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DESIGN AND DEVELOPMENT OF A TELESCOPIC AXIAL BOOM

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A special telescopic boom has been design-optimized, developed and qualified to carry an S-band Antenna for the DFS-Deutscher Fernmelde Satellit (German Telecommunication Satellite) - KOPERNIKUS. This paper describes the "design driver" requirements, the alternatives investigated and the final technical solution, the tests performed, and identifies the special problem areas encountered during its development.

INTRODUCTION

The design of the DFS-Boom was driven by the following system/subsystem requirements:

- undeployed length of the boom without antenna of 0.908 meter and deployed length of 1.675 meters. The large undeployed length (limited by the launcher fairing) is designed to provide a limited transmission capability in the event of a failure in the driving/deployment mechanisms. Refer to Figures 1, 2, and 3.

- vertical mounting on the antenna platform as depicted in Figures 1 and 4.

- deployment of the boom just after the separation of the last stage of the launcher (ARIANE 3/4); i.e., during the transfer orbit.

- relatively high stiffness of the boom in order to avoid excessive dynamic cross coupling and the resulting higher or harmful amplifications.

The following basic properties have been determined by test and/or analysis:

- undeployed lateral modes = 55 Hz Requirement ($\geq$ 50 Hz)

- undeployed axial mode = 480 Hz Requirement ($\geq$ 60 Hz)

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- mass $\leq$ 2.6 kg

- minimum thermal deformations $\leq$ 0.5 mm (measured at the top)

- Though retractability of the boom in orbit is not required, it has been incorporated in the design to aid ground testing.

- deployment time: 60 sec. (approximately)

- alignment requirements for the boom; - deflection (measured at the top): $\leq 1°$
  - rotation (measured at the top): $\leq 5°$

- One of the most demanding requirements derives from the integration and guidance of the highly sensitive coaxial cable which is incorporated into the boom. It is required that the minimum bend radius be above 1 in. (25.4 mm) at any stage of stowage or deployment.

DESCRIPTION OF THE DESIGN

A considerable development effort was spent in finding the best solution for the guidance of the coaxial cable, particularly to satisfy the minimum bend radius requirement.

The final solution, to be described later, crystallized after analysis of a number of alternatives. Thus, for example, in one solution disc-like parts were envisaged to protect individual semicircular cable loops from being forced into a bending radius below the minimum value. Extension and retraction was ensured by means of spiral springs and guide rails (see Fig. 5). Guiding concepts which were based on the "Nuernberger Schere" (lazy tongs) principle were also considered. All these concepts, however, were either too complicated, too heavy, too expensive, or involved too high a risk.

Another solution, which had been favoured for a long time is shown in Figure 6.

The cable penetrates from the antenna platform (see Fig. 4) through the lower plate of the boom into the inner boom space and directly into the cable box, which is positioned along the boom, parallel to the drive. Between the plate and the cable box, the cable attachment is such as to avoid tensile stresses in the cable. In the cable box the cable is stored in a snake-shaped manner; this storage needs a minimum of cable length, since the cable can nearly be drawn straight. Also no torsional loading occurs.

In order to prevent the bending radius of the cable falling below its minimum value ($R_{min} \geq 25.4$ mm) "shaping beads" are attached to the cable. These beads sit loosely over the cable and guide the cable into the snake form during deployment (and retraction) of the boom. Being a close (sliding) fit with the walls of the cable box they also serve to prevent, during launch, any lateral movements of the cable generated by vibrations. Adjacent beads are linked with wire springs to define the bend radius of the cable and, additionally, to prevent mutual torsion between the beads. Since these beads are attached to the cable with clearance they do not obstruct cable deformation during extension (see Fig. 6).

At the upper end the cable box lead-in section is in the form of a funnel in order to provide guidance to the shaping beads during retraction, and avoid twisting of the cable.

As an additional precaution, the upper end of the cable is fixed with a clamp, to prevent tensile forces loading the connectors.

As it was not certain from theoretical analysis whether this solution would work flawlessly, a simple model was manufactured (see Fig. 7). Tests with this model have shown that the shaping bead guidance system works well.

Although this method of cable guidance fulfilled the functional requirements, a number of additional concepts were investigated in order to find a lighter weight solution. After evaluation of the advantages and disadvantages of all the alternatives, the "centre cable guide" solution crystallized as the final weight-optimum cable guide system.

The centre cable guide concept is a simple and reliable design, meeting all the requirements with the lowest weight and is comprised of the following components:

- two telescopic tubes with guide rings and end connection plates
- cable supports and guide plates
- telescopic drive mechanism
- electrical equipment

The main design features are depicted in Figure 8; a description of the main components is as follows:

Telescopic Tubes

The main body of the boom consists of two Carbon Fiber Reinforced Plastic (CFRP) tubes. The inner tube is fixed at the bottom end to the Antenna Platform (see Fig. 4) by means of a ribbed Aluminum flange plate, which also provides a mounting facility for the worm gear. In addition, three support plates have been incorporated inside the inner tube. The first carries a motor and a cable guide elbow, the second carries a cable guide having a slot for cable support in the undeployed condition, and the third carries a bracket supporting the cable guide half ring. Further, two guide rings have been incorporated near the top to provide smooth sliding of the outer tube over the inner tube. A guide rail along the outer surface of the inner tube slides on a machined part of CFRP bonded on the inside surface of the outer tube, which prevents rotation of the outer tube during deployment.

The outer tube is made from CFRP in order to ensure sufficient stiffness, minimum mass, and low thermal deformation. It carries an Aluminum connection plate at its top end as a mounting facility for the S-band Antenna. The cable support guide rail, an Aluminum framework, is hung on the lower side of this connection plate.

It is a peculiarity of this design to have the bigger diameter tube as deployable and the smaller diameter tube as fixed, this being contrary to other more common telescopic booms. This type of arrangement was selected to prevent bending of the coaxial cable beyond its permitted 1 in. radius, to fix the cable supports, and to introduce pre-compression in the outer tube against the inner tube during the launch phase, thus preventing fretting between the tubes. Further, this design approach allows the accommodation of motor plus worm gear drive and cable, etc. inside the inner tube to achieve a compact design solution and a maximum deployment length in comparison with the stowed length.

Cable Supports and Guides

The support of the coaxial cable needed for the transference of signals to and from the S-band antenna necessitated a guidance and support scheme. This consists of two elbows, one half circular guide and two holding slots in the support plates, fixed in the inner tube at appropriately separated locations. In addition, a support framework is hung from the top S-band connection bracket.

This elaborate arrangement has been dictated by the need to guarantee proper fixation/support of the coaxial cable during launch, to ensure smooth and reliable flexure during deployment and to avoid bending the cable below its allowable minimum radius of 1 in.

Telescopic Drive Mechanism

This device performs two main functions, namely, deployment of the boom and secondly, precompression of the outer tube against the inner tube, to avoid mutual fretting during launch. The mechanism comprises:

- DC motor with brake (TRW-Globe, Type 5A3396, Micro Switch Honeywell, Type MS 23547-1 and -2)

- steel telescopic car antenna (Bosch-modified to suit space application) driven by a wire wrapped in a stiff plastic cover. The top end of this wire is attached to the S-band antenna's mounting plate, the other end being fixed to the drum.

- a plastic drum onto which the wire is wound. This drum is connected to the worm gear transmission.

-- The worm gear shaft is driven by the DC motor, but with one end extending outside the box. Although the design concept is for the motor to provide the necessary pre-compression between the inner and outer tubes, the shaft extension allows this pre-launch adjustment to be done by hand, if necessary.

By means of special tools, therefore, the worm gear shaft can be torqued so that a predefined tension in the drive core wire can be achieved. This tension in the wire is controlled through strain gauges. The self-blocking behaviour of the worm gear and brakes on the motor shaft avoid unwanted release of the tension in the wire.

-- an aluminum box, which houses the drum, the worm gear and at the same time supports the motor through an adapter bracket. This box is mounted on the fixing flange of the inner tube. The motor and the telescopic antenna are additionally supported within the inner tube by means of a CFRP-bracket.

-- The complete drive mechanism along with the cable and its guides, etc. is fully accommodated inside the inner tube, having fixation brackets at the base and a mounting facility for the payload (here an S-band antenna) on the top of the deployable tube. The design adopted thus provides a very compact telescopic boom assembly.

Electrical Equipment

In addition to the DC motor mentioned above, there are three switches, two power/signal lines and a cable (Raychem, Type 44, AWG 22 and 26). The lines and the cable are led out of the boom through sockets. These lines provide the motor with electric power and at the same time serve as signal carriers for the switches. In this manner, the boom electrical design is simple, consisting of only a few space-qualified parts.

FUNCTIONAL DESCRIPTION

For deployment of the boom, an initiating signal is transmitted. This signal releases the motor brakes and starts the motor. The resulting rotation of the drum unwinds the wires of the telescopic drive, thereby deploying the outer tube, which in turn switches a signal line, transmitting confirmation of the deployment process.

A second switch is activated as soon as the outer tube is fully deployed, signifying the end position of the boom. A third switch disconnects the flow of the current to the motor. This last switch was located at such a place that a small overdrive of the motor and/or thermal expansion is possible and admissible.

For the purpose of ground testing, a device in the EGSE circuit (see Fig. 3) was incorporated to limit the current flow to the motor during retraction of the boom. This was necessary to avoid overloading the motor. In this case the end switch was not used, so that precompression could be achieved.

DEVELOPMENT AND QUALIFICATION TESTS

In order to establish the sensitivity limits of the coaxial cable system and verify the functional capabilities of the envisaged cable storage and guidance devices, several component tests were performed at an early stage. These included the determination of the load capability of the drive, and the frictional resistance of all moving elements.

With the full-scale, qualification model, manufactured to flight-product assurance standards, the following development and qualification tests were performed:

1. Electromechanical Functional Test

The parameters of the deployment were measured in ambient and in thermal vacuum environments. The margins in the load-carrying capability of the drive, the deployment time, the alignment at the top of the boom, and the input electrical current and voltage were determined.

The following main results were obtained:

Minimum compressive force margin:	100 N
Deployment time:	45 sec.
Deployment qualification	
Temperature range:	$-5°C \leq T \leq +60°C$
Vacuum:	10^{-5} mbar = 10^{-3} Pascal

2. Vibration Test (see Fig. 10)

The general behaviour of the boom during simulated lift-off was investigated during sine and random vibration testing with the following results:

Inputs

Sine frequency range:	5 - 100 Hz
Maximum input excitation:	6 g lateral
	12 g axial
Sweep rate:	2 oct/min
Random frequency range:	5 - 2000 Hz
Input: 0.2 g^2/Hz; composite:	20 g_{rms}
Duration:	2 min/axis

Results

lateral eigenfrequency in stowed position:	55 Hz
axial eigenfrequency in stowed position:	480 Hz
maximum response acceleration:	57 g at the top of the boom
	100 g (about) at the motor.

3. Thermal-Vacuum Test in Deployed Position (see Fig. 11)

This test simulated thermal conditions to be experienced during the mission. The aim of this test was to show that the high thermal deflection difference between aluminum and CFRP would not lead to a delamination or other destruction of parts of the boom. The worst-case temperature range tested was: $-100°C \leq t \leq +100°C$

4. Electromagnetic Cleanliness Test

The aim was to verify the emission and the inrush current values caused by the electromotor.

Before and after tests numbers 2 to 4, the function of the boom was tested with a simple go - no go test.

The boom passed all tests and is now space qualified.

ACKNOWLEDGMENT

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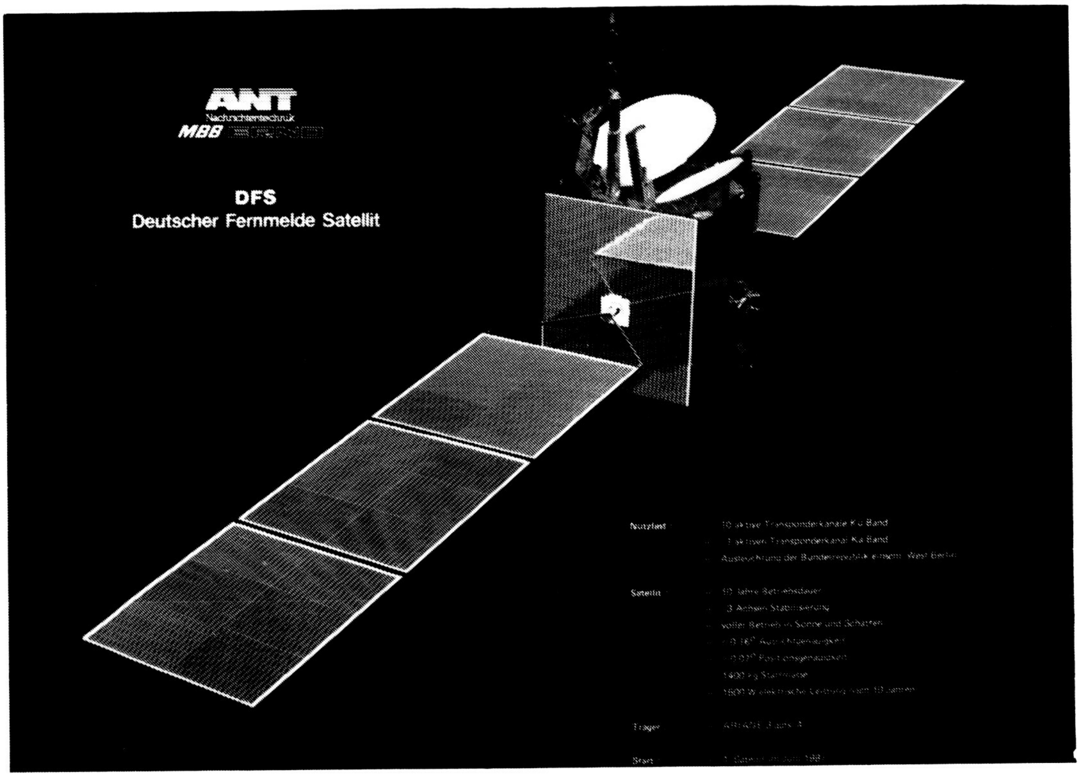

Figure 1. - KOPERNIKUS satellite.

Figure 2. - S-Band antenna boom in stowed position.

Figure 3. - S-Band antenna boom in deployed condition.

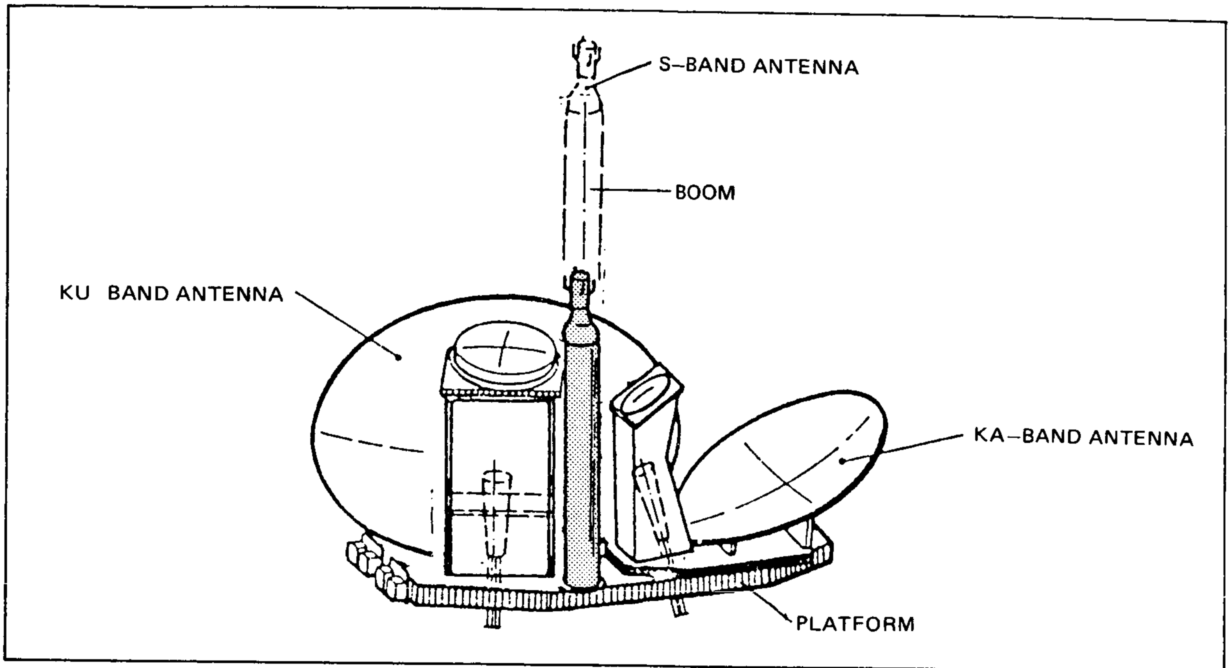

Figure 4. – Antenna module with boom.

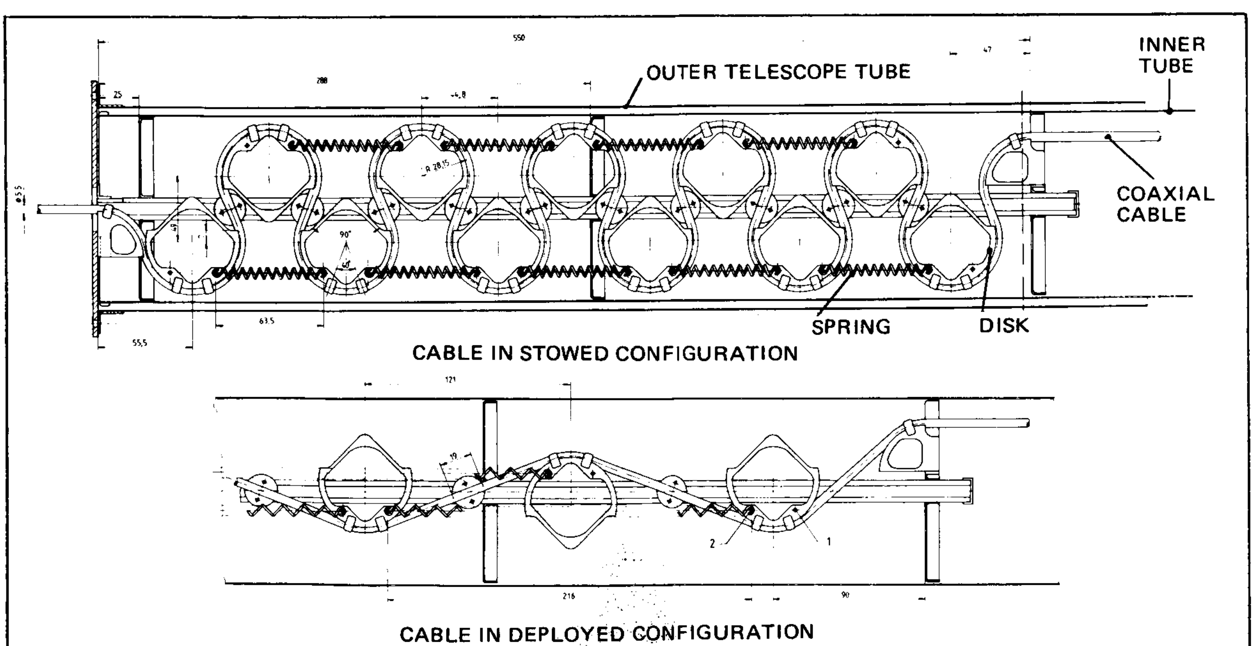

Figure 5. – Cable guidance with discs.

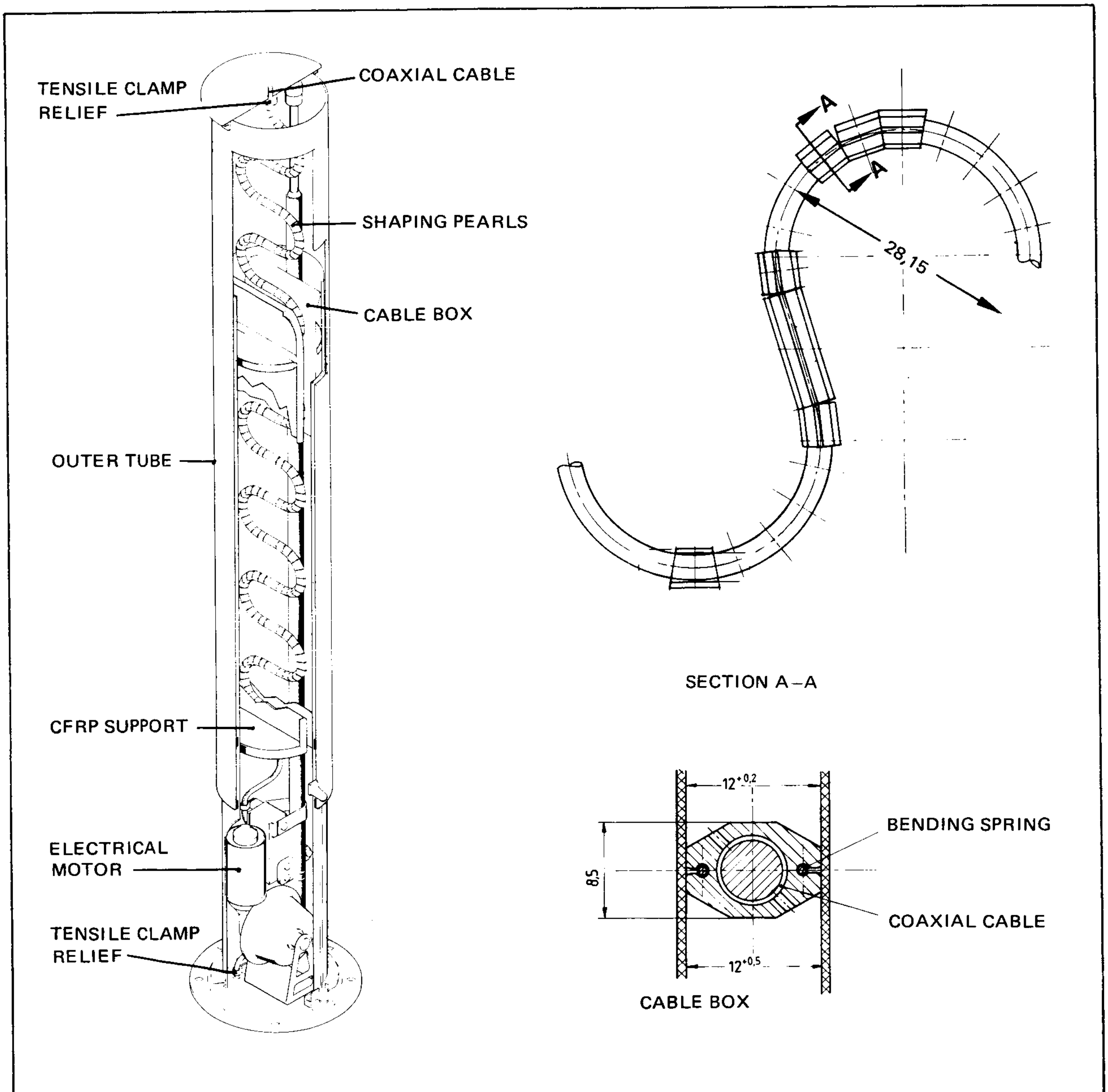

Figure 6. - Boom with cable guidance provided by "shaping beads."

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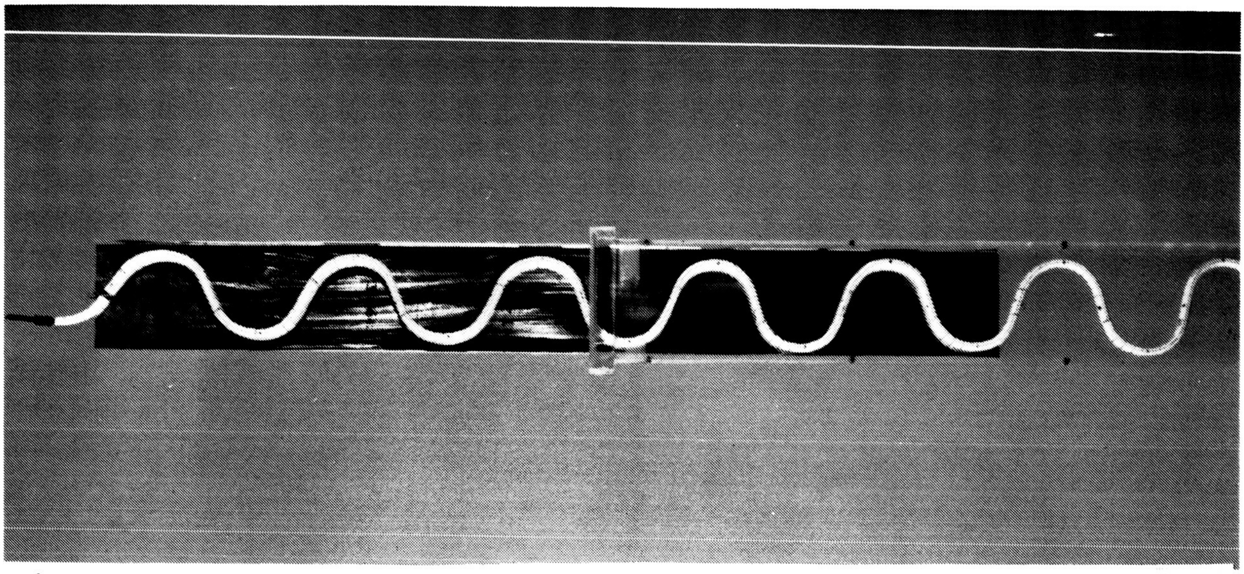

Figure 7. - Simple functional model for shaping bead cable guidance system.

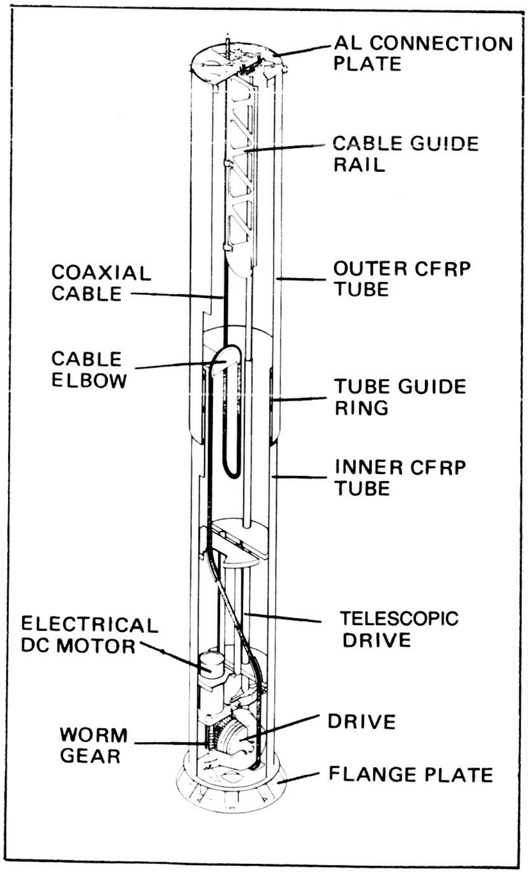

Figure 8. - Final design boom with cable guide rail.

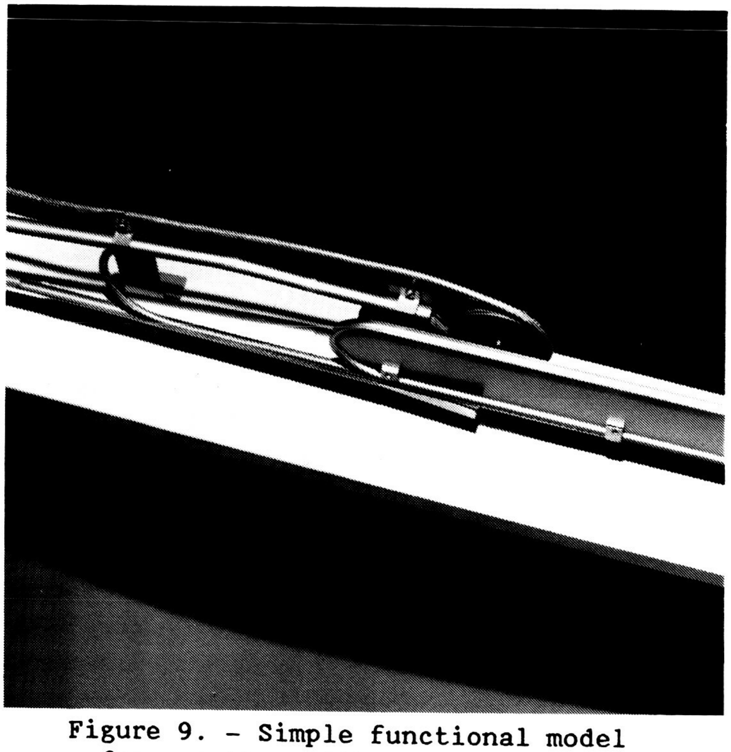

Figure 9. - Simple functional model for solution with cable guide rail.

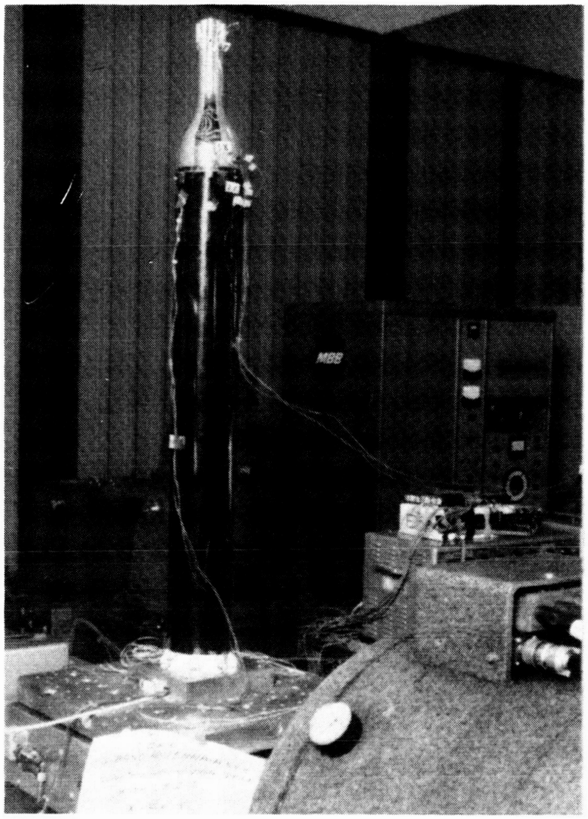

Figure 10. - Vibration test.

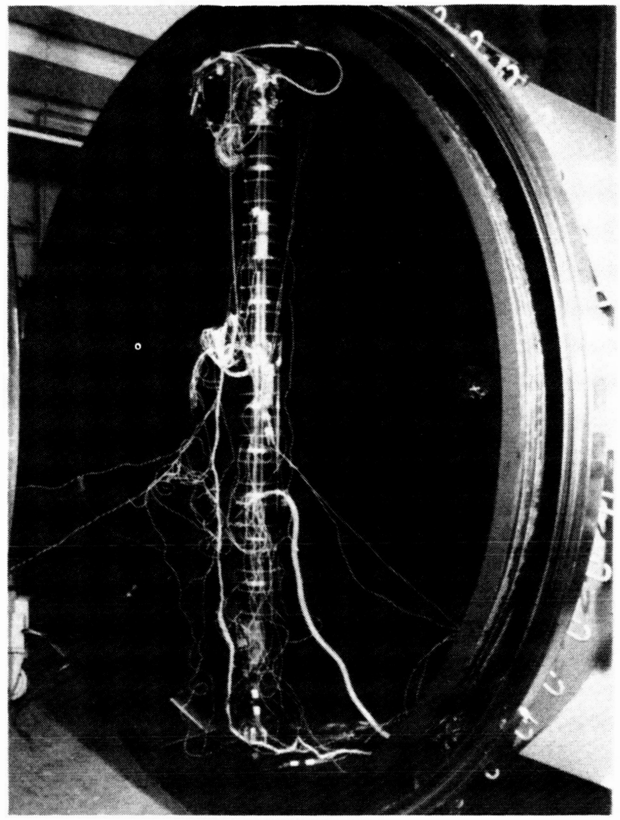

Figure 11. - Thermal vacuum test.