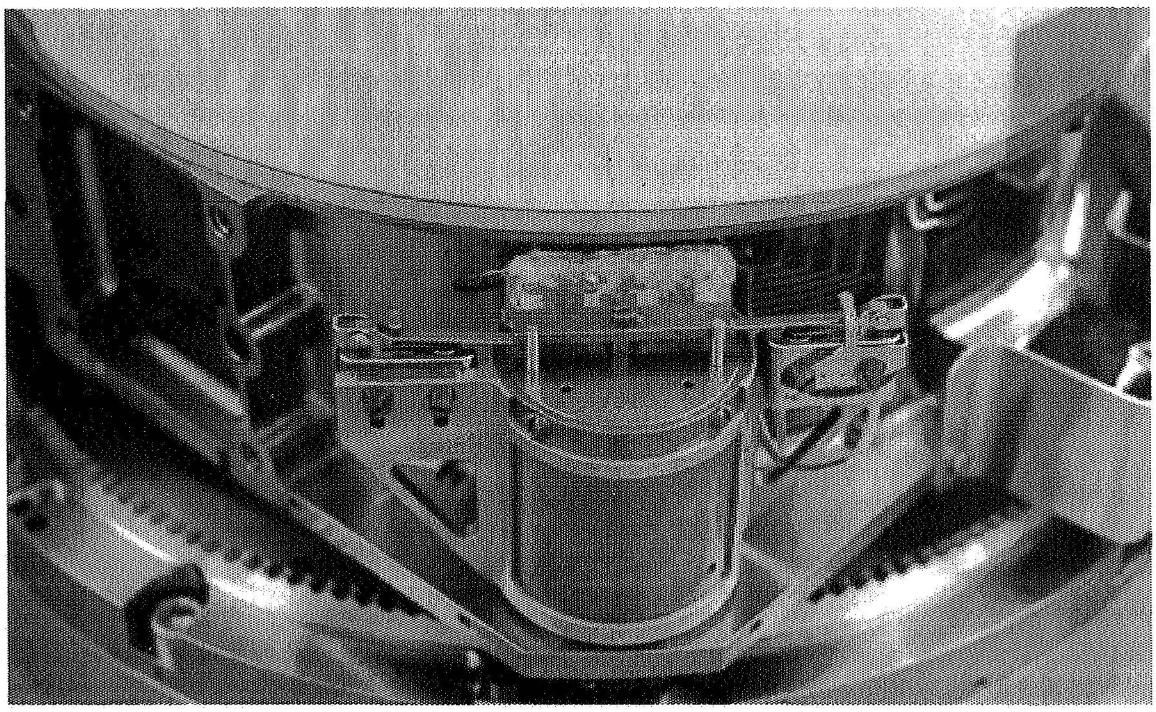

Figure 7: Blocking-Device actuator with a part of the castellated track.

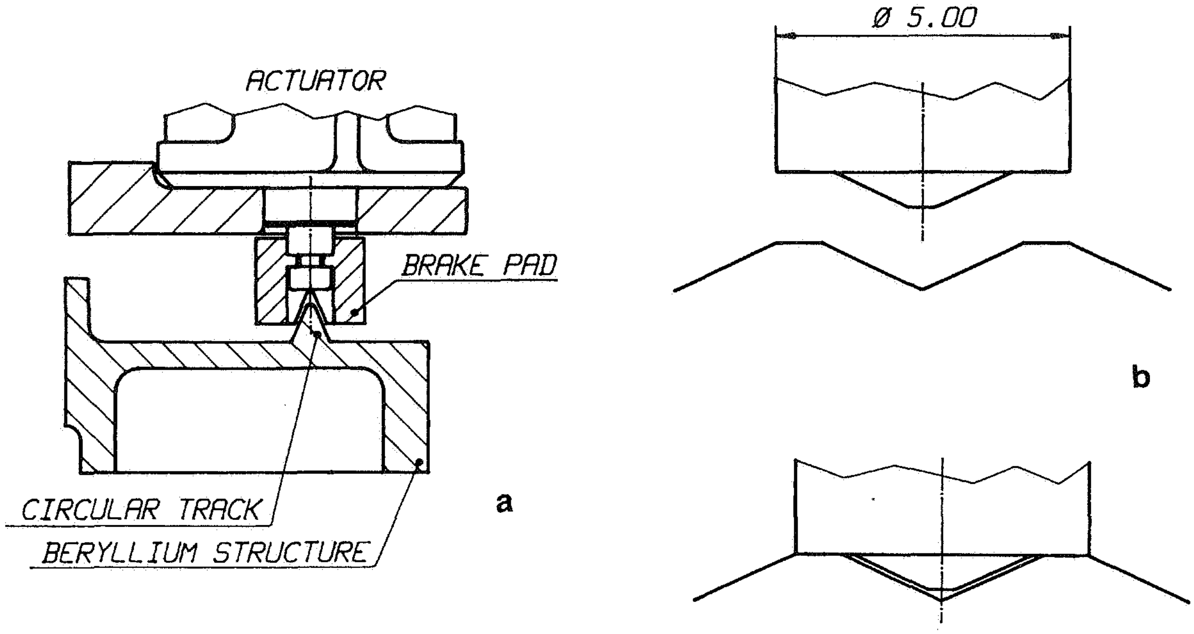

Figure 8: Blocking-Device braking elements:
a) initial design, b) final principle.

Conclusions

The search for solutions in the development of this articulation with very demanding specifications led to a number of lessons summarized below:

- Tribological phenomena, especially with non-conventional materials, are unpredictable. When the mechanism requires the friction coefficient working range to be bound by lower and upper limits, considerable care is necessary to assure a sufficient stability on this parameter.

It is recommended to avoid this situation by creating mechanisms whose function does not depend on friction, or, if not possible, to have only one limit (upper or lower) on the friction coefficient.

- The problems generated by material shipment (clean and shock-proof packages, customs handling, reliable transports), and by manipulation by well trained and competent people, but belonging to different laboratories obeying to different rules, imply important impacts on price and planning.

It is most advantageous to consider the mechanism as a unit sub-system, which should, in the largest possible extend, be completely assembled without transfer.

- The price increases drastically and planning is badly affected by late design verification and modifications. Analytical investigation cannot replace experimental verifications of the designed principles, especially when the effect of environment must be predicted for extreme accuracy conditions.

The early production of a bread-board model is highly recommended. Its definition should be as close as possible to the final one, though differences may advantageously be accepted to avoid impact of long lead item procurement and reduce the price of some parts. Testing of the breadboard must not be neglected particularly with respect to environmental constraints.

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