S12-37

Antenna Pointing Mechanism for ESA ENVISAT Polar Platform

504410
125126

J. Serrano*, J. San Millán* and R. Santiago*

Abstract

INTA is currently developing a two-degree-of-freedom antenna pointing mechanism (APM) as part of the ESA ENVISAT POLAR PLATFORM (PPF) program. This mechanism will drive a Ka-band antenna within the Data-Relay Satellite System (DRS) on board the Polar Platform satellite. The first mission using PPF is ENVISAT, which is expected to be flown in 1998.

This paper describes the main requirements, design, and test results of this pointing system, as well as the main technical problems from customer requirements and how those have been faced to achieve a final design.

Introduction

The performance of the PPF Ka-band antenna requires a fine pointing device to allow linking with the DRS Ka band and ground.

The APM for PPF (APM-PPF) (Figures 1 and 2) is a two-motorgear azimuth (AZ) and elevation (EL) gimbal system, which drives the 1-m antenna with a large pointing range. The mechanism is joined to a deployable boom, and the antenna is supported by a four-bar linkage to the platform during launch (Figure 3).

The (a) absence of an off-loading device, (b) the presence of external wave guides and rotary joints, (c) the large size of the antenna and its large motion range, and (d) the large antenna-boom distance produced high loads on the mechanism and drove some aspects of the mechanism to be designed according to strength/stress criteria for a proper structure.

A first EQM (Engineering-Qualification Model) has been already delivered to the customer after qualification tests. The unit passed all tests successfully.

Design Requirements

Main design requirements are given below. For each field, they are listed by the degree of difficulty found by designers in meeting them (1 means top difficulty). Also listed are any complications produced in meeting another requirement.

* INTA, Spanish National Center for Aerospace Research, Madrid, Spain

Operating and performance

1. Geometrical constraints (Figure 3):
   - presence of wave guides and rotary joints
   - large size of antenna and large motion range, which create an increased interference envelope
   - antenna COG eccentricity with respect to the top of the boom
2. Large antenna pointing ranges: ±165° (AZ), -30°/+90° (EL)
3. Long life: 10 years (88000 pointing cycles of 330°)
4. Mass limitation: 12.4 kg
5. Motorgear interchangeability
6. Overall pointing target: 0.070°
7. High number of cables (26 main + 26 redundant = 52) to be moved along the complete AZ rotation range
8. Pointing precision of 0.010° per motorgear
9. Antenna mass: 13 kg
10. Maximum speed: 4.2°/s
11. Maximum acceleration: 1.0°/s^2
12. Others

Environmental requirements
Key requirements are given below with the same criteria:

1. Stiffness for deployed configuration: 7 Hz
2. Random vibration levels of PSD_{max} = 0.125 g^2/Hz on 20- to 2000-Hz range (global RMS = 11.4 g)
3. Deployable loads: APM has to withstand loads due to on-orbit pyros
4. Shock: 60g in 0.5 ms
5. Motorgear operating temperatures: -40°C/+100°C
6. Sinusoidal vibration levels: 15-g amplitude on 10- to 100-Hz frequency range
7. Stiffness for launching configuration: 100 Hz

Mechanism Design

The mechanism consists of two motorgears (AZ and EL) joined by means of an L-shaped structure. The AZ actuator is joined to a deployable boom by means of a 1-m (3-ft) bracket, while the EL unit is joined to the antenna.

Figures 1 and 2 show the complete unit with no Multilayer insulation (MLI).

The motorgear concept is shown in Figure 4.

Bearings
The design consists of the following bearings: one preloaded output ball bearing pair that supports the encoder, the output shaft, and loads; one preloaded pair; and a deep groove, single bearing that supports the stepper motor and the gear input shaft.

All ball bearings are commercial 440C stainless steel for space applications and have vacuum oil-preimpregnated phenolic cages.

Encoder
One 16-bit absolute encoder, manufactured by CODECHAMP (France), is located on the output shaft. The encoder was customized to the housing.

Gear
One harmonic drive gear (type HDUC-20-BLR ratio 100), made of stainless steel, is manufactured by Harmonic Drive System (Germany). These gears were used because of their optimal reduction/mass ratio and previous in-house experience with these harmonic gears.

During the development phase, accelerated life tests were performed to assess gear performance with lubricants, as well as application procedures and controls. These tests included the application of gold coatings on contacting surfaces, but this process was decided to be excluded.

Due to the long-life requirements, the harmonic drive was customized to produce oil reservoirs (phenolic cages).

A harmonic drive (size 20) was selected to meet the torsional stiffness requirement of 7-Hz at the deployed configuration, since the 13-kg antenna COG has a considerable offset (350 mm) with respect to the AZ and EL motorgear axes.

Motor
The motor is a 23PP stepper motor from SAGEM (France). It provides a holding torque of 0.27 N-m. The stator and rotor are bonded to the outer case and shaft.

Motorgear Casing
The motorgear casing is made of Ti6Al4V, which provides a compromise between mass and thermal compatibility with standard elements made of stainless steel. The external case contains provisions for thermal hardware. The attachments and stop devices (mechanical and electrical) are different for AZ and EL (different motion range), so the unit was designed to contain all necessary provisions to be used as either an AZ or an EL drive.

To reduce loads on bearings due to different temperatures on motor shaft and outer case during thermal analysis, a thin membrane was used on the motorgear bottom.

Lubrication

Lubrication was one of the key requirements because of the long-life requirement (88000 330° pointing cycles). The first baseline considered the use of solid lubricant (MoS_2) for bearings and gear.

A preliminary life test showed the inadequacy of sputtered MoS_2 for gears and long-life applications. The test unit failed after about 7000 cycles (requirement was 88000). The backup solution, based on oil, was then considered. The oil selected was the ESA-qualified Fomblin Z25 from Montedison (Italy).

The gear oil lubrication was performed during motorgear assembly by local oil application on the contacting surfaces of the harmonic drive gears. Due to the criticality of this operation, oil reservoirs were foreseen for teeth mesh oil feeding.

The lubrication process included antispread application to avoid oil migration.

Thermal Hardware

The design considers heaters, thermal switches, and thermistors for thermal control. Heaters and thermistors are located on the motorgears external case, on the encoders, and the stepper motors.

Redundancy

Motors windings, encoder electronics, thermal hardware, electrical switches, and the harness are redundant.

Structures

The motorgears are joined by an L-shaped structure of 3-mm thickness. A support fitting (2-mm thickness) joins the AZ unit to the deployable boom. A bracket was designed to support one antenna rotary joint to the wave guides. All main structures are made of Ti6Al4V. Secondary structures are made of aluminum alloy 7075.

As previously explained, the structure design was faced with three main problems from the complex physical interfaces and reduced space available: (a) the large antenna-boom distance, (b) the large antenna COG offset wrt the AZ and EL axes, and (c) the presence of wave guides, rotary joints, and antenna envelope for the motion range.

These design constraints produced quite a large main structure (L-shaped) to be as light as possible, but stiff enough to comply with the stiffness requirements. On the other hand, the effect of transverse temperature gradients across the sections during operation led the design to include an MLI and to consider a 3-mm thickness to minimize the pointing perturbances. In spite of this, this remained as the main contribution to the APM pointing errors.

Cable Drum

Due to (a) the high number of cables coming from the antenna and EL motorgear and (b) the large motion range of the AZ motorgear, a winding device was implemented to:

- minimize the resistant torque of twisting 52 cables with thermal protection.
- control the cable motion during launch and operation to avoid possible damage to MLI or other equipment.
- control temperature of the cables.

The cable drum is made of aluminum alloy (1.5-mm thickness) to reduce mass and contains two slots for main and redundant bundles to be wound in opposite directions. This made cable resistant torque compensation possible. To allow a controlled winding, a flat cable was considered. The resistant torque was reduced to an almost constant torque of 0.150 N-m along the complete rotation range. The mass increase from the drum and cables was 1.2 kg.

Figure 5 shows the cable output from the cable drum.

Thermal Protection

The complete unit is coated with thermal protective coatings and an MLI on an L-shaped fitting to reduce extreme temperatures for hot and cold cases.

Structural Analysis

As mentioned before, due to the mechanism/structure duality of this equipment, a detailed strength analysis task was carried out. Along with a large amount of hand calculations, the final structural analysis of the mechanism was carried out by the Finite Element Model (FEM) technique. Figure 6 shows the APM FEM. The software used was MSC/NASTRAN, and the main analysis can be summarized:

- modal analysis
- vibration levels analysis (random, sinusoidal and pyroshocks), including a complete study of loads on the L-shaped fitting, support fitting, and motorgear cases, including bolts. Also, torques on harmonic drives and acceleration levels seen by electronic components were subjected to analysis
- deployment phase study to determine effects of antenna inertias on EL axis
- thermoelastic analysis to obtain pointing errors.

Testing

Test performed on EQM unit (qualification levels) are grouped below:

Functional
Motorgears were successfully tested, including the following:

- Pointing and backlash: mean values obtained were about 0.005° per motorgear
- Overall performance: speed, acceleration, motion ranges, and limit devices activation

Functional tests performed before and after the tests discussed below showed identical performance.

Environmental
EQM was satisfactorily subjected to the following tests:

- Sinusoidal vibration levels: 15-g amplitude on 10- to 100-Hz frequency range
- Random vibration levels with a maximum PSD = 0.125 g^2/Hz on 20- to 2000-Hz range and global RMS level of 11.4 g
- Shock: 60 g in 0.5 ms

Figure 7 shows the mechanism and fixtures for environmental testing.

Figure 8 compares predicted (FEM) and measured natural frequencies of the APM. The average difference is about 4%.

Life Test
One unit, including all the mechanical hardware (encoder and motors were excluded), was submitted to the following accelerated life test to check the performance of liquid lubrication on bearings and gears:

- accelerated life test, consisting of externally backdriving the unit with the following motion parameters: 10x maximum speed (120°/s), 100x maximum acceleration (88.5°/s^2), 1.25x pointing cycle (330°, 88,000 cycles). The gear was inspected after the test and showed no signs of wear. The starting torque and torsional stiffness were also checked before and after testing and showed identical performance. Figure 9 shows the test setup.

Alignment/Pointing Tests
Optical tests were carried out using laser techniques to check the following:

- motorgear axes variation along complete rotation range. Maximum orientation errors detected were about 0.008° for the worst axis.
- orthogonality between AZ and EL motorgears (0.030° constant along motion). This error can be accommodated by software during in-orbit performance.
- angles between AZ and EL axes wrt a fixed mirror cube on support fitting to establish the APM real pointing vector after mounting.

The test setup is shown in Figure 10.

Lessons learned

(a) As already mentioned, the imposition of severe geometrical constraints made the design extremely complicated because of the interference with other requirements, such as stiffness, adequate harness routing, mass, etc.:

(1) From the analysis, two local modes, at about 20 Hz, were predicted during launch due to the harmonic drive torsional stiffness, combined with the rotor inertia; the L shape (due to the presence of wave guides) of the interface fitting between both motorgears excited the AZ gear, thus producing theoretically high torques (above the gear capacity) on gear mesh due to the inertia of the gear input shaft (that tried to rotate at high speeds due to the reduction ratio). Although this phenomenon was detected during a development vibration test, and not during the formal sinusoidal test due to the existing damping, it was still an important concern.

(2) The presence of this L-shaped, thin structure (3 mm) produced the highest pointing distortions due to the temperature gradients along the cross-sections, even with an MLI as thermal protection (estimated by analysis).

The use of external wave guides and other geometrical constraints must be evaluated carefully from the beginning of the project because of the important design impacts.

(b) Interchangeability of both motorgears reduced cost and effort, but it required external location of all limit devices (electrical and mechanical) for easy mounting, since motion ranges were different for AZ and EL motorgears. However, an additional mass was necessary to locate all external provisions.

(c) The cable drum solution showed good behavior, which minimized the resistant torque of the cables. Different options were considered, and some of them tested. Inconveniences are a slightly more expensive solution and the additional mass.

(d) The liquid lubricant concept worked well. Even though a complete thermal vacuum (TV) test is pending for qualification, results until now are sufficient to eliminate lubricant concerns.

(e) Dry lubrication on gears (sputtered MoS_2) was shown to be inadequate for this application. Moreover, some key parameters, such as the layer thickness, are difficult to control.

(f) The absence of an off-loading device has produced high loads on bearings, thus leading to an increase in the size of the preloaded bearings and subsequently of motorgears, thus affecting the mass and operational performance (higher friction and noise). Although implementing an off-loading device would not have been an easy task, this option should have been considered in the first program stages.

(g) The presence of an external wave guide (delivered by the customer), made of aluminum alloy and joined to the main APM structure, has doubled the pointing error due to thermal distortions (estimated by analysis).

Conclusions

The results of the APM-PPF for the EQM show that the equipment satisfies the contractual technical requirements. However, formal qualification tests, as well as a TV test and TV life test, are still pending and will include the same tests that have already been completed for EQM.

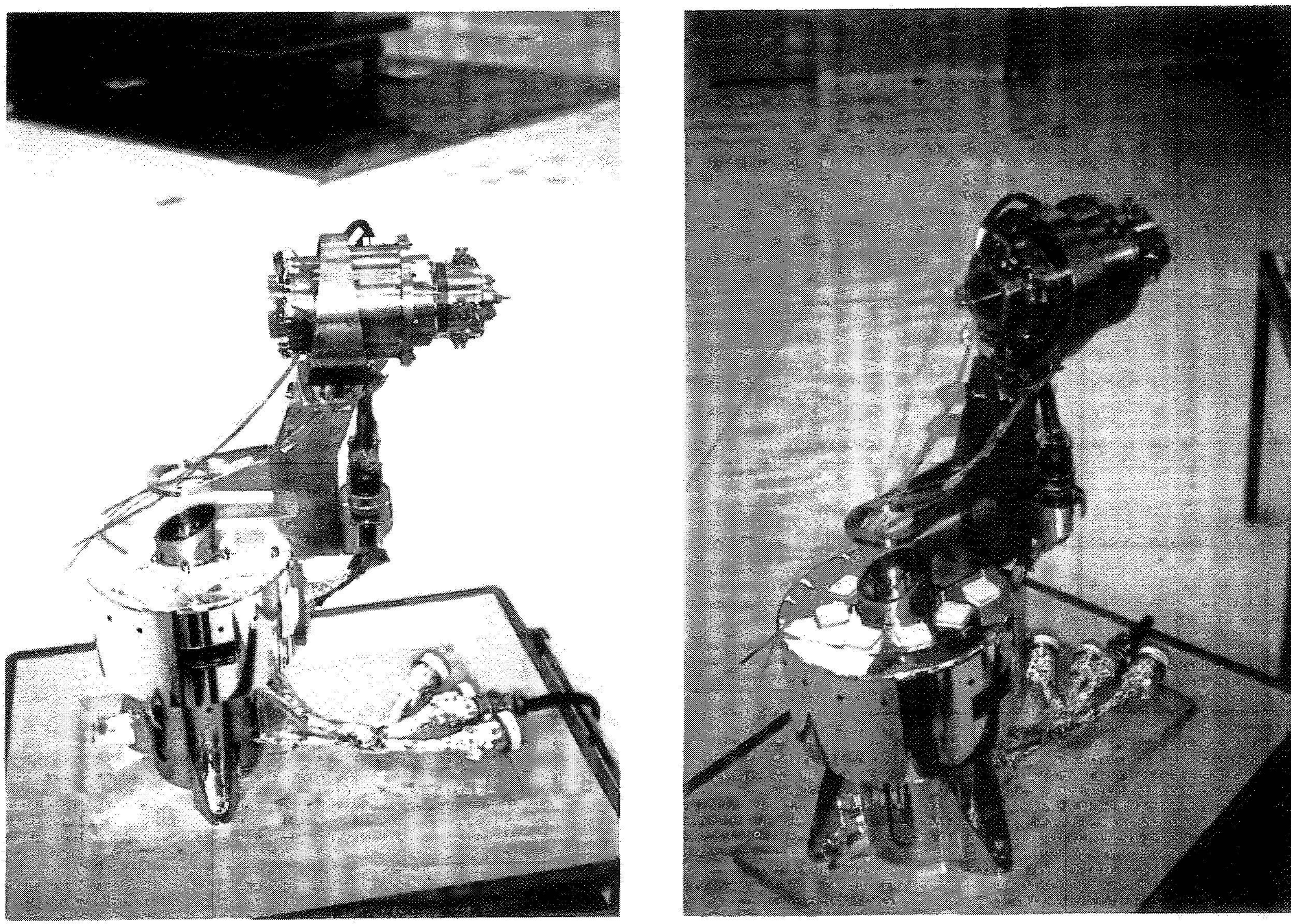

FIGURE 1: APM-PPF (EQM). Complete Assembly with no MLI

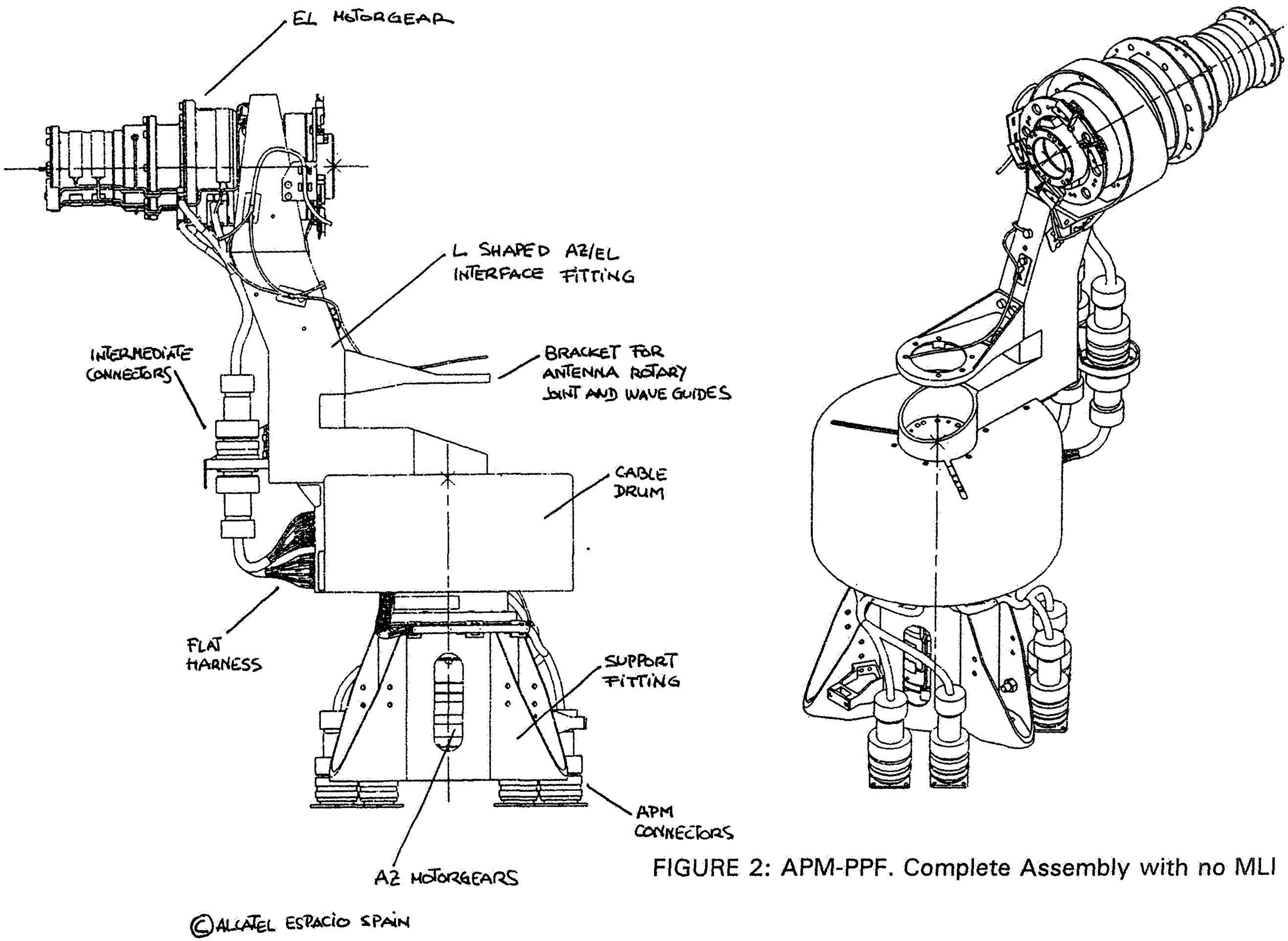

FIGURE 2: APM-PPF. Complete Assembly with no MLI

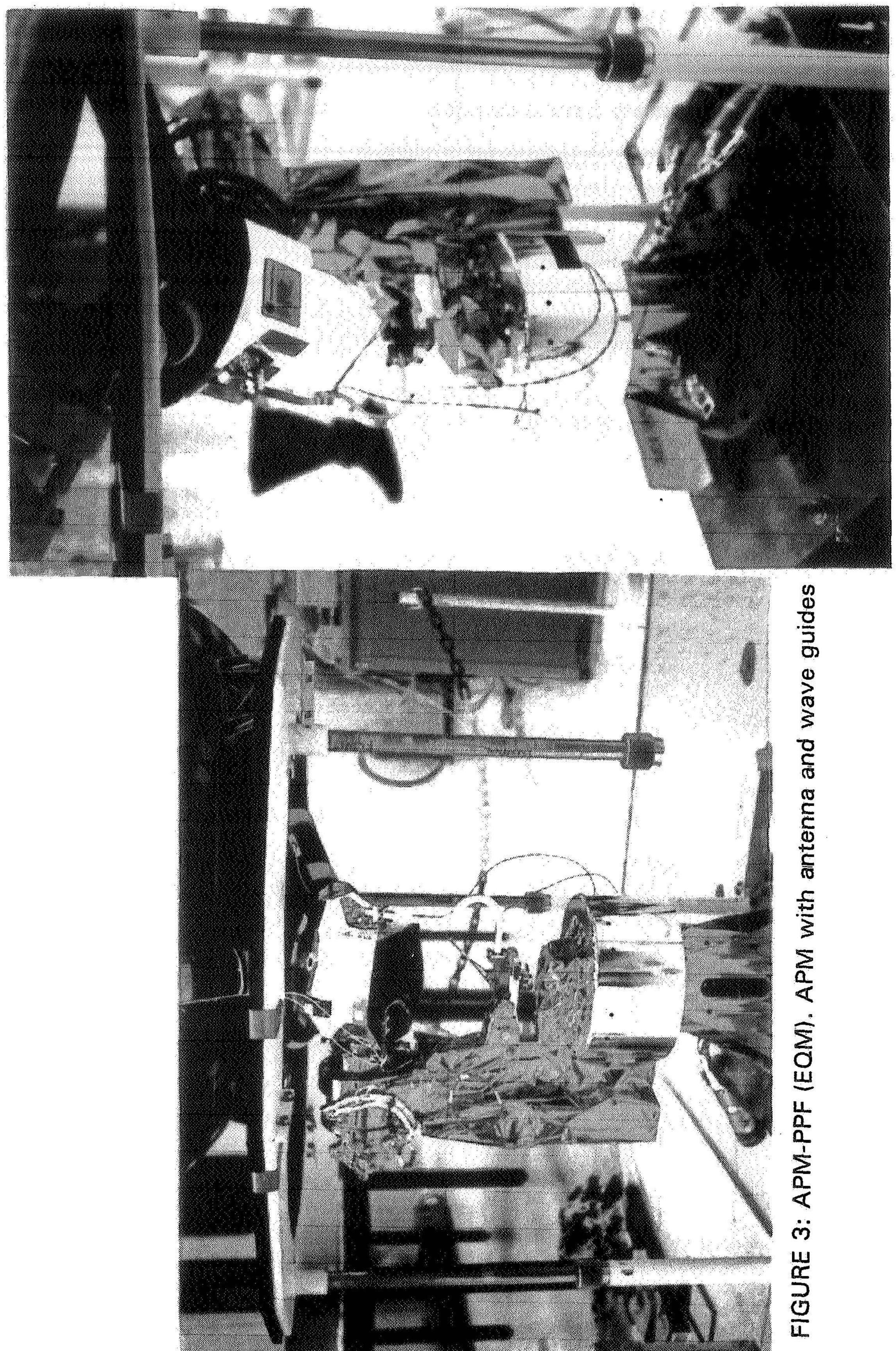

FIGURE 3: APM-PPF (EQM). APM with antenna and wave guides

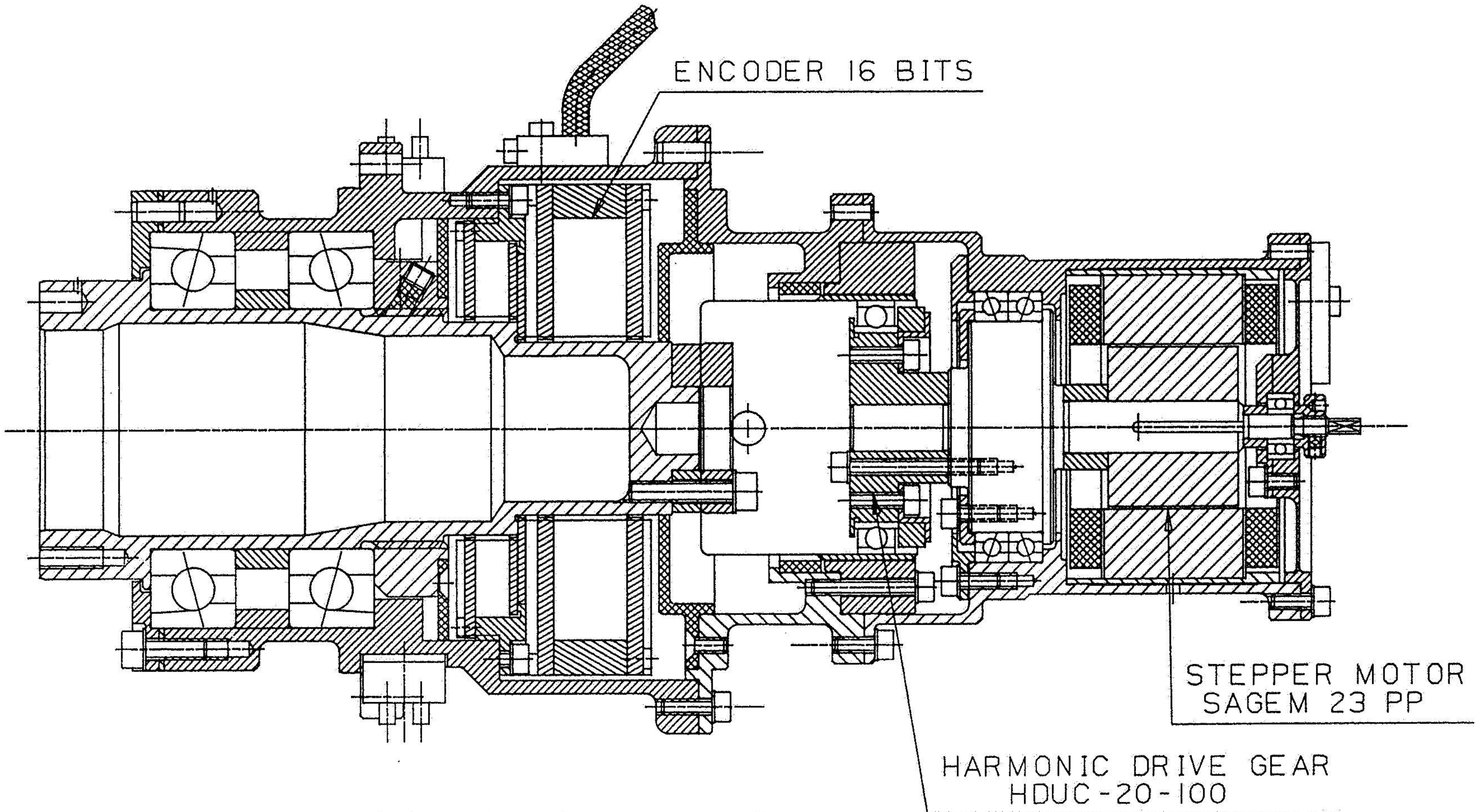

FIGURE 4: APM-PPF. Motorgear Concept

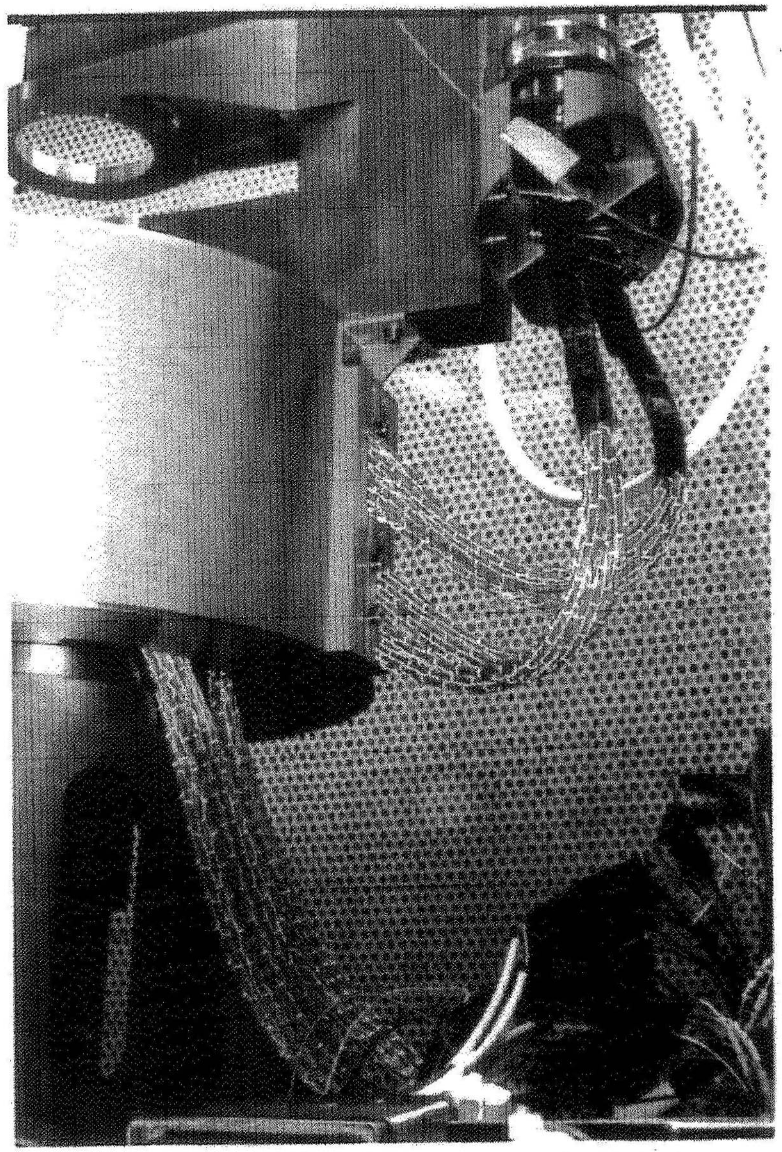

FIGURE 5: APM-PPF (EQM). Detail of Cable Drum

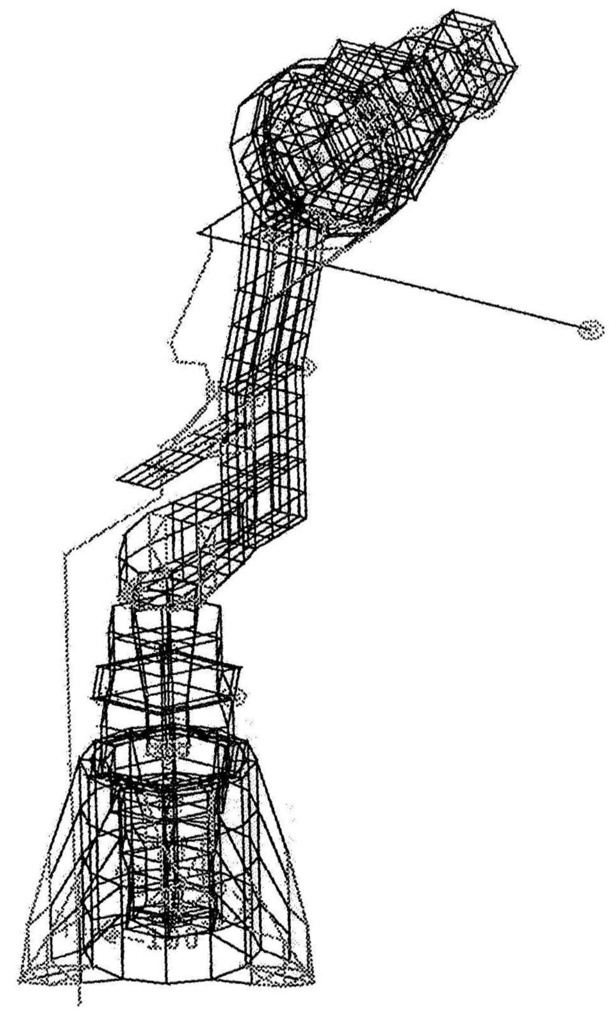

FIGURE 6: APM-PPF. Finite Element Model

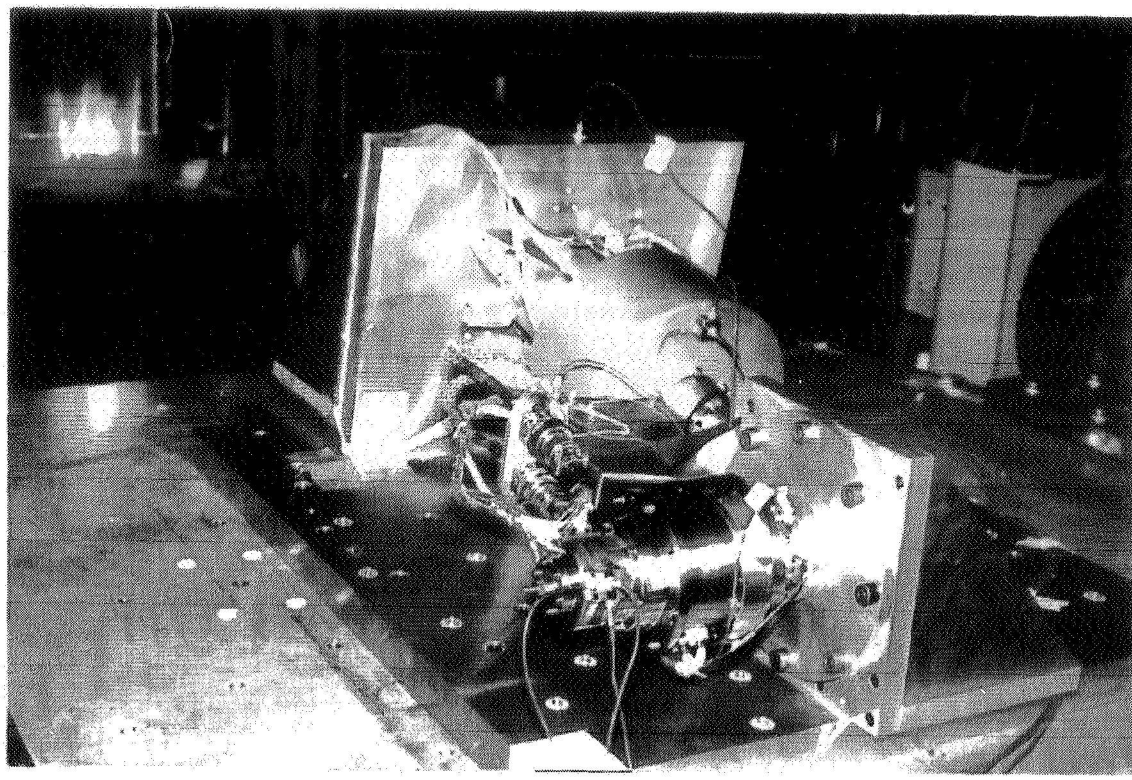

FIGURE 7: APM-PPF (EQM). Vibration Test

EQM TEST freq.	EQM FEM prediction	difference (%)
136 hz	143 hz	4.9
220 hz	205 hz	7.3
231 hz	230 hz	0.4
247 hz	246 hz	0.4
279 hz	274 hz	1.8
311 hz	329 hz	5.5
337 hz	367 hz	8.2

FIGURE 8: Frequencies Table

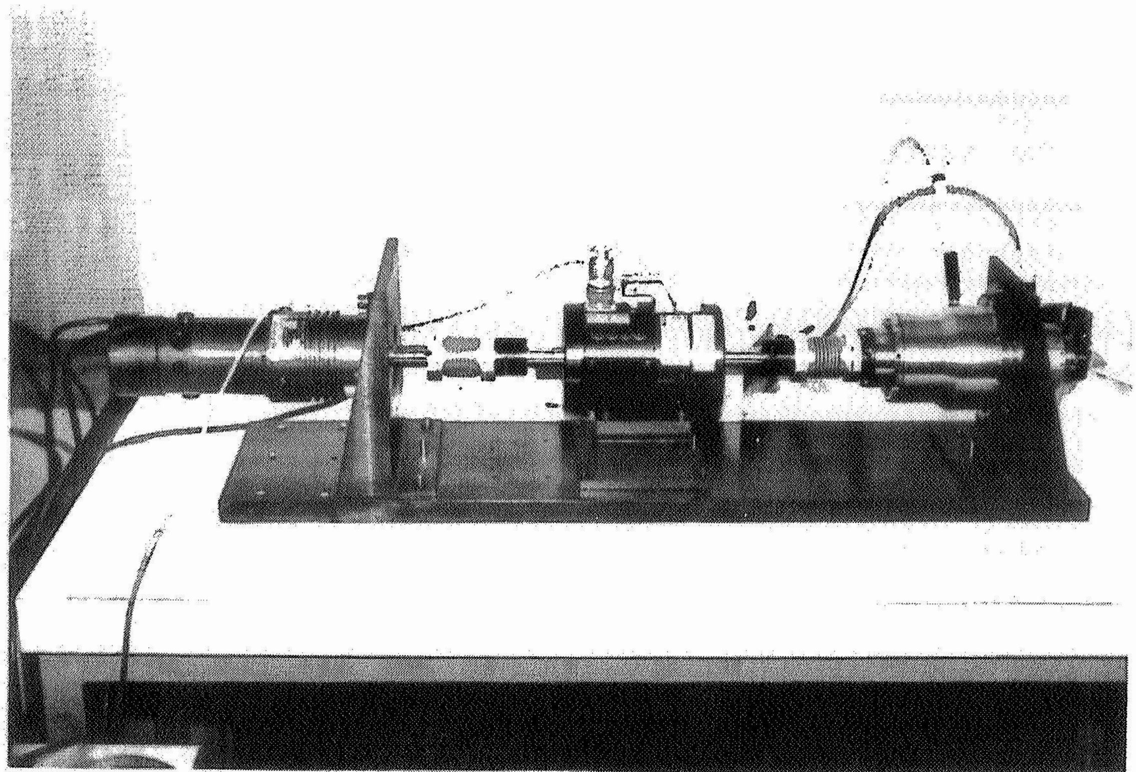

FIGURE 9: APM-PPF (EQM). Accelerated lifetest

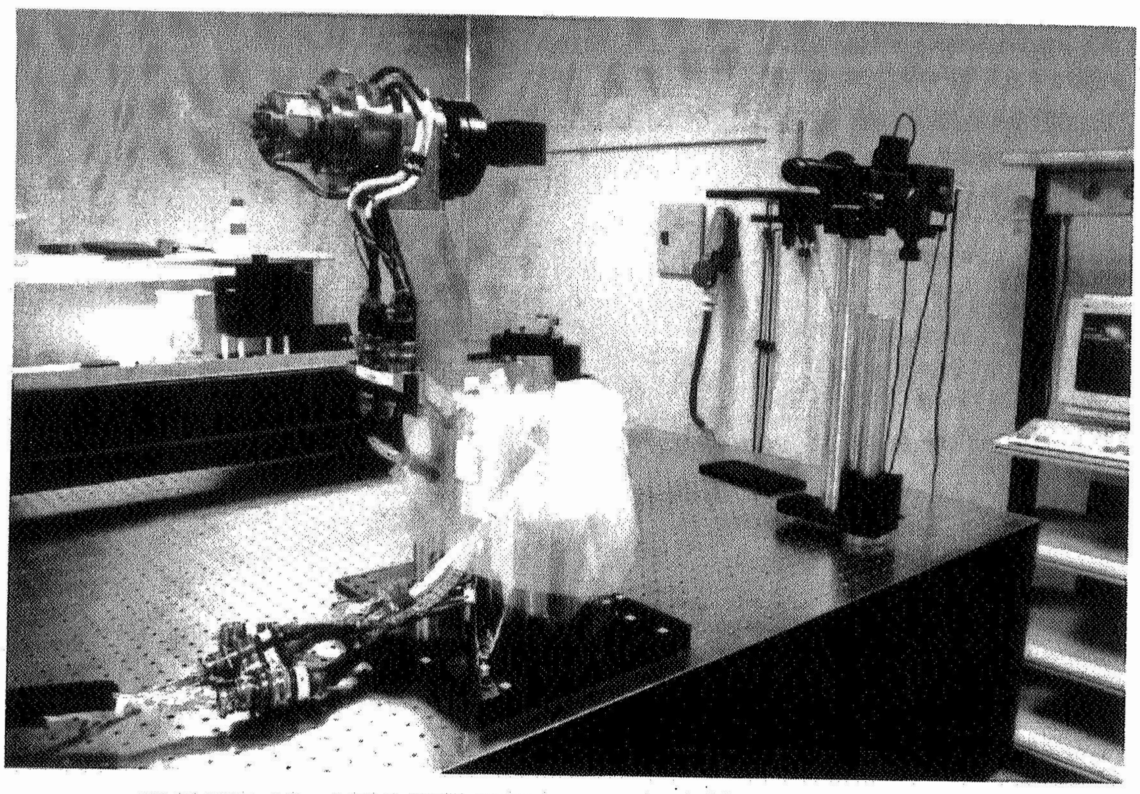

FIGURE 10: APM-PPF (EQM). Optical Measurements