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VISCOUS ROTARY VANE ACTUATOR/DAMPER*

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SUMMARY

JPL has developed a compact viscous rotary actuator/damper for use on the Mariner '71 and Viking Programs. Several functions have been combined into this single mechanism to control the deployment, latching and damping of the solar panel arrays used on these space vehicles. The design, development and testing of the actuator/damper are described, and major problems encountered are discussed.

INTRODUCTION

The Jet Propulsion Laboratory's Mariner Mars spacecraft, launched in 1971, and the Viking Orbiter spacecraft, launched in mid 1975, required the use of panels of solar cell arrays for electrical power generation. Because of the size of these solar panel arrays, they were folded parallel to the spacecraft's longitudinal axis to fit within the launch vehicle shroud. After launch and shroud removal, they were rotated to their flight position. Deployment of the solar panels from their launch position, latching of the solar panels in their proper flight position and damping of solar panel perturbations caused by the spacecraft engine firings were functionally controlled at the hinge line of the panels. These three main functions were incorporated into a single unique fluid-filled viscous rotary vane actuator/damper. The concept was originally developed for Mariner '71 and then modified and improved for use on the larger solar panels on Viking Orbiter. This paper will deal primarily with the design configuration flown on the Viking Orbiter spacecraft.

DEPLOYMENT AND LATCHING

Deployment of the solar panels is accomplished by the release of stored energy from a torque spring. This was a clock spring design on Mariner '71 and later modified, because of weight and reliability considerations, to a pair of constant torque multi-leaf springs for Viking. The torque level for the deployment springs was set by a design goal of maintaining a torque margin of four times the maximum resistive torque.

This resistive torque comprises the friction of the hinge joint, the tare torque of the deployment device, plus the items that bridge the hinge joint such as electrical wire bundles, attitude control gas lines and the coaxial

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cable for the relay antenna. These torque values and the deployment torque margin can be seen in Figure 1. The variations in available deployment torque are from the mounting of the actuator; its crank and linkage to the solar panels form a four-bar linkage that has an increasing mechanical advantage that approaches one to one at the deployed position.

Under free running conditions, this excess torque margin would drive the solar panel assemblies too fast and cause high shock loads to the system at latching; therefore the springs are configured to drive the panels in parallel with the fluid actuator. This causes compression of the fluid between the vanes of the actuator pumping the fluid through the orifice gap formed between the stationary vanes and the outer rotating wall. This can be seen in the cross section of Figure 3. The actuator in this case acts as a rotary rate-limiting device that is velocity sensitive and will, for a constant torque input, maintain a constant deployment velocity. The device can be adjusted to control the rate of deployment independently of the input driving torque. The input torque is based on the resistive torques and the required torque margin; then the fluid viscosity and the orifice gap are selected to balance the input torque for the deployment rate desired.

After deployment, the solar panels are latched in their flight position by either or both redundant lock pins located in the rotating vanes. The lock pins are spring loaded taper pins that engage conically reamed holes. This configuration allows for a gradual entry of the lock pins into the holes and near-zero backlash when engagement is complete. When coupled with the controlled deployment velocity, this arrangement provides for small or negligible impact loads at latching.

To insure that the solar panels are in the proper position at latching, the solar panels must be aligned to actuator's locking pin locations. This adjustment is made at the flight assembly by means of the turnbuckle linkage assembly connecting the panels to the rotating portion of the actuator. This linkage and its attach points are shown in Figure 2.

DAMPING

After deployment and latching, it was necessary to have a damper in the system to minimize any interaction between solar panel perturbations and the spacecraft's attitude control system (ACS). The requirements to decouple the solar panel assemblies' resonant response from any known pulses of the spacecraft ACS system were determined to be a minimum undamped natural frequency of .5 Hz and at least 30% damping. To meet the damping requirements, the actuator/damper had to have a dual spring rate, one for deployment and one, much higher, for system frequency control. This was accomplished in the device by the action of the latching pins. As the pins stop the system deployment, they lock out the deployment springs and couple the actuator/damper's outer rotating body to the inner stationary base through the center shaft, which is a tuned torsion bar. The torsion bar had to be configured stiff enough to meet the frequency requirement but flexible enough to allow sufficient panel rotation at engine firings and shut-off for the damper to be effective. For the Viking solar panel assemblies, the torsion bar provided an undamped natural frequency of .87 Hz. The flexing of the torsion bar allows relative motion between the damper vanes, displacing fluid through the orifice gap. It is the work required for this fluid displacement that damps the solar panel vibrations.

The damping of a rotary device like this is dependent upon the geometry of the vane configurations, the working fluid viscosity and the orifice size and shape. The parameters easiest to adjust to meet the damping requirements are the fluid viscosity and the orifice size. To meet the damping requirements of the Viking spacecraft with its larger, heavier solar panels as compared to the solar panels on Mariner '71, it was necessary to increase the working fluid viscosity and decrease the orifice gap. The combination finally selected was a dimethyl silicone oil, because of its relative flat viscosity vs. temperature curve, with a kinematic viscosity of 178,000 centistokes and an orifice gap of 0.015 in. With this combination, the damper was able to provide the required 30% damping over the predicted temperature range of -10°F to +115°F, with damping ranging from 30% to 53%. Although this fluid and orifice size did provide the needed damping, they presented a problem to the deployment function of the actuator/damper. With the input torque of the deployment springs set and this high fluid viscosity and small orifice, the deployment time became unacceptably long. To shorten the deployment time, a step, shown in Figure 3, was added to the inside wall of the body to increase the orifice gap. This gives a faster rate at the beginning of the deployment and a gradual decrease to the slower rate about halfway through the deployment.

Another problem that had to be considered is the fluid expansion and contraction with temperature. At high temperatures, the fluid expansion causes high internal pressure, increasing the possibility of leakage or a structural failure of the pressure vessel. At low temperatures, the fluid contraction can cause a void within the fluid. This vacuum "bubble" allows relative vane motion without forcing the fluid to be pumped through the orifice and greatly reduces the damping capabilities of the device. To prevent these problems from occurring, a temperature compensator was used to provide an additional spring-pressurized reservoir that supplies the expansion volume needed at high temperatures and the make-up fluid needed at low temperatures. The temperature compensator, shown in Figure 3, consists of a sealed piston, a compression spring of conical washers and a small orifice connection to the working fluid chamber.

DEPLOYMENT TESTING

For the deployment testing, the solar panel assemblies were positioned with the hinge axis vertical to minimize the gravitational effects. All of the development testing was performed using a pair of simulated solar panels shown in Figure 4. Deployment tests were conducted to check the actuator's deploying, rate limiting and latching functions. Because the Viking system was a double folded panel pair, with the outboard panel deployed and latched during the deployment of the inboard panel, the effect of this two-panel deployment was investigated during the deployment and latching tests.

The flight solar panel structure was not capable of supporting the cantilevered weight of the outboard panel, so the panels could not be free-deployed in the flight-like manner. To minimize the complexity and cost of the testing equipment and the risk to flight hardware, it was decided to deploy the flight panels in steps using a mid-hinge support for the deployment of the outboard panel. Testing of the flight panels is shown in Figure 5. By running tests with both the simulated panels and the flight panels, a collation of the deployment times was assembled for evaluation of pre-flight checks and a prediction of flight deployment times.

DAMPING TESTING

Damping tests were performed on the test setup shown in Figure 6. It consisted of a simulated solar panel assembly, the actuator/damper in an insulated box shroud and a liquid nitrogen/hot air temperature control system. To simulate the maximum .16 g force on the solar panels from a main engine firing, the simulated panel and actuator/damper are assembled in the deployed position (latch pins engaged) and mounted at an angle of 9° from vertical. When released from this position, the horizontal component of the weight will approximate the load the torsion bar and damper will see in flight.

All dampers were tested in this manner at various temperatures from -19°F to 124°F, with the damping ranging from 30% to 53% for all flight units. A typical damping curve taken at room temperature is represented in Figure 7.

Certain problem areas were identified from the development and acceptance tests conducted. Early damping tests showed that the temperature compensator must be decoupled from the damper or the pressure on the fluid would force it into the compensator and not past the damper vanes. This was corrected by making the fluid passages between the compensator and damper a pair of .006-in. diameter holes. A suddenly applied load would not drive fluid through this small orifice, but a gradual change in temperature would allow fluid to flow between the damper and compensator. Also the device had to be pressure filled to a level that would remove any axial play within the unit and completely seat the "O" ring seals so that they would not move or "breathe" when a load was applied.

VIKING FLIGHT PERFORMANCE

During the launch and early flight of the Viking missions, data was transmitted that allowed evaluation of the flight performance of the actuator/damper assemblies. With four assemblies per spacecraft and two successful launches, the data received gives a good indication of the actuator/damper's flight characteristics. The data gave direct readings for deployment times and latching but not for the damping function; this was interpreted from data of other spacecraft subsystems.

Solar panel deployment times were estimated, based on pre-flight testing and the predicted flight temperature range, to be between 2 minutes to 2 1/2 minutes, with the bay 1 panel being the slowest because of increased inertia due to a relay antenna attached to the outboard panel.

The last ground tested deployments and flight actuals are shown below:

TABLE 1. VIKING SOLAR PANEL DEPLOYMENT TIMES

Location	Last Preflight Test	Launch A Time +6.7 sec -0.0 sec	Launch B Time +6.7 sec -0.0 sec
Bay 1	2 min 2.8 sec	2 min 11 sec	
Bay 5	1 min 39 sec	2 min 2 sec	
Bay 9	1 min 43 sec	1 min 55 sec	
Bay 13	1 min 39.7 sec	1 min 55 sec	
Bay 1	1 min 49 sec		2 min 10 sec
Bay 5	1 min 48 sec		2 min 1 sec
Bay 9	1 min 41 sec		1 min 54 sec
Bay 13	1 min 39.5 sec		1 min 47 sec

It can be seen from the flight deployments that all actuators functioned quite well, giving a uniform deployment within a small time variation. Actual flight deployment times were slightly faster than predicted because of the fluid's sensitivity to temperature. The flight devices were close to nominal temperature, and the predicted times were based on the low temperature predicts.

Based on the ACS gas usage, the actuator/dampers functioned properly, preventing any adverse interaction between the solar panel natural frequency and the ACS gas jet firings. Confirmation of the latching and damping functions of the devices was given by the midcourse engine firing in that there was no discernible c.g. shift, indicating a free or non-latched panel; in addition, the ACS system showed normal operation after the engine firing.

CONCLUDING REMARKS

This viscous rotary damping device has been developed, tested and successfully proven on two spacecraft programs. The major unexpected phenomena encountered with the design and their solutions have been discussed; however, there has been no attempt to describe all of the problems, pitfalls and agonies encountered with a design effort of this nature from concept to a proven flight-ready mechanism. Because of the nature and complexities of this type of fluid actuator/damper, the design does not come only from careful analysis but must be gained from testing and experimentation. This device has the advantage of being designed and developed for one program, then re-evaluated and expanded to requirements greater than the original design goals. This additional work and testing have increased the knowledge of the device's performance characteristics and capabilities.

Because of the device's versatility, it has been considered for many applications where panels, booms or other appendages have to be deployed and/or damped in a space environment. It is currently being used on JPL's Mariner Jupiter/Saturn Program and Rockwell International's Global Positioning Satellite. It has also been included by Martin Marietta and General Electric Space Division in proposals for other spacecraft and satellites.

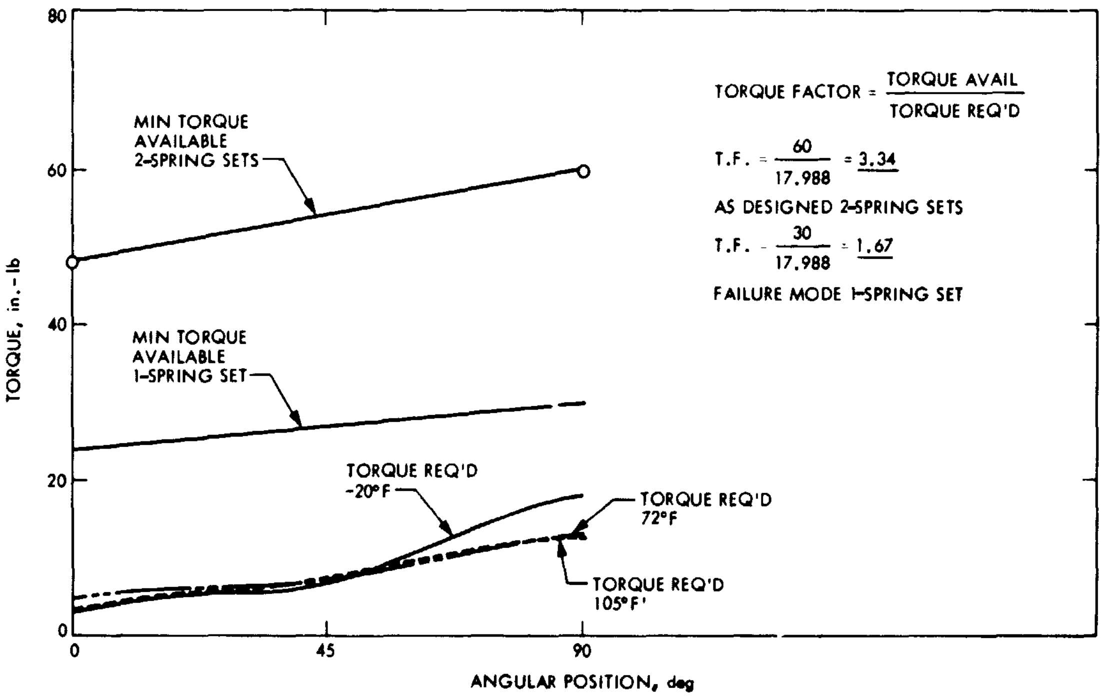

Figure 1. Input Torque Available and Resistive Torques Compared to Panel Angular Position

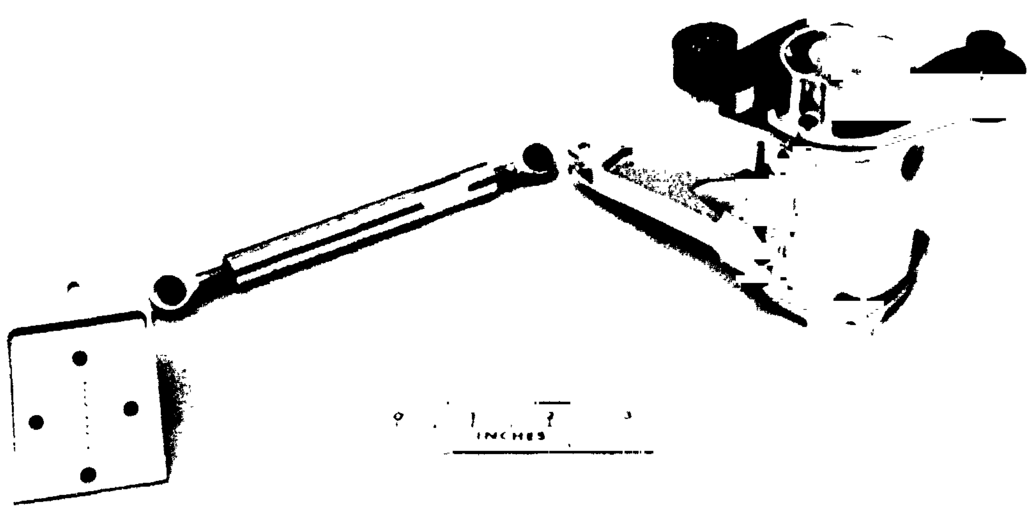

Figure 2. Actuator/Damper, Turnbuckle Linkage and Solar Panel Attach Bracket

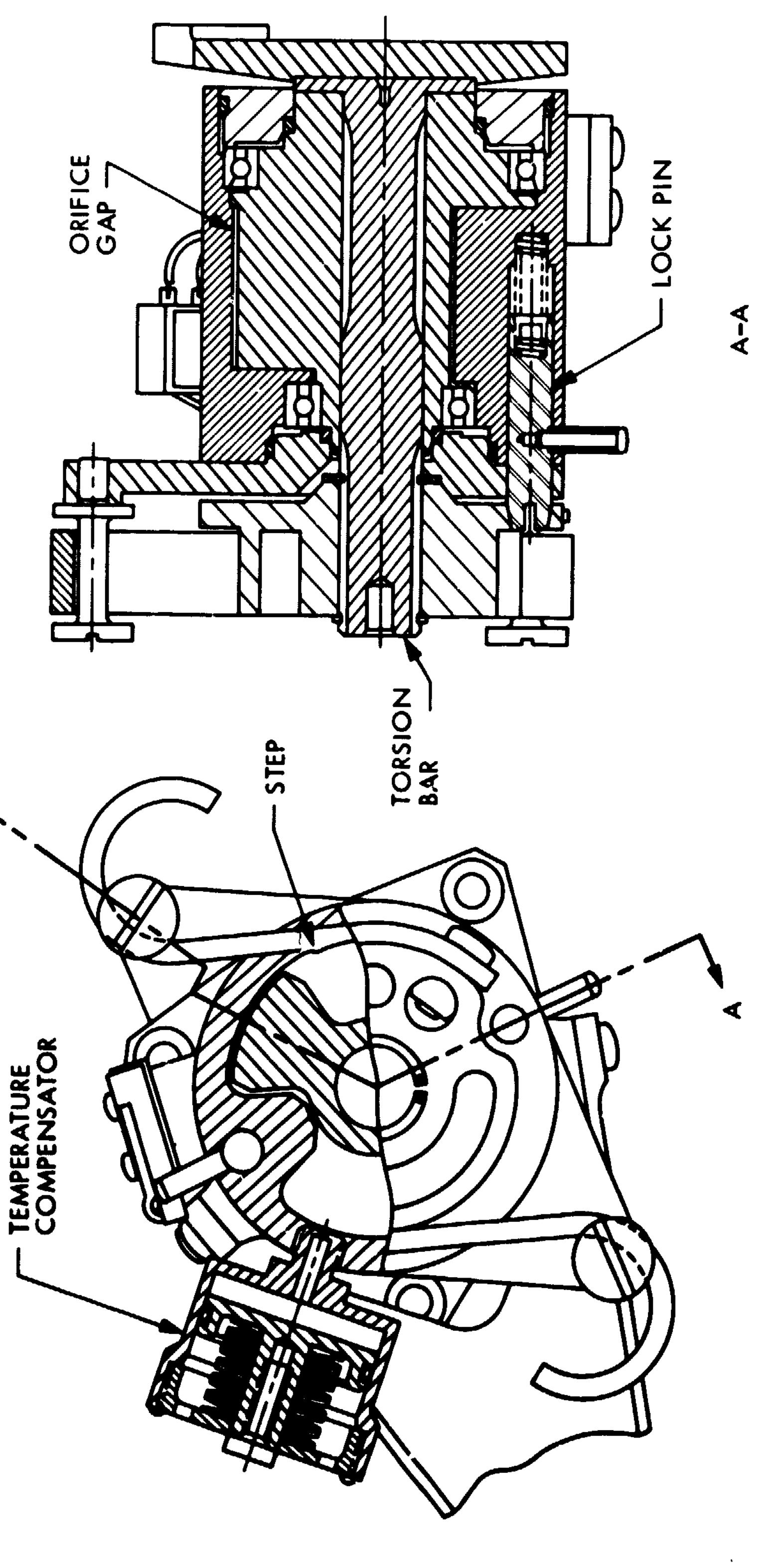

Figure 3. Rotary Vane Actuator/Damper Assembly

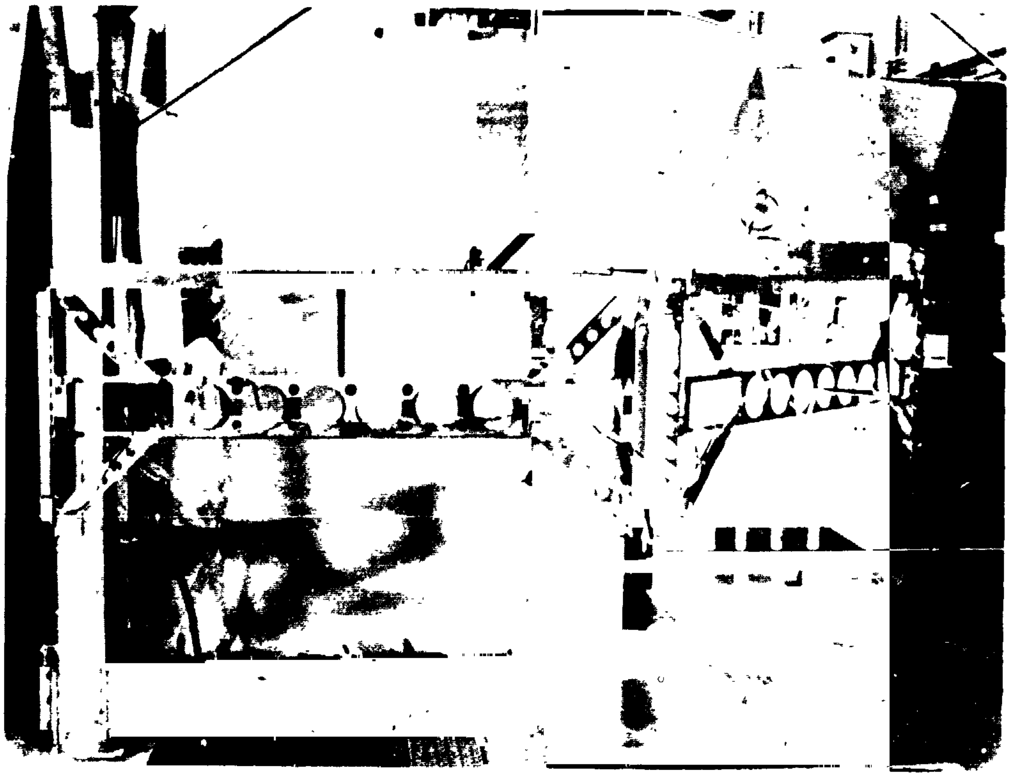

Figure 4. Deployment Test Setup With Simulated Solar Panels

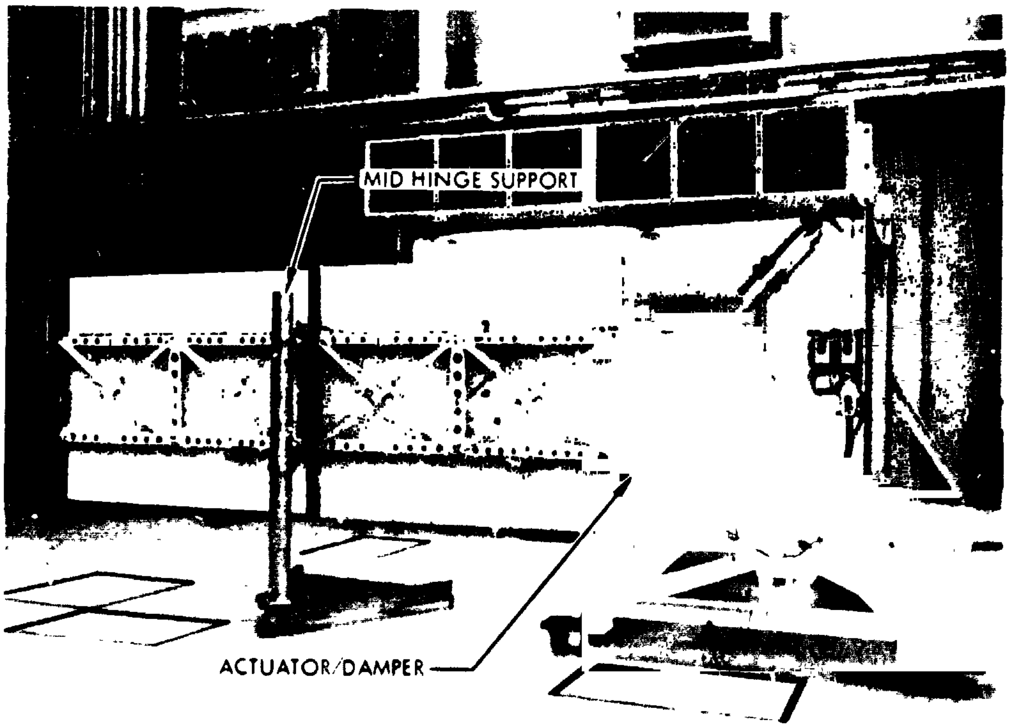

Figure 5. Final Testing of Flight Solar Panels and Actuator/Damper

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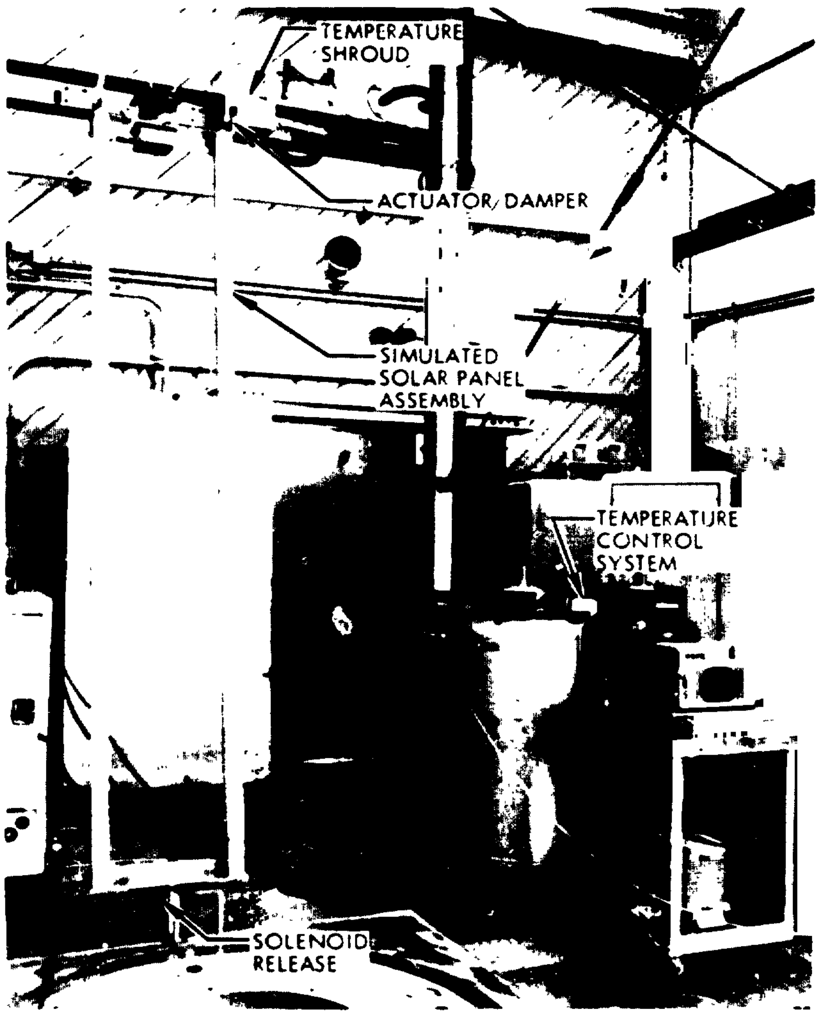

Figure 6. Damping Test Equipment

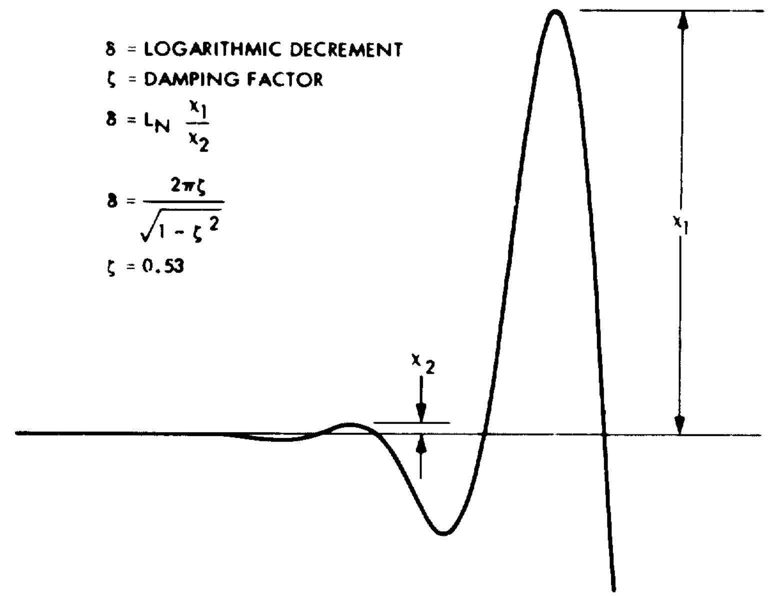

Figure 7. Representative Damping Curve