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SECURING MECHANISM FOR THE DEPLOYABLE COLUMN OF THE HOOP/COLUMN ANTENNA

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ABSTRACT

The Column Longeron Latch (CLL) was designed and developed as the securing mechanism for the deployable, telescoping column of the Hoop/Column antenna. The column is an open lattice structure with three longerons as the principal load-bearing members. It is divided into telescoping sections that are deployed after the antenna is placed in earth orbit. The CLL provides a means to automatically lock the longeron sections into position during deployment as well as a means of unlocking the sections when the antenna is to be restowed. The CLL is a four-bar linkage mechanism using the over-center principle for locking. It utilizes the relative movement of the longeron sections to activate the mechanism during antenna deployment and restowing. The CLL design is one of the first mechanisms developed to meet the restowing requirements of future spacecraft which will utilize the STS retrieval capability.

INTRODUCTION

The National Aeronautics and Space Administration currently has a program for development of Large Space Structure Technology (LSST). Some future spacecraft such as the Hoop/Column antenna and the Space Station will be so large that they will have to be either assembled in orbit or deployed once they are clear of the STS cargo bay. One of the Langley Research Center (LaRC) programs is the development of concepts for deployable large space structures.

The Hoop/Column antenna concept, as shown in Figure 1, has been selected as a focus for development of all system disciplines and is being designed as a candidate Shuttle cargo. The antenna, possibly as large as 122 meters (400 ft) in diameter, with the electronic feed system suspended on an 85 meter (279 ft) column, will be stored in the STS cargo bay. It will be deployed while in orbit and then restowed for STS entry/landing.

The main column for antenna deployment is composed of 23 internally-nested telescoping sections. Each section has three longerons spaced 120° apart with a CLL located at the end of the longerons. There are a total of 63 identical CLL's in the column. A servo motor located in the center bay applies a tensile force to cables that are threaded through each set of longerons, as seen in Figure 2, to effect deployment. The same servo-motor may be used for retrieval by pulling on a single cable that is threaded through the center of the column and is attached to the top column section.

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REQUIREMENTS

It is required that the antenna column sections be sequentially locked during extension and unlocked during the restow operation. Each of the longerons when deployed must carry a compressive load of up to 1114 N (250 lb). The CLL was designed to fit within the 19.05 mm (0.75 in) diameter longeron. The design load for the CLL components was taken to be 2304 N (515 lb). This load was developed from the longeron compressive force of 1114 N (250 lb) plus 334 N (75 lb) latch margin in the locked position to allow for some tolerance buildup and to provide column rigidity. The 1447 N (325 lb) force on the latched mechanism and the CLL latching geometry generates a maximum force of 2004 N (450 lb) at the instant the mechanism passes the center point. An additional factor of 1.15 was superimposed to allow for a factor of safety resulting in the design load capability for the CLL of 2305 N (515 lb). Stainless steel (17-4 PH) was selected for the CLL test components to accommodate the design loads in the small sized package.

OPERATION

Deployment of column sections initiates the rotation of the actuator arm that is extended into the housing at the base of each longeron. As longeron B and C move relative to longeron A, the CLL restraining and actuator arms rotate as shown in Figure 3. The actuator arm then rotates into an over-center position, locking the linkage into position. After latching over-center further rotation is stopped when surface A of the restraining arm mates with surface B of the actuator arm in Figure 3. In the action of locking, the stops of longerons A and B merge into position engaging two guide pins, which force alignment and provide shear restraint.

The belleville spring washers and piston housed at the top of each longeron, see longeron A in Figure 3, are an integral part of the latching system. As the restraining arm swings toward the locked position, it drives the piston against the washers causing them to compress. In general, over-center mechanisms rely on the four-bar linkage to deflect when moving to an over-center position. The classic approach was unacceptable for the CLL because the small size caused excessive stress in the pins and linkage. In the CLL design, the belleville spring washers absorb most of the deflections and serve to limit the maximum force necessary to latch. The resulting preload of spring and actuator arms is set to provide a rigid column for the expected external loads.

The single cable attached to the top column section retrieves the column. The bottom of each longeron strikes the extended actuator arm, as seen in Figure 4, unlatching the CLL. This process is continued until all sections are restowed to their original positions.

ANALYSIS

Three analytical models were used in the analysis of the CLL. A kinematic model was used to develop the length and pivot locations of the four bar linkage. The links and pins were sized by closed form mathematical expressions developed from force and moment diagrams. Finally, a finite element model of the restraining arm was generated to allow a more accurate calculation of the stresses in this element, since this was identified as the most critically loaded link from the previous closed form solutions.

The kinematic model of CLL is shown in Figure 5. During deployment, link BC actuates the four-bar linkage consisting of BD, DE, EF, and FB. During restow, link AB actuates the four-bar linkage. Links DB, DE, and GH are loaded in compression while links EF and FG react bending loads. Links FH and FB are loaded in tension to react the bending and compression loads. The linkage is centered when angle I, between links BD and ED, equals 180^o. Further counterclockwise rotation of DB into an over-center, locked position decreases angle I to 165^o, point G travels in a positive y-axis direction .25 mm (.010 in) as angle I changes from 180^o to 165.2^o. The belleville spring washers prevent a sharp increase in the stresses in the restraining arm during the over-center travel of the CLL. The perpendicular distance to point D from a line joining point E to point B equals .86 mm (.034 in). This distance represents the margin of safety for the CLL against accidental restow. Point G exerts a maximum compression force of 2004 N (450 lbs) on the belleville spring washers when angle I equals 180^o.

All components of the CLL were analyzed by closed form solutions. Forces, moments, free body diagrams and load, shear, and moment diagrams were generated. As a result of the analysis the pins were required to be 3.17 mm (.125 in) in diameter. The maximum force at point C and A respectively, as shown in Figure 5, to latch and unlatch the CLL was calculated to be 150 N (33 lb).

The restraining arm was further analyzed by a finite element model as a check on the closed form stress solution because it is the most highly stressed link and has a complex shape. The maximum bending stress of 454 x 10^6 Pa (66,000 psi), shown in Figure 6, occurs when angle I, from Figure 5, equals 180^o. This stress is within 15 percent of the stress predicted by the closed form solution. The steady state stress, when the CLL is latched, is 289 x 10^6 Pa (42,000 psi). Corresponding deflections at point A from Figure 5 are 127 x 10^{-3} mm (.005 in) when angle I equals 180^o and 76.2 x 10^{-3} mm (.003 in) when latched.

TESTING

Four tests were conducted in developing the CLL. A compression test of the top housing, piston, and belleville spring washer assembly was necessary to develop required preload capability shown in Figure 7. A compression test was conducted on the total latch assembly to simulate the deployed column loading condition, shown in Figure 8. Two tests were conducted to confirm the column longeron loads necessary to latch and unlatch the CLL shown in Figure 9 and 10.

The compression test of the top housing, piston, and belleville spring washer assembly was conducted to determine the number and combination of washers required to obtain a piston preload of 1447 N (325 lb) with the CLL latched while limiting the maximum piston load to 2004 N (450 lb). The combination of 11 belleville spring washers shown in Figure 7 gave the required load conditions with a piston stroke of 0.58 mm (.023 in).

The compression test of the latch assembly gave the preload and the strain in the restraining arm. As a load was applied, the distance between the stop distance A was measured. At a load of 1438 N (323 lbs), a gap was obtained, and the test was stopped. The gap signified that the preload of the latch had been obtained. The steady state strain in the restraining arm was measured at 1.25×10^{-3} corresponding to 258×10^{6} Pa (37,500 psi). This differed from the finite element model results by only 11 percent.

The latching load was determined by test, shown in Figure 10, to be 850 N (190 lb). This is six times the value predicted by calculations. The large variance is attributed to a high friction load between the loading longeron and the test housing assembly, and the friction between links and pins. However the peak strain in the restraining arm was 1.76×10^{-3}, which represents a stress of 363×10^{6} Pa (52,800 psi). This stress is 20 percent lower than the peak stress predicted by the finite element analysis. The unlatching load was determined by test, shown in Figure 9, to be 530 N (119 lb), which is over three times the calculated value. This difference is attributed to friction between pins and links.

CONCLUSIONS

The test data verified the analysis with the exception of the latching and unlatching loads. These differences are attributed to excessive friction in the test setup. A modification to the latch assembly test housing is being made for retesting of the deployment loads. A modification may be made to the actuator arm to reduce the latching and unlatching loads. Based on the design, analysis and tests, the CLL design shows good potential for a solution to the latch and unlatch problem of a deployable space system where a restow capability is required.

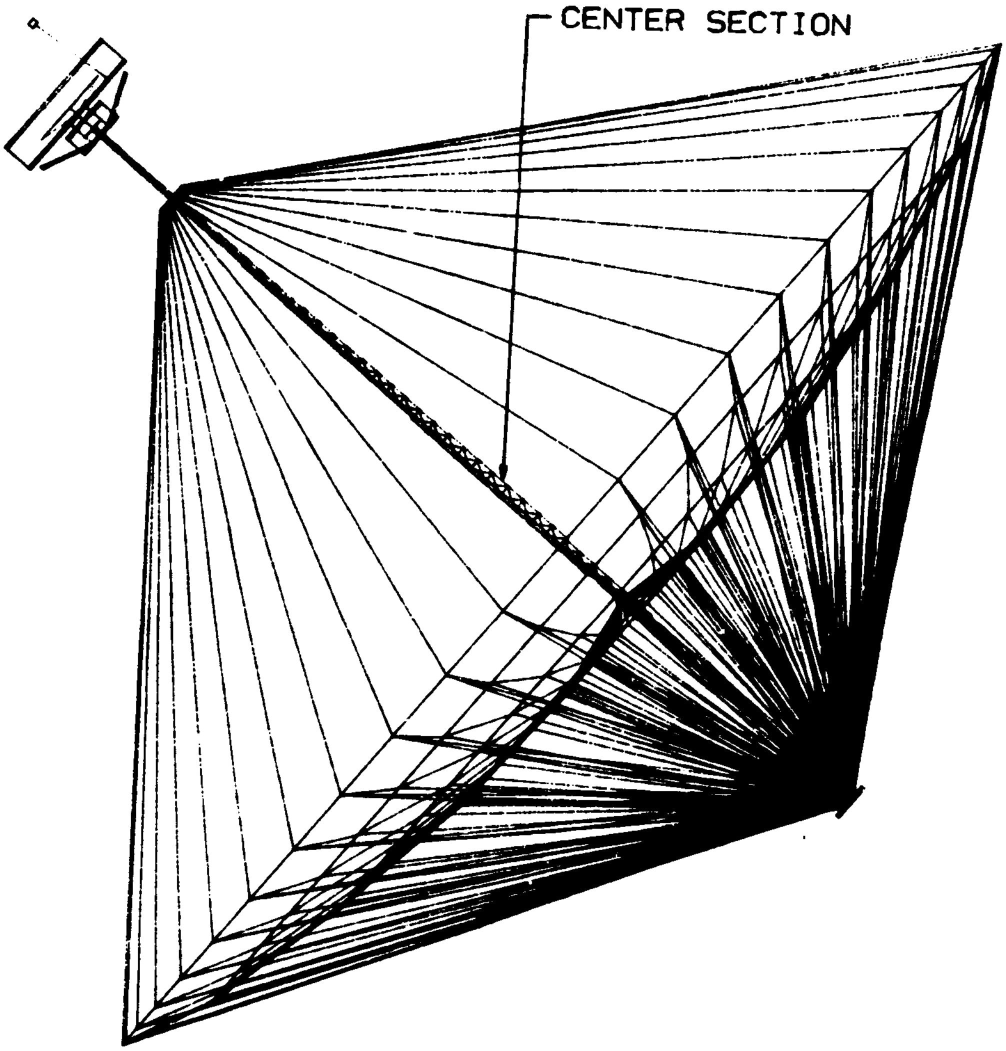

FIGURE 1.- HOOP/COLUMN ANTENNA

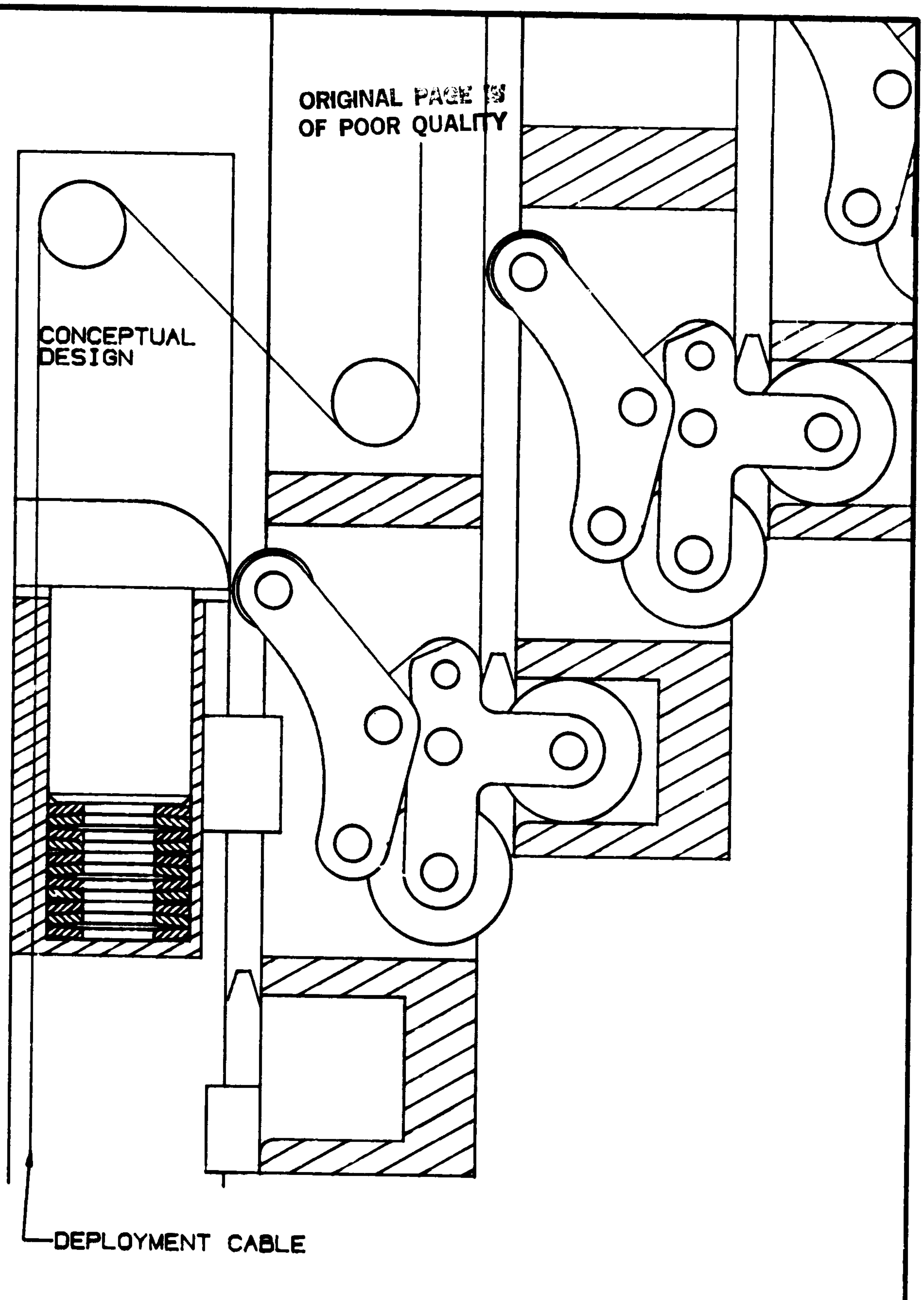

FIGURE 2.- LONGERON DEPLOYMENT

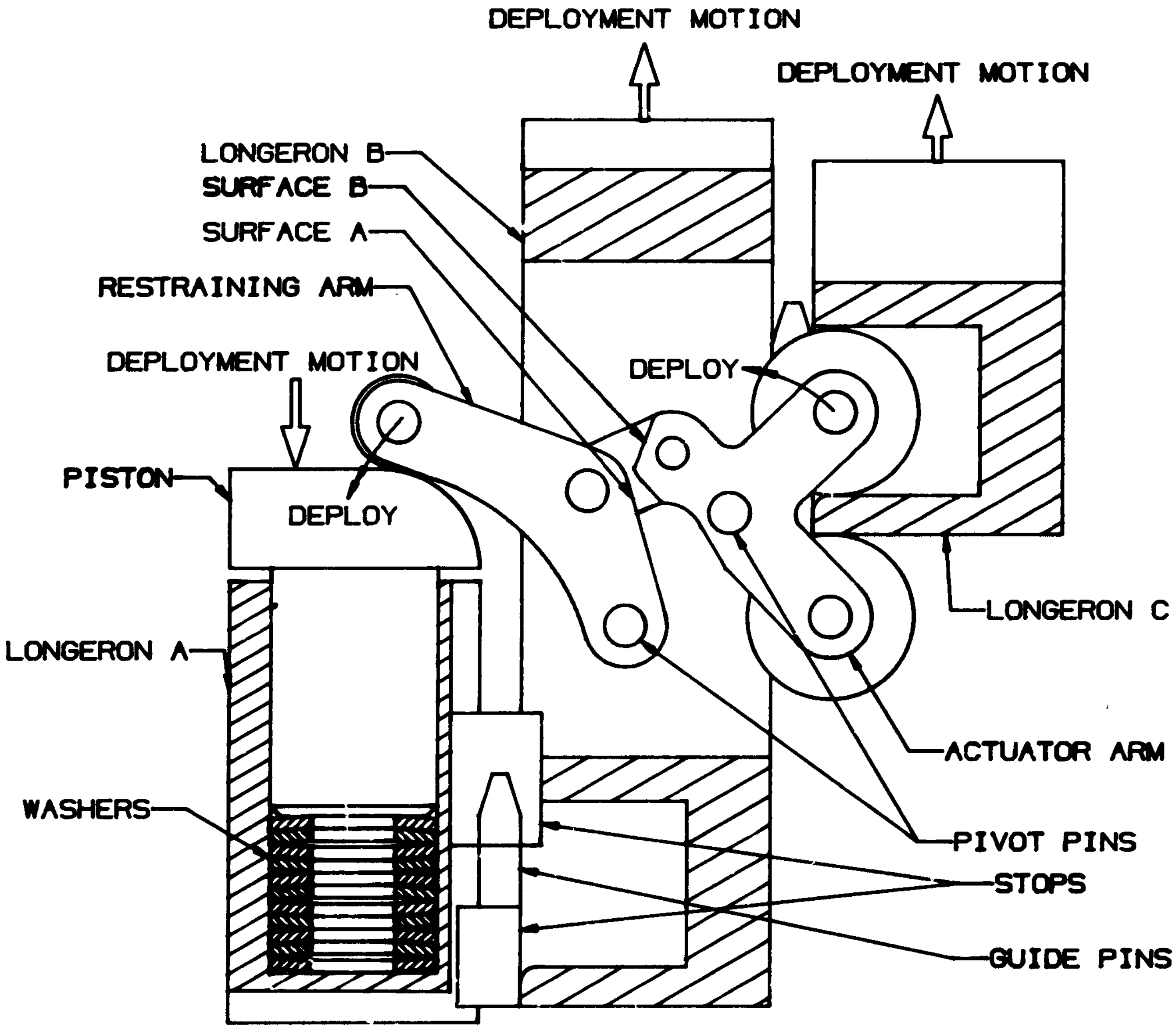

FIGURE 3.- LATCHING MODE

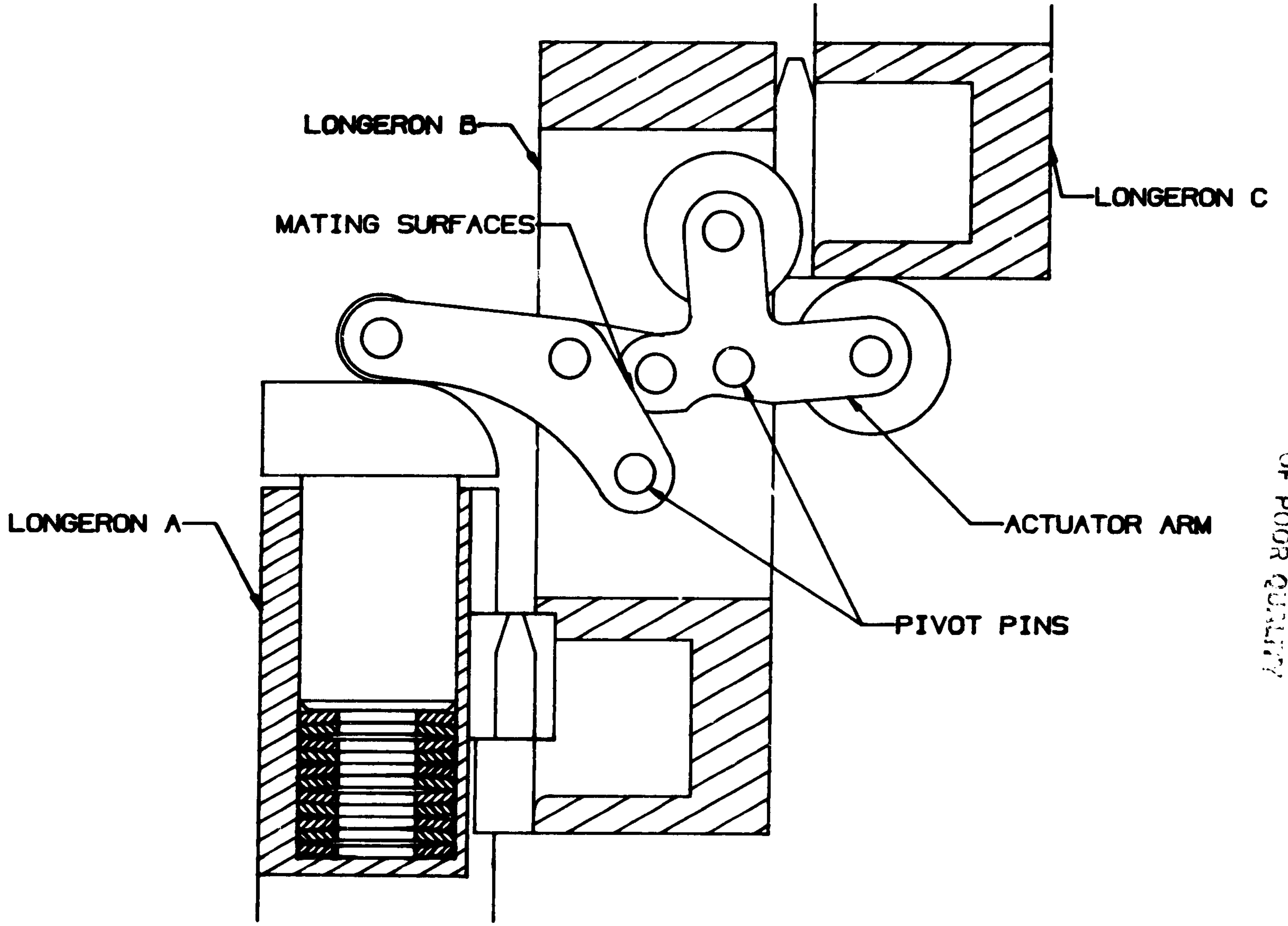

FIGURE 4.- DEPLOYED LATCH

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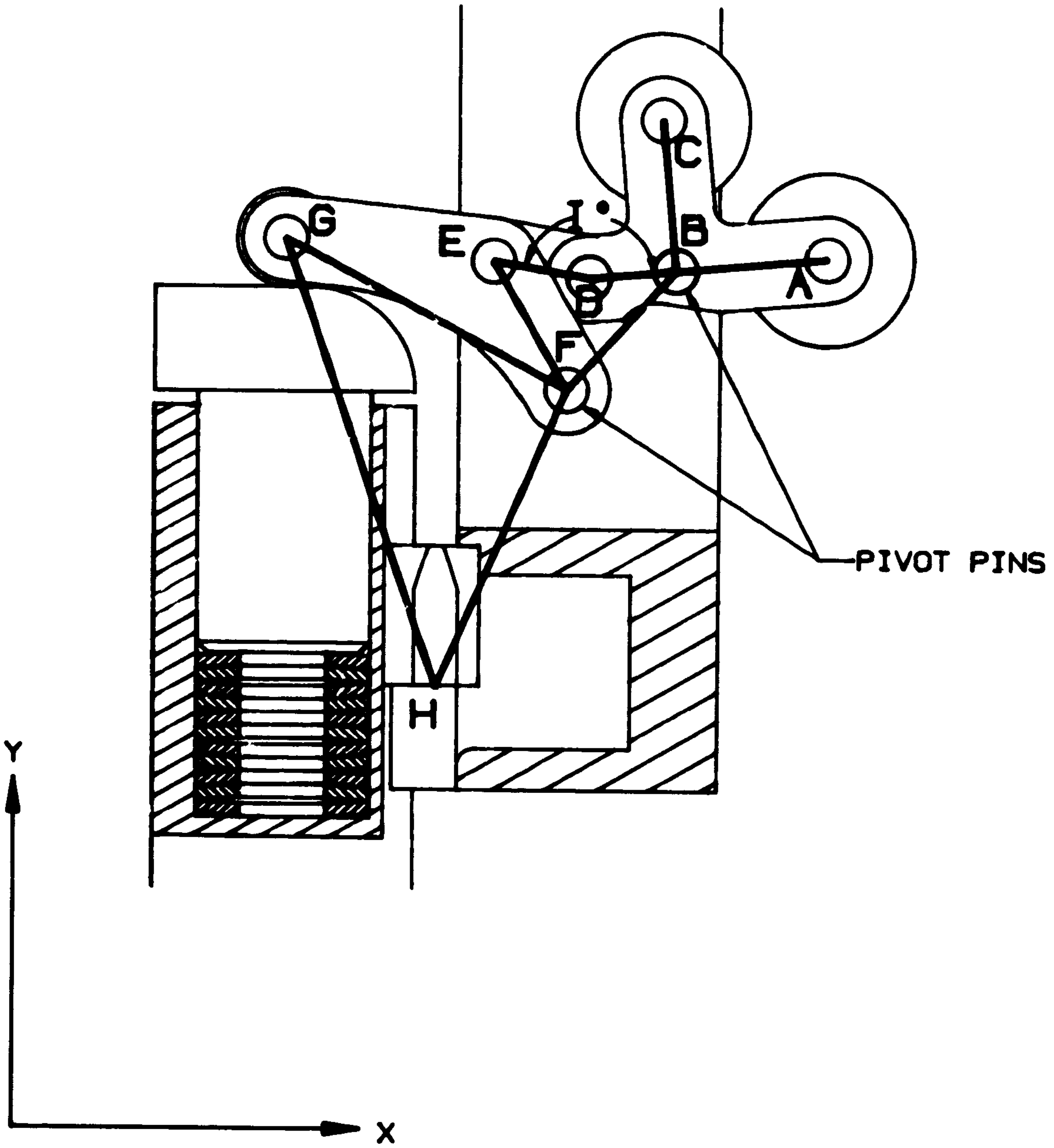

FIGURE 5.- KINEMATIC MODEL

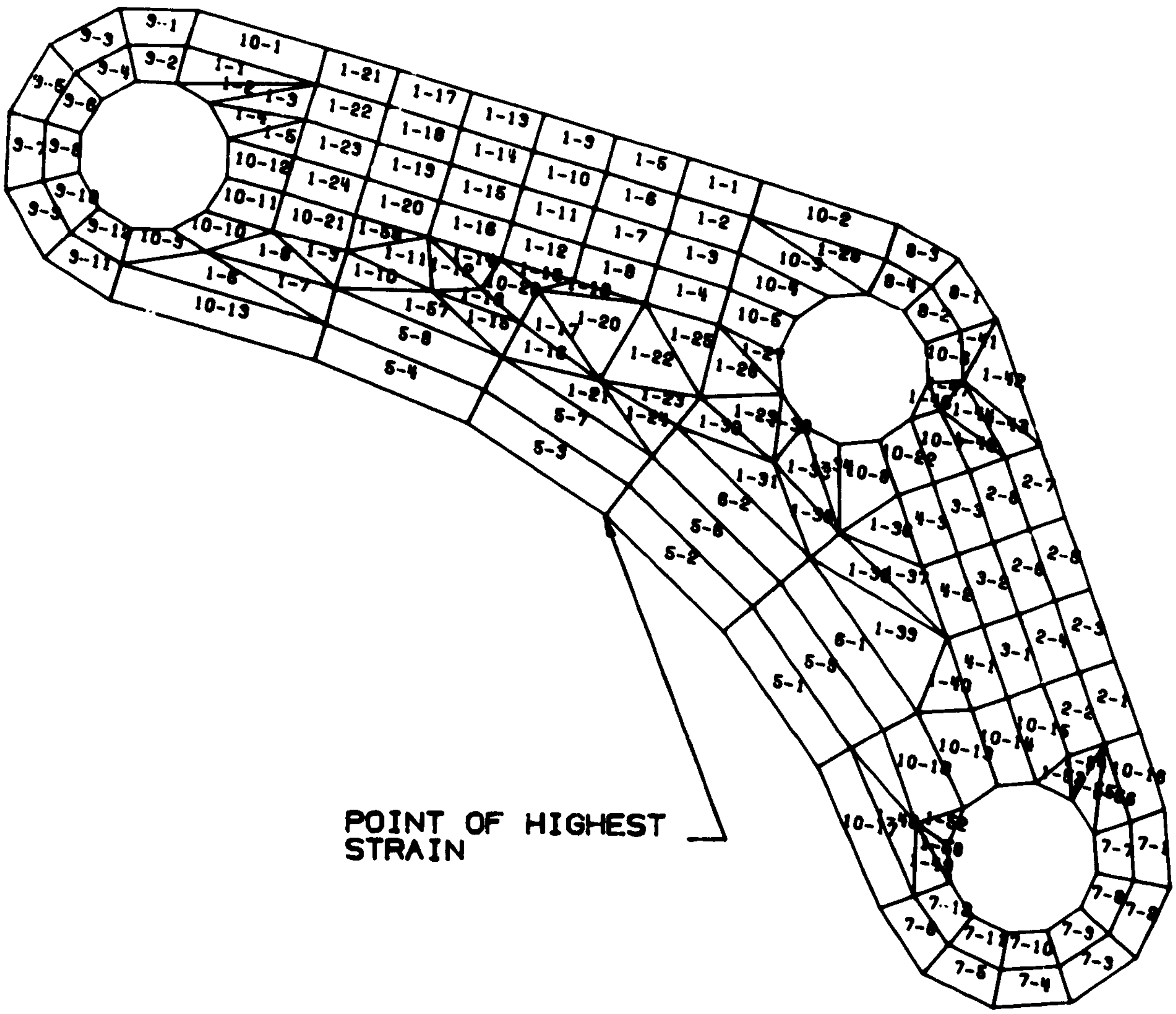

FIGURE 6.- FINITE ELEMENT MODEL

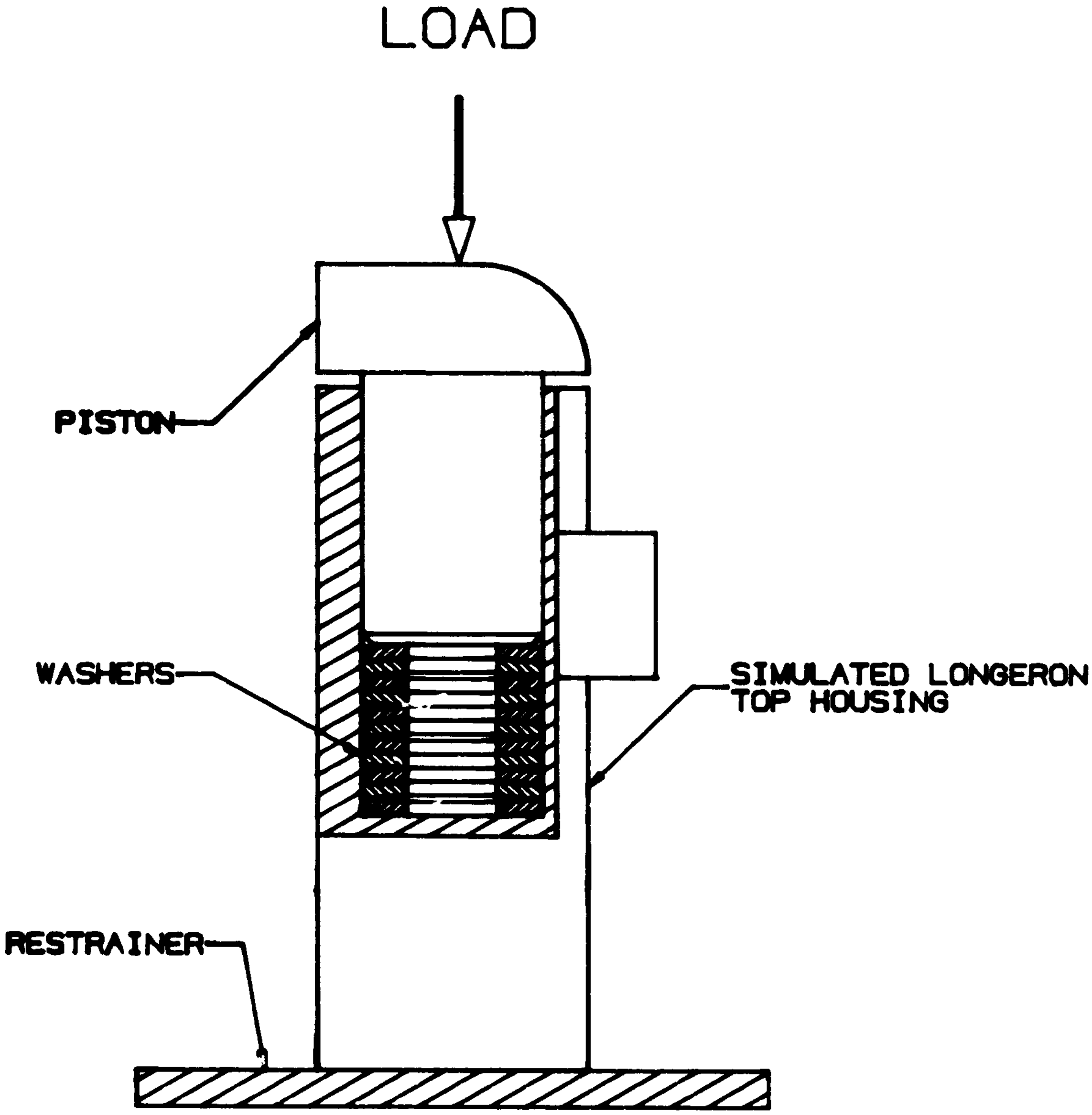

FIGURE 7.- COMPRESSION TEST

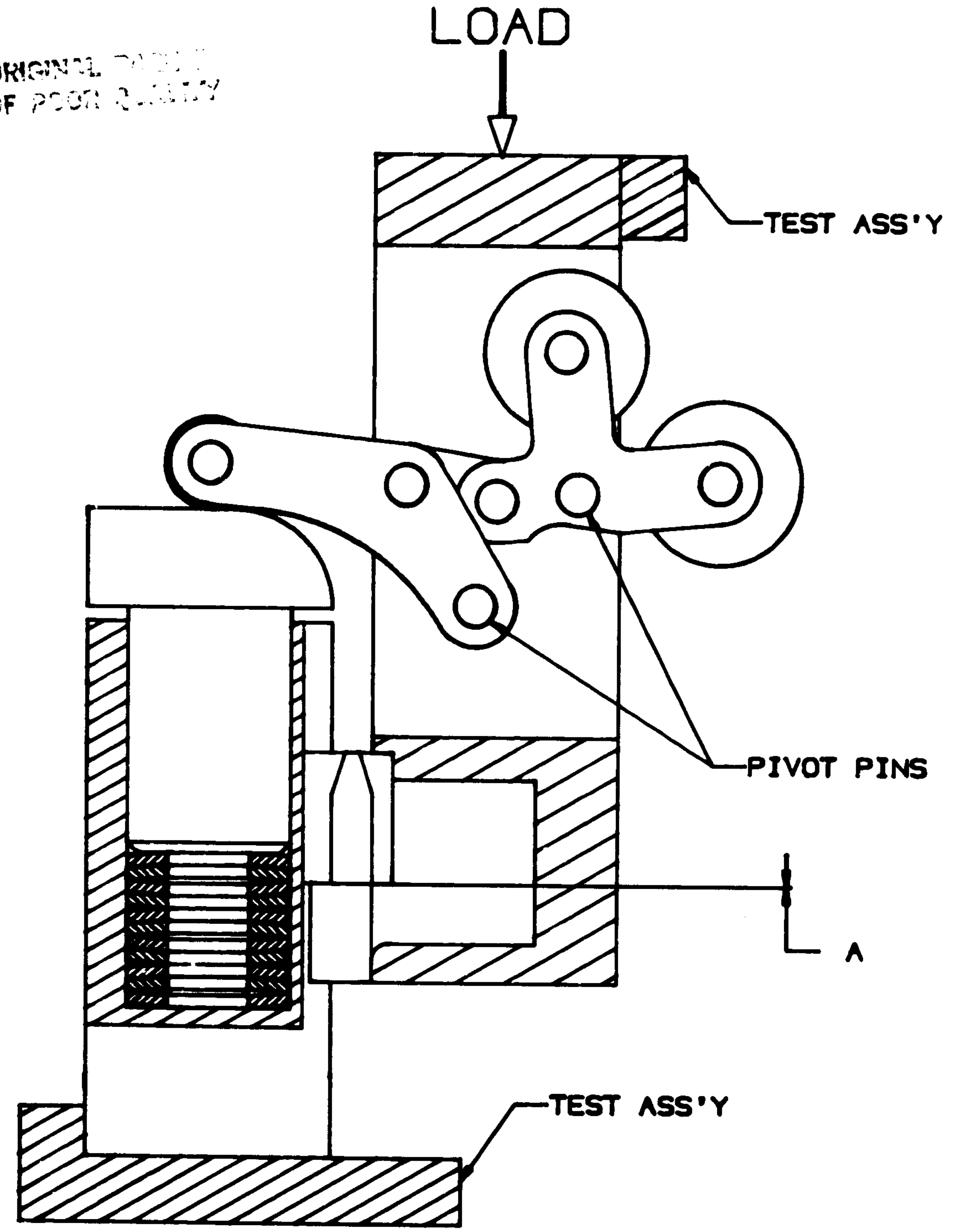

FIGURE 8.- COMPRESSION TEST ASS'Y LOADED CLL

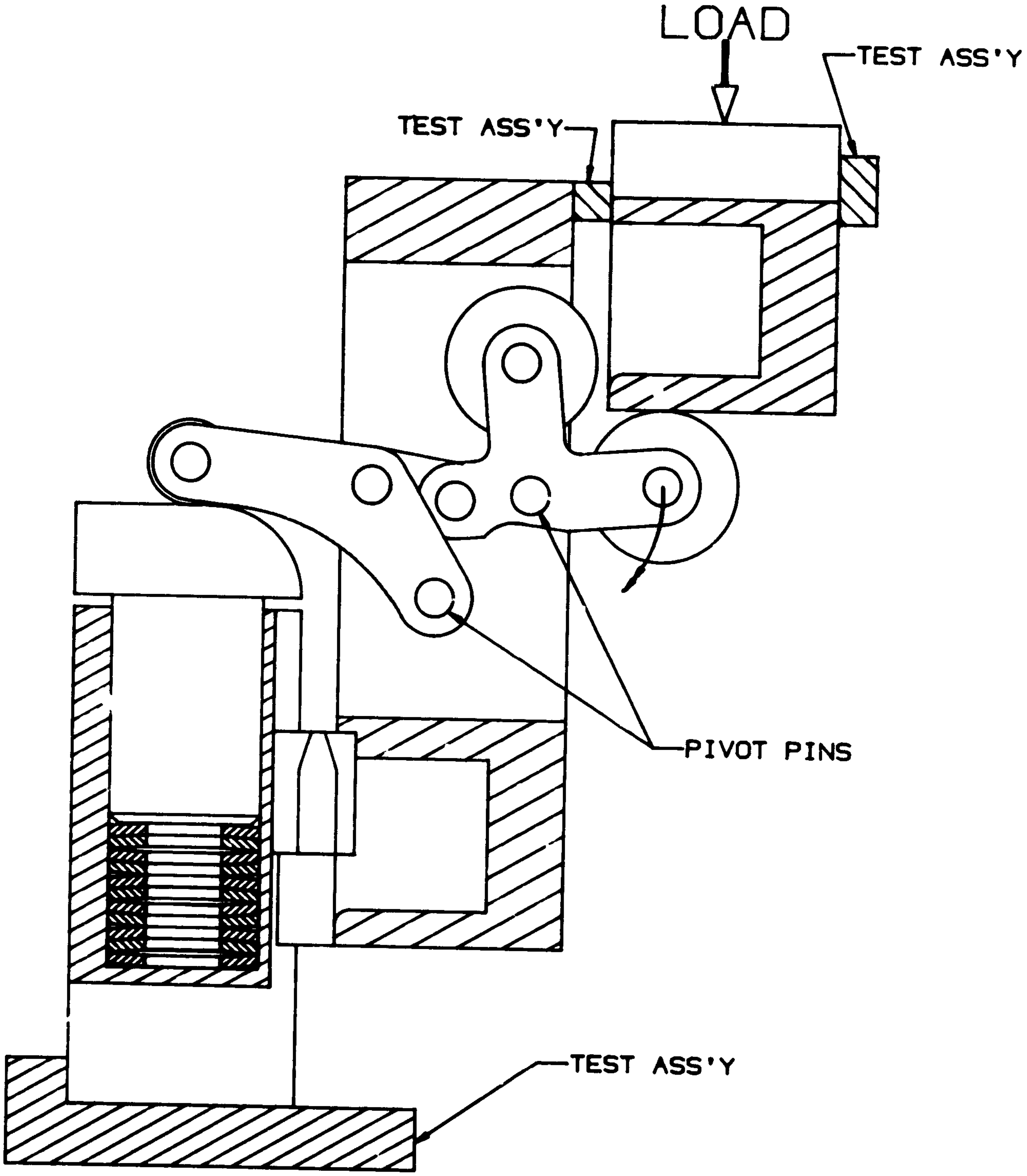

FIGURE 9.- UNLATCHING TEST

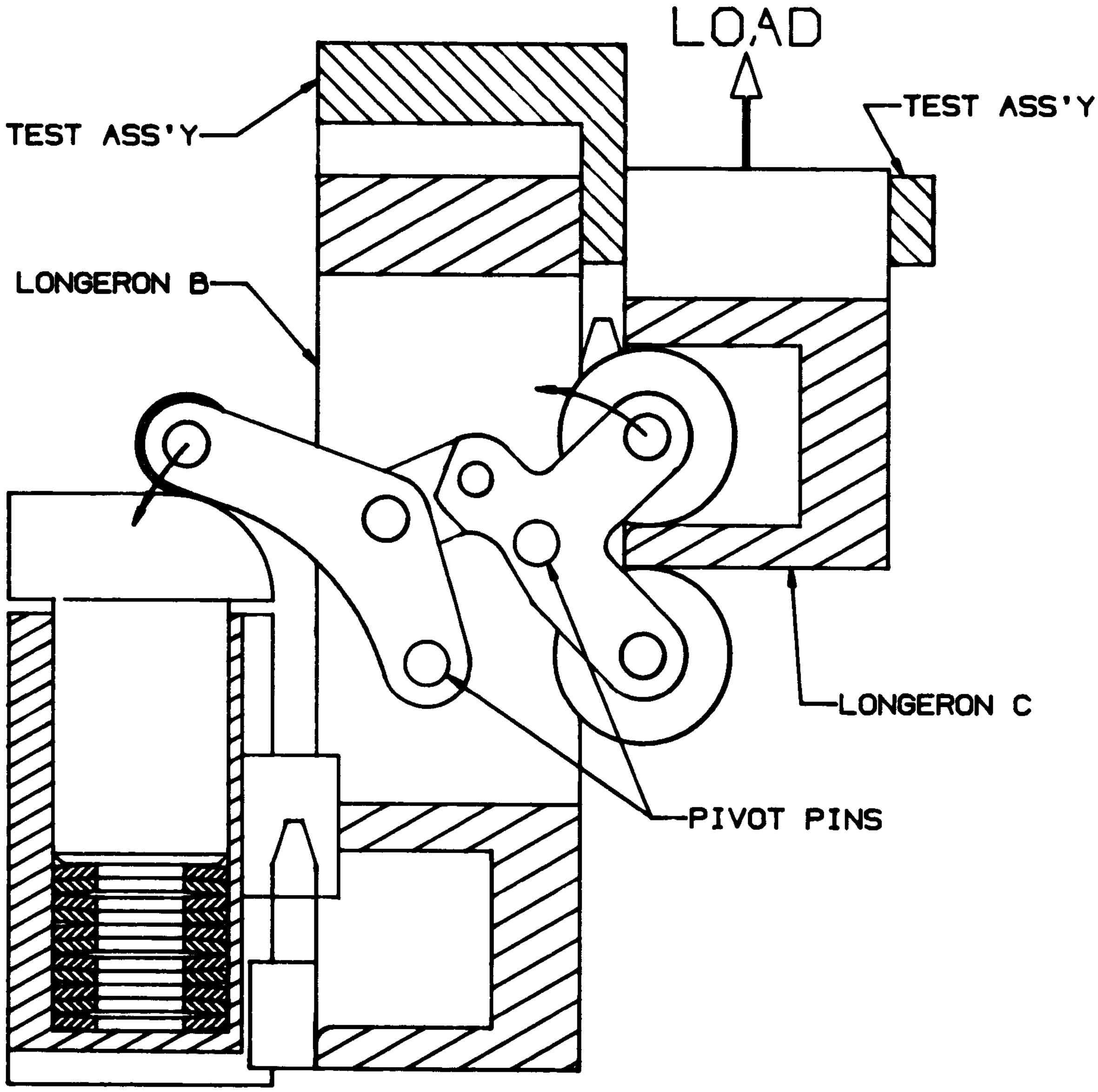

FIGURE 10.- LATCHING TEST