SPACE TELESCOPE - SOLAR ARRAY PRIMARY DEPLOYMENT MECHANISM

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ABSTRACT

This paper describes the requirements, the design, and the test program which has been carried out in producing the Space Telescope Solar Array (STSA) Primary Deployment Mechanisms (PDM). The PDM will be used to rotate the rolled solar array supporting boom from its launch position alongside the telescope housing, through 90° to its use position. After five years in space the array is to be re-rolled and by use of the PDM swung back to its stowed position alongside the telescope housing for capture and return to earth via the Space Shuttle.

INTRODUCTION

A Primary Deployment Mechanism powered by redundant stepper motors is developed for the primary deploy and stow operations of the Space Telescope Solar Array. The mechanism must lock the array boom in the deployed position and have the capability of releasing the boom at the end of mission for restowing before capture and earth return via the Space Shuttle. Due to a continual growth in the design load of the PDM a condition was reached where the system exhibited instabilities. At this point in the program a redesign was made introducing a planetary gear train between the motors and the primary level arms. This resulted in a very stable system allowing for even more increase in system load if required. Three flight models (two flight and one spare) were produced and successfully tested (see Fig. 1). Acceptance testing, besides ambient operational tests, included vibration and thermal vacuum tests with operational testing being included in the thermal vacuum environment.

SYSTEM REQUIREMENTS

The PDM has been developed to comply with the following basic requirements:

- withstand Shuttle launch and return operations.

- withstand a five year orbital lifetime.

- stiffness in the stowed position to be compatible with an overall first resonance frequency above 25 Hz for the complete array. Stiffness to be at least equivalent to an EI of 3.6×10^4 Nm^2. This requirement shall still be met after five years in orbit and return to earth.
- deploy and stow rates less than 1 deg./sec. with full deploy or stow in less than 20 minutes.
- an astronaut manual override is to be provided for in-orbit contingency operation.
- each articulation to be positively driven through its angle of rotation.
- capable of five years inactive deployed condition in space followed by correct response to restow commands. The system is to be capable of 50 operations in-orbit after the five years of inactive lifetime.
- the array boom is to be independently locked in the deployed position with release for restow by command, or manually (by astronaut) to permit array retraction.
- ground operation, powered or by hand, shall be possible using a zero-G simulator.
- command capability with either or both motors of the forms:
  - start - continue deploy
  - start - continue stow
  - stop
- redundant μ switches shall signal deployed position.
- redundant temperature measurements will be made at each PDM hinge.
- passive thermal control shall be used.
- thermal control design limits of +65°C and -40°C.
- system reliability for the first two years of operation is 0.9999 and no single point failures which will endanger telescope recovery or affect astronaut safety.

PROGRAM SEQUENCE

The principal tasks for this program were:

- interpret the system requirements and formulate several alternate solutions.
- derive a system concept through trade-off studies.
- identify areas of technological risk.
- develop a "bread-board" model with sufficient fidelity to determine and study potential problem areas.

- produce a high fidelity development model of the mechanism, an accurate dummy load and a zero-G test jig.
- perform parametric tests to determine system limitations:

  In parallel with the above an intensive research program was carried out to establish a satisfactory bearing lubrication system.

  Additionally, a qualification model was manufactured and successfully passed qualification level testing.

  Finally, three flight level models were manufactured and each successfully passed the acceptance test program.

SYSTEM SELECTION

In selecting a suitable drive system several concepts were developed to sufficient depth to allow for a trade-off study to be carried out. The system finally selected for development consisted of redundant stepper motors driving an array support boom by a pair of primary and secondary lever arms. This system displayed redundancy with no single-point failures. Other systems investigated included worm drives, universal gear drives and a harmonic drive system.

During the progress of the development program the driven load increased until a point was reached at which the system exhibited a tendency to become unstable. At this point the specified load had reached twice the original estimated load. A further study was made which resulted in the addition of a set of planetary gears located between the motors and the lever arms. This restored system stability and the system subsequently passed all test requirements.

TECHNICAL DESCRIPTION

The PDM assembly consists of the following principal components:

1. Support Bracket
2. Boom Fork
3. Boom
4. Motors
5. Motor Housing Assembly
6. Motor Housing Support Assembly
7. Planetary Gear Assembly
8. Lever Arm System
9. Deployed Position Holding Clamps
10. Deployed Position Microswitches
11. Thermistor Installation
12. Wire Harness
13. Manual Drive System
14. Cover Plates
15. Thermal Control Provisions.

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Motors

The drive motors for the PDM consist of two stepper motors. The motors are independently powered, only one motor being used in a normal operation with the second motor being provided for redundancy. The two motors are mechanically connected together in a housing with the rotors driving the primary lever arms through a planetary gear system. The stepper motor will rotate through approximately 624° in rotating the boom through approximately 90°. This operation requires about 2080 steps giving a step resolution of 0.045° (2.68 min). With a step frequency of 4 Hz the total time for deploy or stow is approximately 8.5 min. The stepper motors are powered with a nominal 360 ma ± 10%. The PDM has been successfully tested with a minimum current of 310 ma.

Motor Drive Assembly (see FIG. 2)

The stator from each stepper motor is installed into a motor housing unit and positioned with an alignment pin. Alignment between two two stators is achieved by means of control screws rotating each stator to obtain a position of maximum torque. The rotors of the two motors are bolted to the shaft of the drive unit. Non-magnetic stainless steel has been used for the shaft and inner housing to minimize thermal induced loads on the bearings. The motor shaft is connected to the sun gear which in turn drives the three planetary gears. The planetary gears are mounted on a disc which replaces the short primary lever arm on one side of the motor housing. The outer or ring gear which meshes with the planetary gears is bolted to the motor housing. The disc on which the planetary gears are mounted is connected by means of a center shaft to the primary lever arm on the opposite side of the motor housing. The astronaut interface is a 7/16 inch hex fitting designed to interface with the astronaut standard tool. For thermal control purposes thin sheet Aluminum cover plates have been added which cover both the motor assembly and secondary lever arms as well as the motor bracket assembly including the electrical connectors.

Bearing Assemblies

Two sizes of bearing were used in the design of the PDM, 50 mm and 20 mm bore angular contact bearings consisting of:

Balls - Cemented Tungsten Carbide Steel with TiC coating in place of the standard steel balls
Races - 52 100 Steel (no surface treatment)
Cages - Lead Bronze in place of the standard Phenolic cages

In selecting a bearing lubrication system several methods were investigated. A comprehensive test program was performed comparing lead, MOS2 and TiC, with the finally selected system being as noted above.

The bearing preloads have been defined as follows:

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- Main Trunnion - Total Rigid Preload	100 N
- Secondary Lever Arm/Fork Piece - Total Flexible Spring Ring Preload	118 N
- Secondary Lever Arm/Primary Lever Arm - Lever Arm Flexible Preload	50 N each
- Stepper Motor - Motor Housing Flexible Preload	100 N
- Center Shaft - Total Flexible Spring Ring Preload	124 N
- Astronaut Interface - Rigid Mounted, No Preload	

Flexible spring rings are Nickel plated steel wavy washers. The reason for the rigid and flexible bearing system is best explained as follows:

Since the bearings themselves consist of steel and the assemblies they are built into are made of Aluminium, thermal loads are responsible for the worst case load conditions. In the specified temperature range from $-55^{\circ}C$ to $80^{\circ}C$ the differential expansion of the bearing with respect to the surrounding Aluminium could reach values of up to 0.064 mm. Because on one hand a radial gap of 0.064 mm is not tolerable, and on the other hand, the axial load onto the bearing would be excessive if most of the differential expansion is transformed into stress, two steel interface rings are provided between the bearing races and the Aluminum parts. For the outer bearing race, the steel ring is shrunk into the Aluminum part. Concerning the inner bearing race, the Aluminum axis (required only to transfer axial load) produces a radial gap with respect to the steel bush. Thus the radial thermal expansion of the inner bearing race is independent of the radial expansion of the Aluminum axis. In order to ascertain that all bearing balls maintain contact under all possible loads (especially in a hot case, assuming a reasonable temperature gradient between the outer race and the inner one), the bearing is axially pretensioned.

Deployed Position Holding Clamps

After deployment by the PDM the array is held in the deployed position by spring loaded ball detents mounted on the ends of the primary lever arms. Because the primary and secondary lever arm center lines are aligned together in the deployed position the mechanical advantage of the drive system is maximum in this position. The spring force of the ball detent is easily overcome during the locking and unlocking operation.

Deployed Position Microswitches

Redundant single pole double throw microswitches have been incorporated to provide deployed position information to the motor power control electronics. One switch is mounted on each side of the motor housing and positioned so that when the PDM is fully deployed the primary lever arms actuate the two switches.

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Manual Drive

The PDM incorporates provisions for manual operation of the PDM in the event that the power operated system fails. This manual operation has the capability of either deploying or stowing of the array. Operation of the manual drive is performed by a suited astronaut, a hex fitting being designed to interface with the astronaut wrench. The PDM can be rotated in either direction and the rate of PDM rotation can be controlled by the astronaut.

Temperature Measurements

Two thermistors are bonded to the PDM to provide in orbit information on the thermal gradients across the PDM.

Wire Harness Routing and Tie-Down Provisions (see FIG.3)

The solar array power wire bundle from the Solar Array Drive (SAD) enters the PDM through the support bracket. At the point of entry the wire bundle is separated and formed into two equal bundles. These two bundles pass under the main trunnion shaft around the outside of the motor housing and thence down the length of the boom to the Secondary Deployment Mechanism (SDM). The wire bundles are held within two recessed areas on the outside of the motor housing by metal clips. Attachment of the wire harness to the boom is accomplished by means of cable clamps.

Thermal Insulation

Three types of thermal insulation are used for the PDM. The first type consists of standard shop practice material surface finishes such as black anodizing or Alodine 1200 S. A second type of thermal provision used is high reflecting Aluminium type. A third type of thermal provision consists of high performance multilayer insulation blankets.

SYSTEM OPERATION

Launch Configuration (see FIG. 4)

The launch configuration of the PDM is known as the stowed position. In this condition the center line of the PDM boom may be displaced a maximum of 91.5° from the deployed position. The theoretical maximum displacement of the boom, or the point at which the two lever arms form a straight line, is 92.862°. Thus during launch the primary and secondary lever arms are never in a straight line and therefore act to assure no transfer of launch induced loads into the PDM motor unit. In the stowed configuration the PDM and array is restrained by two holding devices mounted on the telescope which interface with each end of the SDM.

Array Release and Deployment (see FIGS. 5 and 6)

After the space telescope is in orbit and ready for deployment the telescope mounted array holddowns are activated to release the solar array. Power is

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then applied to either or both of the two PDM stepper motors, rotating the boom at a defined rate until the array reaches the deployed position. At this time the deployed position redundant microswitches signal the control electronics to stop power to the motors. In this deployed position the primary and secondary lever arm center lines are superimposed and the ball detent ensures that this position is maintained.

Array Stowage

At the end of mission the solar array is to be returned to the stowed position. This is accomplished by energizing the stepper motor to rotate in the reverse direction. Final positioning of the stowed array is done by a pull-down device mounted on the telescope and interfacing with the SDM.

SYSTEM MASS

The measured mass of the delivered units is approximately 19.75 kgm.

TEST PROGRAM

During the PDM program three types of tests were carried out: development, qualification and acceptance.

Development tests included:

Bearings

In parallel with the PDM mechanism development program a separate program was initiated to develop a suitable bearing lubrication system. Existing solid lubrication systems proved to be unsatisfactory. Use of oil base lubricants were not seriously considered because of the strict sealing requirements imposed with the use of voltaile materials. A research program was carried out resulting in a bearing system consisting of standard SNFA SEB 20 and EB 50 bearings modified in the following ways:

- the phenolic cages have been replaced with lead bronze cages
- the steel balls have been replaced with cemented carbide balls with a Titanium Carbide (TiC) coating.

Life tests of the bearing systems proved satisfactory and subsequently passed all system tests with no problems.

NOTE: For the lubrication of gears within the PDM the E-metal process has been applied. This is an electrolytic process for Aluminium alloys which produces a hard protective surface on the gear teeth so that in this application no additional lubrication is required.

PDM (see FIG. 7)

During the development of the PDM a significant problem was the steady growth of the specified load. As each new load was imposed a series of operational tests was performed to re-establish system performance margins. The initial specified load was 480 m^2kg for which the initial design was very adequate. Mid-way through the program this load had increased to 821 m^2kg. The system still functioned but with no margin of safety. A redesign was completed adding a planetary gear train between the motors and the primary lever arms. No discrepancies (instabilities, missing steps etc.) occurred during operation with the following inputs:

- input current 200 to 488 ma
- supply voltage 12 to 28 V
- motor step frequency 2.6 to 10 Hz

QUALIFICATION AND ACCEPTANCE TESTS

Qualification and acceptance level tests were successfully carried out in the sequence shown below:

- bearing system (4 pairs 5000 cycles with maximum allowed torque = 0.08 Nm and maximum measured torque of 0.0095 Nm)
- ambient functional and static load test
- vibration (sine-random-sine in each of the three axes)
- ambient functional
- thermal vacuum and accelerated life test
- ambient functional
- electrical bonding
- mass and center of gravity measurements.

For the thermal vacuum tests the flight configuration boom was replaced with a stub boom (zero-G condition) to accommodate the system to the limited space within the thermal vacuum chamber.

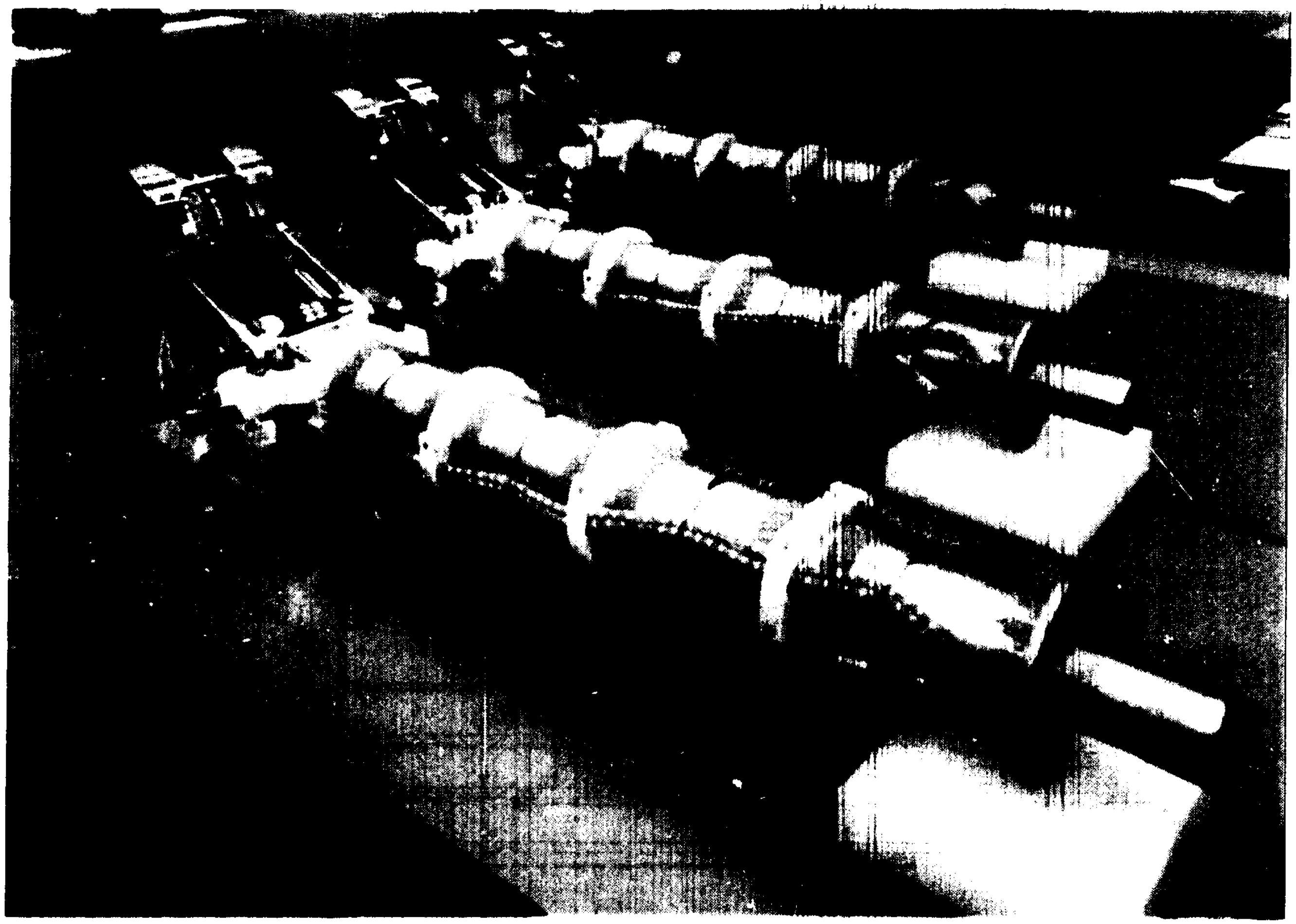

FIG. 1: Two Flight and One Spare Models - Ready for Delivery

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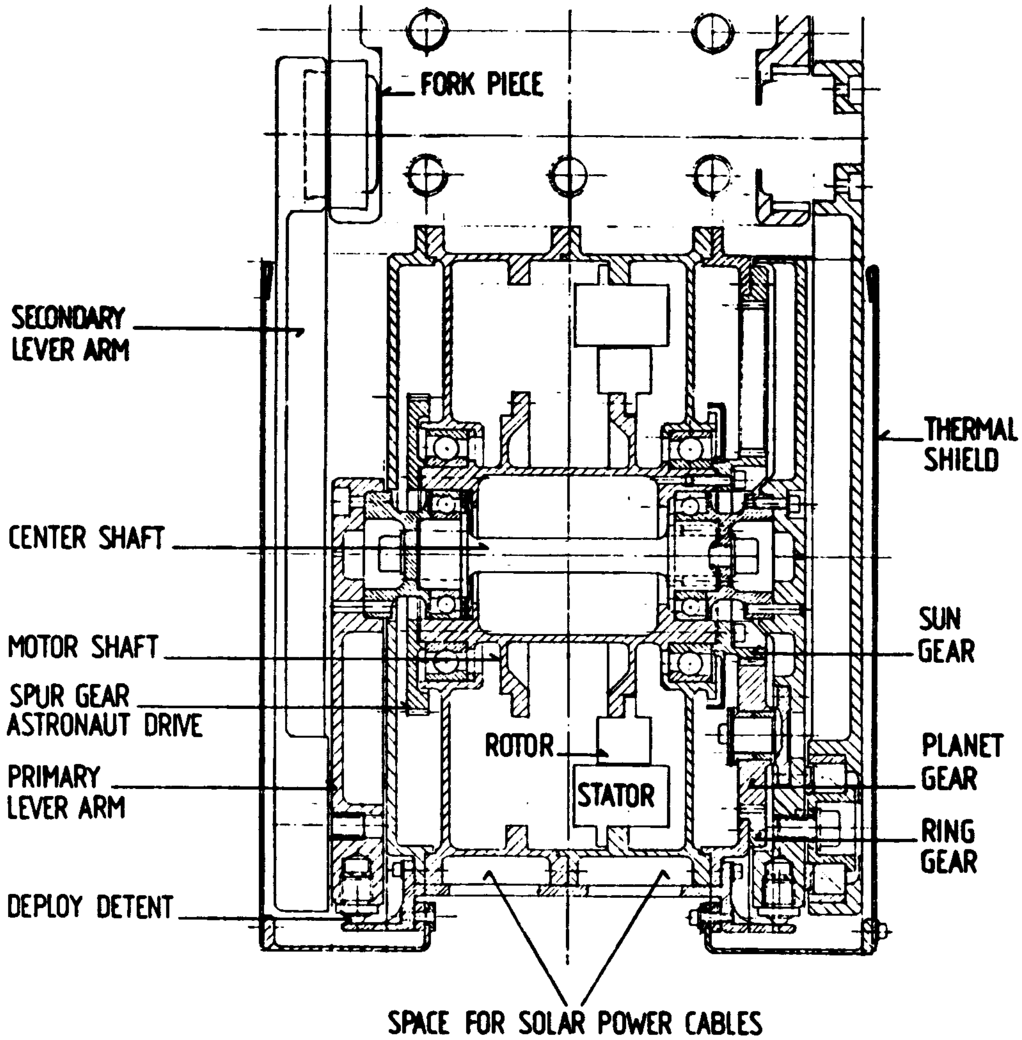

FIG. 2: **MOTOR DRIVE ASSEMBLY** (DETAIL)

FIG. 3: Installing Dummy Load with PDM Mounted in Zero-G Test Stand

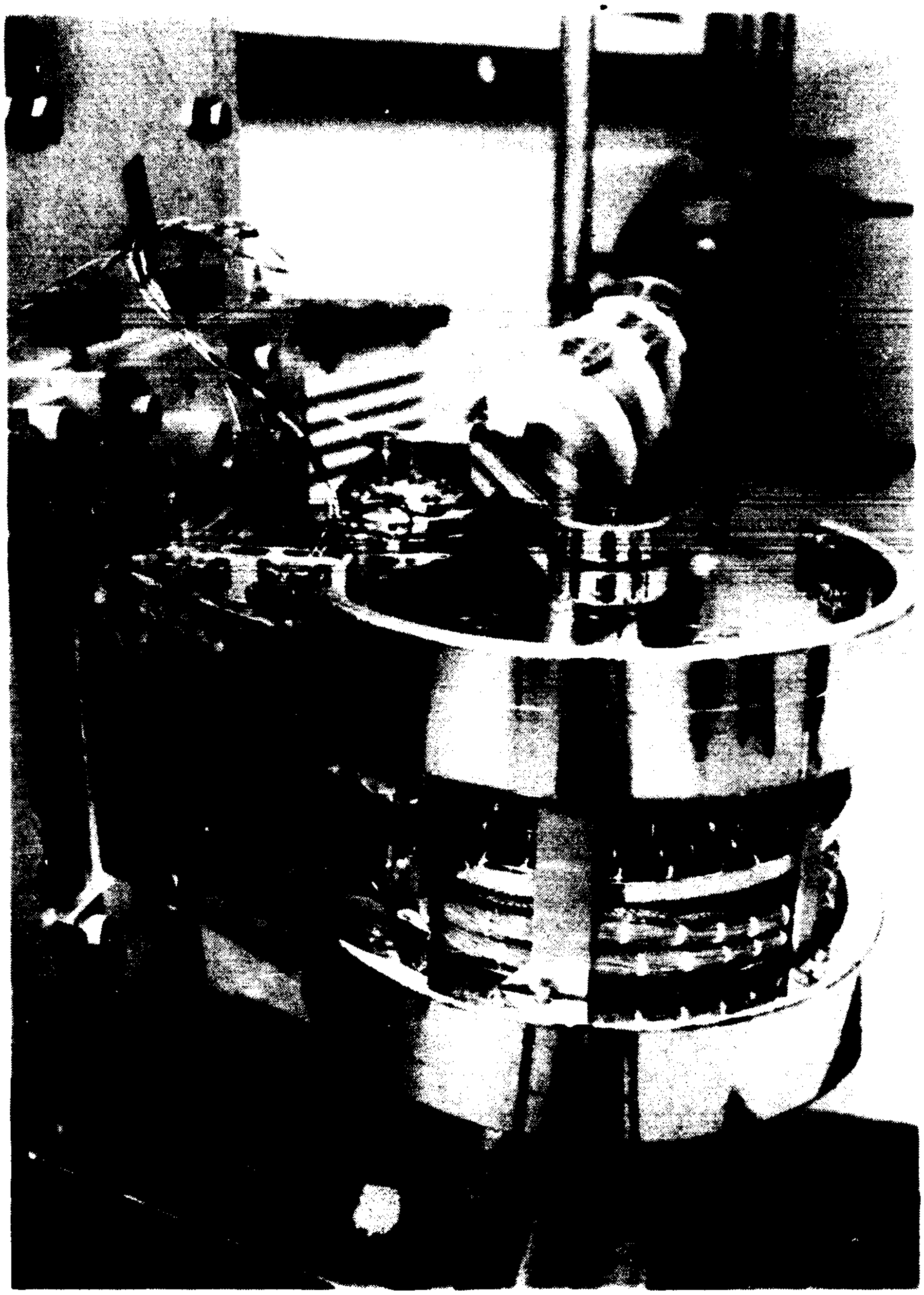

FIG. 4: PDM in Stowed Position in Test Stand
(Launch Configuration)

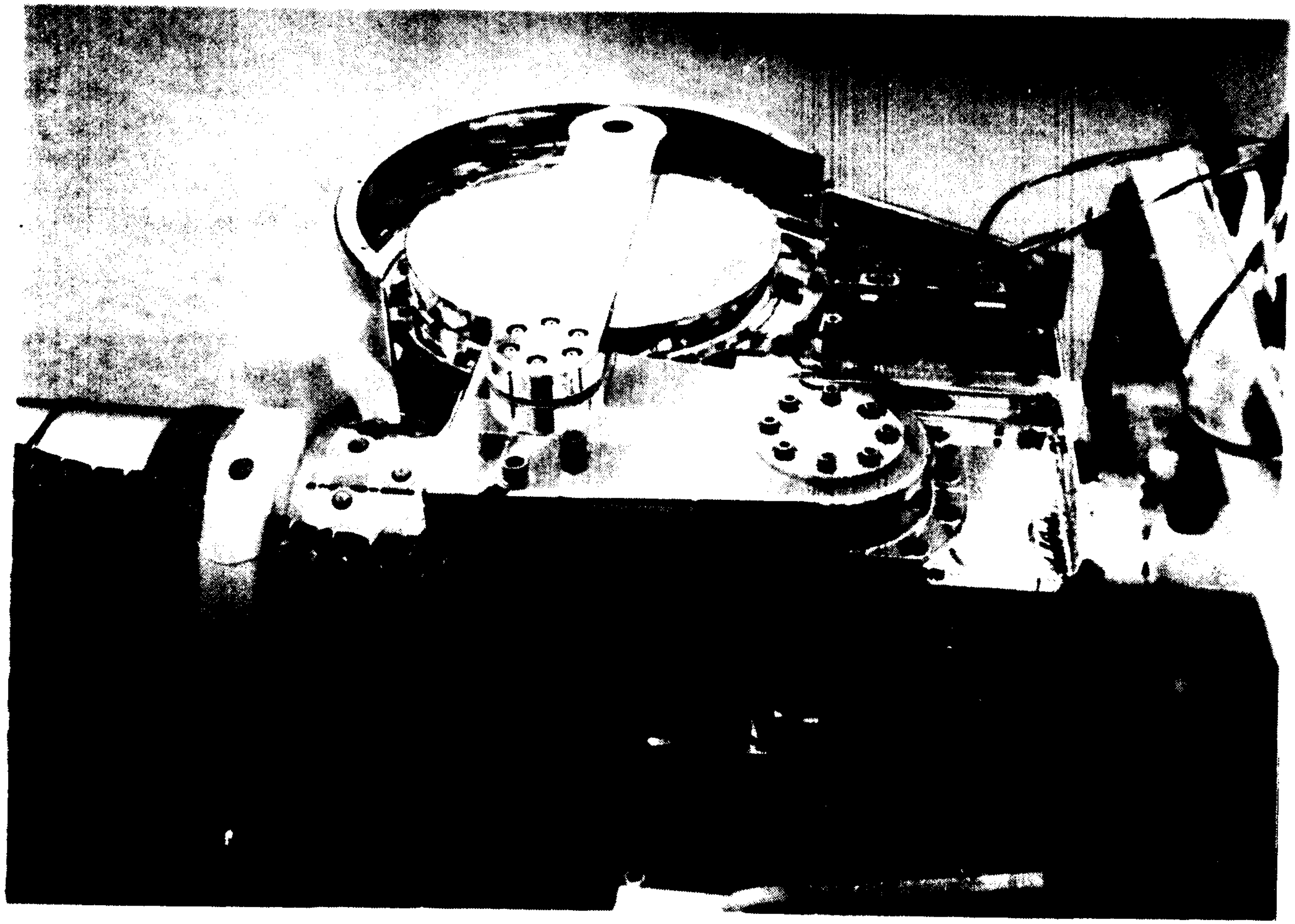

FIG. 5: PDM in Deployed Position

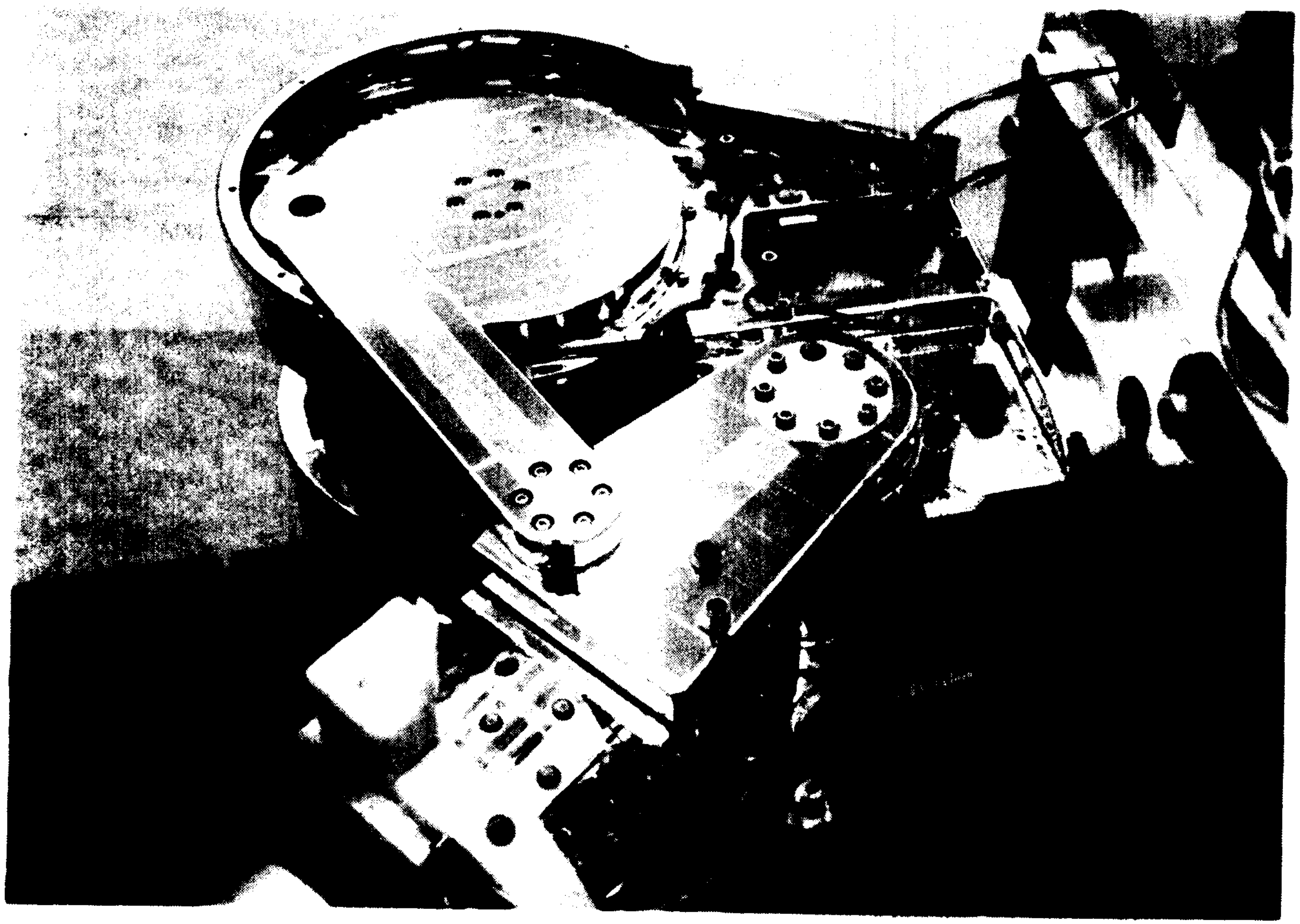

FIG. 6: PDM at Half-Way Position

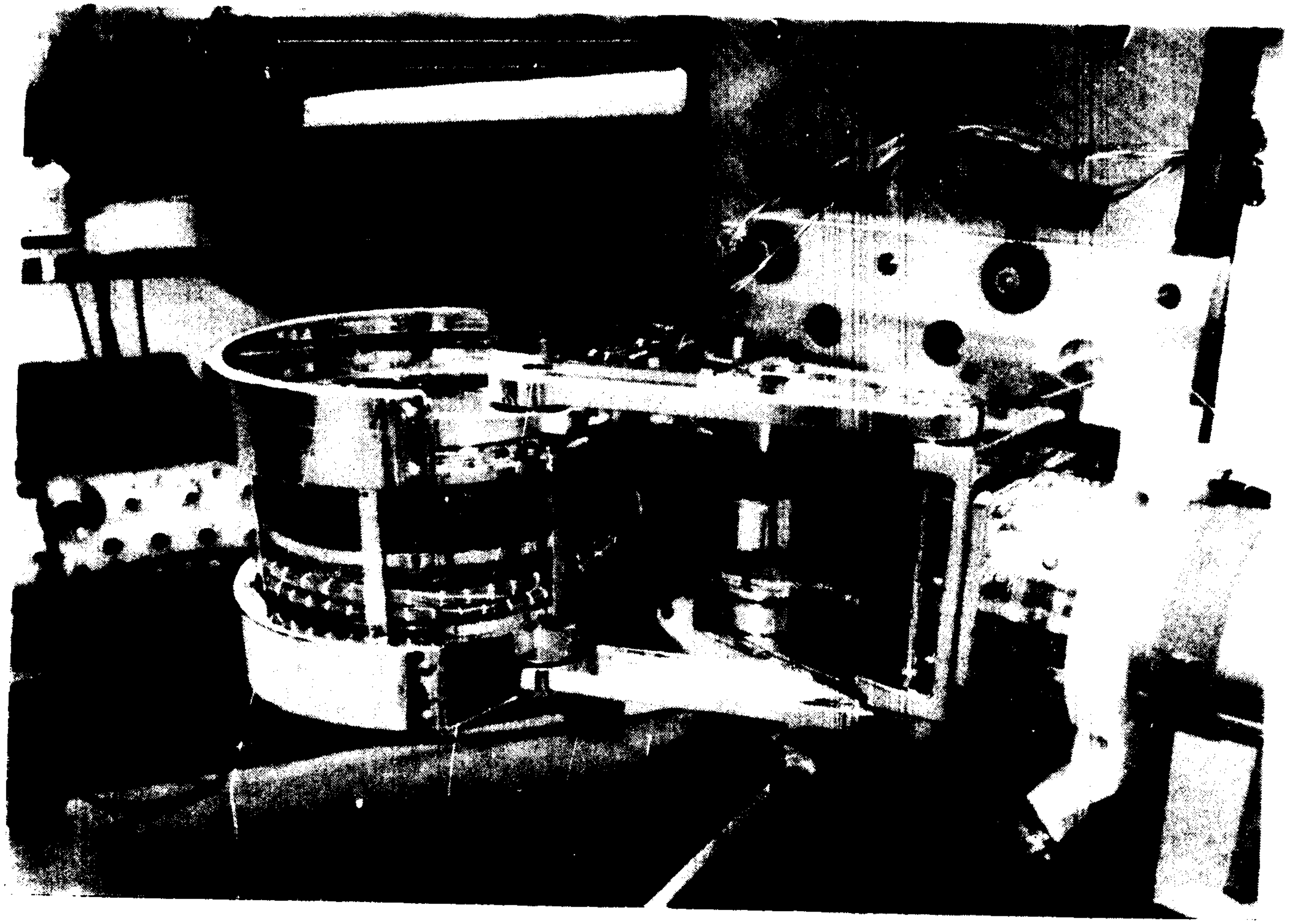

FIG. 7: PDM During Acceptance Test - Note Wire Harness Routing