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CEN-326 (F)

FINAL CORE SUPPORT BARREL INSPECTION REPORT

POST CYCLE SIX

ST. LUCIE UNIT ONE

MARCH 1986

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LEGAL NOTICE

St. Lucie Unit 1 Final Core Support Barrel Inspection Report

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FIGURES

1.0 INTRODUCTION

1.1 Background

During the Post-Cycle 5 outage of St. Lucie Unit 1, repair work was performed on the Core Support Barrel (CSB). The thermal shield, which had loosened from its supports, had been damaged and was removed. The CSB, which was damaged by the loose thermal shield, was nondestructively examined to identify the extent of damage and to select an appropriate method of repair. Non-through wall cracks were machined and blended. Crack arrestor holes were machined into the CSB at the termination points of all through wall indications. To limit bypass leakage through the crack arrestor holes, appropriately sized expandable plugs (for circular holes) and patches (for non-circular holes), secured by expandable plugs were used to seal these areas. A post-repair inspection was performed to verify proper installation of plugs, and patches and to provide a baseline for comparison of data obtained during future inspections. The overall repaired condition of the CSB is illustrated in Figure 1. A description of the repair activity can be found in CEN-272(F)-P, "Final Report on the St. Lucie Unit 1 Post Cycle 5 Plant Recovery Program", issued February 1984, Reference [1]. In accordance with FPL commitments made in CEN-272(F)-P, an inspection of the CSB repaired areas was conducted following Cycle 6.

1.2 Scope of Post-Cycle 6 CSB Inspection

The scope of the Post-Cycle 6 CSB inspection included a visual examination of the repaired areas to look for evidence of looseness, motion, or wear on the plugs and patches as well as indications of new or continued crack growth in the base metal.

In addition, the residual flange deflection of each of the installed plugs was checked; its status documented and compared to predetermined screening criteria.

The visual inspection of the CSB was performed with a remotely controlled underwater TV camera system. Eddy current examination techniques were available as backup to resolve any indications which were identified and considered unresolvable by visual means. The examination included both video scanning for the actual inspection of the CSB and still photography of the repaired areas as a means of providing the permanent visual record.

All repaired thermal shield support lug areas on the CSB were examined. The minimum area of examination extended 3 inches beyond each support lug repair. All previous crack locations were examined for a minimum of 3 inches on either side. Each plug and patch was visually inspected for looseness as would be indicated by wear at the flange, gaps indicating loss of preload, or changes in plug orientation (identified by a "Λ" and the identification number stamped in the plug flange).

Still photographs were taken at each of the repaired areas of the CSB. The photographs provide documentation of the CSB condition. During the Post-Cycle 6 video scanning, photographs taken during the Post-Cycle 5 repair inspection were used for comparative evaluation.

Plug residual flange deflection was assessed by using the same remote inspection technique used after the initial plug installation. The installation process assured that the expandable plugs were sufficiently preloaded to maintain an adequate load for the design life of the plant. The purpose of the mechanical inspection was to determine Post-Cycle 6 plug residual preload by measuring the deflection of the plug flange to ascertain that sufficient preload was retained for the plug to provide its design function.

1.3 Summary of Results

All visual inspections were recorded and detailed by qualified inspectors on data sheets showing the configurations of each lug area inspected. The data sheets and video recording were then evaluated by engineering for final acceptability. The results showed no crack extension and no evidence of plug or patch movement. The CSB condition was found to be unchanged from the Post-Cycle 5 baseline post-repair visual inspection. The results of the visual examination, therefore, show the CSB to be acceptable for continued service.

All flange deflection measurements taken during the Post-Cycle 6 inspection were above the screening criteria for maintaining the plug preload to the end of the plant's design life. The plugs, therefore, have sufficient preload in their present installed condition to continue to provide their design function and are acceptable for continued service.

2.0 TOOLING AND PREPARATION

The following enhancements of inspection techniques were considered for the Post-Cycle 6 CSB visual examination.

(1) Remote delivery of inspection equipment on a stable platform,

(2) Oblique, variable intensity lighting, and

(3) State of the art computer enhancement of the video.

The first two items (delivery system and lighting) were adopted for the inspection. However, an evaluation of the third item (computer enhanced video) showed that, of the several systems considered, none could reliably discern cracks from surface indications such as scratches and, therefore, the technique was not used.

2.1 Visual Inspection Tooling

The exterior of the CSB was visually inspected using an underwater TV camera mounted on an ISI-2B positioner (Figure 2) with oblique and variable intensity light sources. The ISI-2B positioner, which was specifically modified for this inspection to enhance the visual examination capabilities, is an In-Service Inspection, telescoping tube assembly that is normally used for Non Destructive Examination (NDE) inspections of reactor vessels.

The ISI-2B positioner is a 3-part telescoping tube assembly designed to be assembled at poolside and capable of a vertical travel of 38 feet. A specially designed transition assembly is bolted directly to the positioner and provides a 30 inch horizontal travel capability. Incorporated into the transition assembly was a 90 degree pivot mechanism to allow the underwater TV camera or auxiliary tooling to be retracted (to clear the CSB upper flange) upon entry to and removal from the pool. Movement of the positioner was remotely controlled from the console of a Data Acquisition Trailer stationed outside containment.

The video inspection was performed with an underwater TV camera mounted to the transition assembly. A gear box attached to the camera provided 30 degrees of vertical and horizontal motion, providing the examiner with a generous field of view. The TV camera system has a horizontal resolution in excess of 600 lines, an angle of view in water of approximately 22 degrees and a focal length from 3 inches to infinity. The camera was mounted to the transition assembly at the optimum focal distance. Lighting was mounted on the transition assembly and an additional light was mounted on the TV camera with all lights having variable intensity controls. The visual system was qualified and exceeded the requirements of the ASME code for visual examinations. Suspected indications of at least 5 mils in width can be resolved with this camera.

Still photographs were taken with a conventional 35mm camera mounted in a dry box. The unit was pole delivered to the repair areas and provided a permanent visual examination record.

2.2 Flange Measuring Tools

During the Post-Cycle 5 repair, a specially designed measuring tool was used to verify that the plugs were properly installed. For consistency of measurement, the same inspection technique was used for the Post-Cycle 6 inspection. In preparation for the inspection, the following refurbishments and enhancements were made to the plug measuring tools.

(1) All tools were completely refurbished with new hydraulic cylinders, tested and calibrated.

(2) Hydraulic and air lines of the delivery system were replaced with fixed stainless steel lines. This decreased tool changeout time, improved tool handling and stability.

(3) Adjustability of the elastomer position was provided. This improved the engagement of the inspection tool to the plug, reducing the measurement trials required to get consistent readings.

(4) Aluminum air tanks were replaced with stainless steel tanks, thus eliminating air leakage at welded joints.

The plug inspection tool measured flange deflection of installed plugs and was used with a delivery system. The delivery system is a long mast assembly with attached air tanks for buoyancy. The plug inspection tool was attached to the delivery system and the tool was submerged to the elevation of the plug to be inspected. The water level in the air tank was adjusted to make the tool weightless and, therefore, easy to maneuver underwater.

To provide a better understanding of the purpose of the measuring tool, an explanation of a typical plug installation follows. A fundamental design objective for the installed plugs was that they be preloaded in the CSB. When initially assembled on the installation tool, the plugs were preloaded by deflecting the plug flange to generate a spring force in the plug (i.e., similar to the action of a belleville washer). Figure 3 illustrates the process of deflecting the expandable plug flange on the installation tool. The plug is placed over the nose of the installation tool. The collet is actuated so that it closes down and grips the outer periphery of the plug flange. The collet then draws the plug back. Once the inside periphery of the flange contacts the adjustable collar, the force of the backward moving collet rolls the flange back a predetermined amount. The plug is then inserted into the CSB hole and the elastomer expanded in order to bulge the plug into place.

Figure 4 shows a cross sectional view of an installed plug. Once the bulge is formed and seated into the back chamfer of the hole in the CSB, the flange is released by the installation tool collet. Some spring-back of the flange occurs, but the bulge contact maintains the plug flange in a deflected configuration, thus preloading the plug into the CSB.

Figure 5 illustrates the plug inspection tool. The inspection tool is inserted into an installed plug and the elastomer expanded. As the elastomer extrudes into the bulge of the plug it draws the tool forward into the plug until contact of three support pins on the inspection tool is established. In this configuration four linear variable displacement transducer (LVDT) probes measure the deflected condition of the flange. Prior to installation at Post Cycle 5, each expandable plug was tested to establish the load deflection characteristics of the flange at room temperature. The flange deflection of an installed plug can be correlated via the load deflection curve to a preload force in the plug.

3.0 VISUAL INSPECTION

As described in Section 2.1, the visual inspection of the CSB was performed with a remotely controlled, underwater TV camera system. All repaired CSB areas were examined. The minimum area of examination extended 3 inches beyond each thermal shield support lug repair. All previous crack locations were examined for a minimum of 3 inches on either side.

Each plug and patch was inspected for signs of looseness. The inspection consisted of examining for signs of motion or wear at the plug flange, gaps underneath the plug flange indicating loss of preload, or changes in plug orientation. The original orientation is identified by a "Λ" and identification number stamped in the plug flange. The patch interface with the CSB was examined for indications of wear or changes from baseline photographs.

A video recording (with identifying audio) was made of each lug area inspected.

3.1 Screening Criteria

The inspection of the CSB was conducted in accordance with the following screening criteria:

(1) A repaired area of the CSB is considered acceptable if the examined condition is found to be unchanged from the 1984 post-repair baseline as documented by photographs.

Indications detected by visual examination techniques which differed from the post-repair baseline documentation which could not be resolved by additional visual examination techniques were to be eddy current tested. Positive eddy current indications differing from the Baseline Documentation and emanating from an existing crack, hole, or machined area were to be documented and evaluated. Indications exceeding 1/4 inch in length and not emanating from an existing crack, hole, or machined area were also to be documented and evaluated.

(2) A plug on patch installation was considered acceptable if there were no signs of looseness, motion or wear when considered in conjunction with the flange deflection readings.

3.2 Photographic Documentation

Still photographs were taken at each of the repaired areas of the CSB. The photographs provide documentation of the CSB condition. During Post-Cycle 6 video scanning, photographs taken following the Post-Cycle 5 repair were used for comparative evaluation. These photographs will be used as baseline for any subsequent visual inspections.

3.3 Results

All visual observations were recorded and detailed by qualified inspectors on data sheets showing the configurations of each lug area inspected. The data sheets and video recording were evaluated by engineering for final acceptability. The results showed no crack extension and no evidence of plug or patch movement. The CSB condition was found to be unchanged from the 1984 post-repair baseline visual inspection as documented by photographs. These results, therefore, show the CSB to be acceptable for continued service. No eddy current examination was necessary to corroborate the visual findings.

4.0 MECHANICAL INSPECTION

The purpose of the mechanical inspection was to determine the Post-Cycle 6 plug preload by measuring the deflected shape of the plug flange. The expandable plugs and the patches were designed to accommodate the loads and thermal transients resulting from normal operation, upset and faulted conditions. The design objective for the plugs and patches was that they remain in place in the CSB for the design life of the plant. A fundamental design objective for the installed plugs was that they remain tight in the CSB during plant operation. Meeting this objective assures that the plugs seat adequately, thereby limiting bypass flow and motion of the plug due to hydraulic loading.

The amount of preload necessary to limit leakage and plug motion is governed by the pressure differential across the core support barrel, the hydraulically induced static and dynamic loading on the plug, the differential thermal effects caused by temperature gradients between the plug and core support barrel, and the radiation-induced relaxation.

4.1 Screening Criteria

The flange deflection screening criteria were based on an evaluation of the load required on each plug to prevent motion of the plug. The evaluation included the effects of radiation and thermal-induced relaxation, measurement error, CSB differential pressure, friction between the plug flange and the CSB, and differential thermal expansion. The radiation effects were determined for the specific azimuthal and axial location for each plug. The retained elastic deflection of each plug was established from a curve of retained elastic deflection vs. total installed deflection generated from test data for the various size plugs.

The flange deflection screening values employed during the inspection are given in Table 1. A flange deflection lower than these would require further detailed evaluation to determine the acceptability for continued service.

4.2 Plug Flange Deflection Loss Considerations

Plugs were installed into the CSB in a preloaded condition. Loss of plug preload may occur due to the following mechanisms:

(1) Stress relaxation from irradiation,
(2) Loss of flange deflection due to thermal cycling, and
(3) Loss of flange deflection due to vibration.

Irradiation relaxation is a continual process occurring gradually over the plant's operational lifetime. This mechanism has been quantified and incorporated into the screening criteria for each plug. Thermal cycling and vibration testing of plugs indicates that loss of deflection from these mechanisms occurs early in service life after a limited number of cycles. Test data shows that the change in deflection decreases as the number of cycles increases. This observation leads to the conclusion that the observed loss in deflection was the result of a seating-in process of the plugs, rather than being a progressive loss mechanism.

4.3 Results

Review of the inspection data shows that there was an overall loss of flange deflection, as would be anticipated based on the test data. In general, actual plug flange deflection losses were in some cases less and some cases more than that observed in the tests. The magnitude of deflection losses obtained during laboratory testing, however, are not necessarily directly comparable to the field numbers because of the controlled environment of the testing. The important aspect of the test results, however, which is not related to environmental conditions, is that they indicate that the loss in flange deflection due to thermal and vibration effects is not a continual process.

Table 2 presents the plug flange deflection results from the Post-Cycle 6 mechanical inspection. In all cases the Post-Cycle 6 flange deflection is above the screening criteria. These measurements, together with the visual examination results, lead to the conclusion that all plugs have sufficient preload to meet their original design function and, therefore, are acceptable for service through the end of the plant's design life.

5.0 FUTURE INSPECTION AND MONITORING

During the Post-Cycle 6 inspection, plug preload was determined by measuring the plug flange deflection. Any further loss of plug preload is expected to be gradual as a result of an irradiation relaxation process. Future inspection of plugs for a reduction in preload would, therefore, need to be carried out at long-term intervals since the relaxation process is gradual. The relaxation mechanism produces a loss in preload without a consequent change in flange deflection. The present inspection tool, therefore, cannot be used to detect a change in preload due to radiation-induced relaxation.

5.1 Long Range Inspections

FPL plans to perform examinations of the repaired areas of the CSB as part of future ten-year In-Service Inspections. The inspections will, as a minimum, consist of visual examinations of the repaired areas to detect crack extension, new cracks and plug and/or patch movement. The need for a more detailed inspection will be determined based on operating history up to that time. This approach is justified based on consideration of the results of the Post Cycle 6 inspection and the test data of plug and patch behavior.

As stated previously, the Post-Cycle 6 inspection of the St. Lucie 1 CSB showed that no degradation had occurred to the repaired areas of the CSB for the 18 month period encompassing Cycle 6 operation, (5/16/84 to 10/20/85). Visual inspection revealed no crack extension or any plug and/or patch motion. The visual examination results were corroborated by measurements of the plug flange deflection which showed that, although some preload loss had occurred, the residual flange deflection would maintain sufficient preload for the plugs to provide their design function.

While test results indicate that some flange deflection loss is anticipated following initial plug installation, this loss is likely due to a seating-in process resulting from the vibration and thermal environment of the plug. This conclusion is supported by the test data which shows such losses decreased with increasing cycles, indicating that deflection loss is not a continual process. The only expected loss in preload over plant life following the seating in process, therefore, should be due to irradiation relaxation. Additional preload loss from irradiation relaxation would not result in flange deflection losses. Conservative estimates for this loss component were used in the plug life calculations. A loss of preload below the screening values (as result of irradiation induced relaxation) is an unlikely event.

The design objective of the installed plugs was that they remain tight in the core support barrel during operation, thus limiting bypass flow and motion due to vibration. In the absence of any preload from flange deflection, the plug would still be captured in the CSB hole by the plug flange and bulge. During operation, the differential pressure across the CSB produces a force radially inward pressing the flange against the CSB, thereby serving the same function as the flange preload. In this configuration, the plug would still retain its design function. In order to assess the consequences of operating with a plug having little or no preload, a "loose condition" vibration test was performed for each plug size. The plugs were installed in a fixture in which the flange preload was relieved to a minimum amount to simulate the operating pressure differential on the plug. For all sizes, the plugs did not exhibit a resonant response at or near the pump operating frequencies of 15, 20, 75, and 150 HZ. Conservatively, the plugs were vibrated at their maximum response levels and, in all cases, the specimen did not exhibit signs of loosening or excessive wear after the imposed dwell period (approximating 18 months of operation). This indicates that the differential pressure assists in limiting the plug motion during operation, even with little or no preload in the plug flange.

Considering the above information, plug preload need not be a direct concern of future inspections. A visual inspection is sufficient and represents the best approach at this time to identify any future anomolous conditions. As discussed earlier, a record of the installed position of each plug is available from baseline photographs ("Λ" notch index on flange). In the unlikely event that a plug degrades to the point where vibratory motion occurs, the plug would most likely shift from its installed position. A visual inspection should suffice to identify this condition.

5.2 In-Service Monitoring

5.2.1 Loose Parts Monitoring System

The LPM system monitors the output from accelerometers mounted on the external surface of the reactor vessel and steam generators. This system has proven to be an indicator of loose and free parts within the primary system. Metal to metal impacting within the primary system causes higher frequency impulse vibrations on the reactor vessel shell which are detected by the LPM system.

For the LPM system to be effective as a diagnostic tool when a possible loose part is detected, information about the response of the accelerometers to a loose part must be known. This information has already been obtained from impact calibration tests at St. Lucie 1, conducted during the plant's initial startup.

Normal monitoring consists of the LPM system continuously comparing the instantaneous peak value of each accelerometer signal to its individual setpoint. An alarm is indicated for the channel or channels which exceed the setpoint(s). To avoid any loss of an actuating signal, a continuous recording device is available at St. Lucie 1 to save some portion of an initiating signal both before and after an alarm for subsequent evaluation. If the LPM system raises questions as to the integrity of the repair, a limited visual inspection can be performed without removing the CSB from the reactor vessel by using the surveillance holes in the CSB flange at lug locations 2, 3, 7, 8 and possibly 5 (see Figure 1).

6.0 REFERENCES

1. Final Report on the St. Lucie One Post Cycle 5 Plant Recovery Program, February 1984 CEN-272(F)-P (Proprietary).

TABLE 1

POST CYCLE SIX PLUG FLANGE DEFLECTION SCREENING CRITERIA
BASED ON INSPECTION TOOL READING
(FOR PLANT DESIGN LIFE)

LUG	PLUG NO.	PLUG SIZE	FLANGE DEFLECTION SCREENING VALUE (MILS)
1	6-22	3	23.5
	6-30	3	27.1
	6-23	3	18.8
	6-32	3	10.9
	14-1	8	29.8
	16-24	8	41.2
	15-25	8	45.4
3	6-12	3	17.0
	6-13	3	22.1
	6-14	3	26.9
	2-3	5	11.9
	17-5	5	29.4
4	6-37	3	29.6
	6-35	3	30.2
	6-34	3	35.9
	6-36	3	25.9
	4-2	8	28.6
	18-17	8	43.9
	27-1	8	36.1
5	11-1	3	17.2
	22-1	3	10.4
	23-1	3	25.6
	12-8	3	14.2
6	22-2	3	12.4
	21-19	3	25.6
	21-33	3	24.6
	16-20	8	38.2
	4-23	8	34.3
8	1-13	3	23.7
	13-15	3	23.7

TABLE 2

POST CYCLE SIX PLUG FLANGE DEFLECTION INSPECTION RESULTS

LUG	PLUG NO.	NOMINAL PLUG SIZE (INCHES)	SCREENING VALUE FLANGE DEFLECTION (MILS)	POST-CYCLE 6 FLANGE DEFLECTION (MILS)
1	6-22	3	23.5	26.9
	6-30	3	27.1	31.3
	6-23	3	18.8	20.8
	6-32	3	10.9	13.3
	14-1	8	29.8	38.1
	16-24	8	41.2	54.8
	15-25	8	45.4	53.0
3	6-12	3	17.0	18.0
	6-13	3	22.1	26.2
	6-14	3	26.9	31.3
	2-3	5	11.9	18.4
	17-5	5	29.4	31.3
4	6-37	3	29.6	34.8
	6-35	3	30.2	43.6
	6-34	3	35.9	46.0
	6-36	3	25.9	36.1
	4-2	8	28.6	29.2
	18-17	8	43.9	51.5
	27-1	8	36.1	43.7
5	11-1	3	17.2	26.1
	22-1	3	10.4	13.2
	23-1	3	25.6	37.8
	12-8	3	14.2	22.8
6	22-2	3	12.4	19.0
	21-19	3	25.6	31.8
	21-33	3	24.6	30.4
	16-20	8	38.2	48.9
	4-23	8	34.3	47.2
8	1-13	3	23.7	26.9
	13-15	3	23.7	36.6

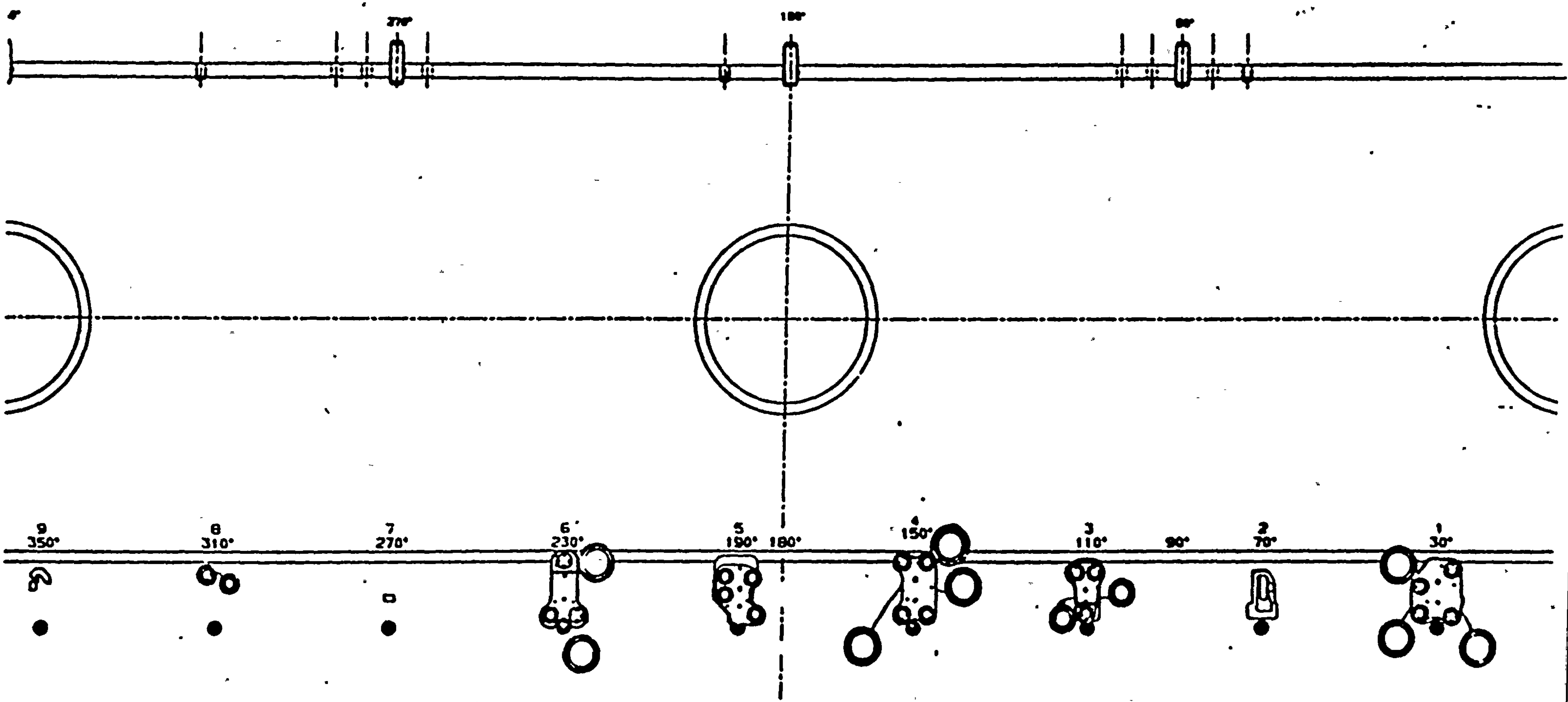

FIGURE 1
Repaired Condition of CSB

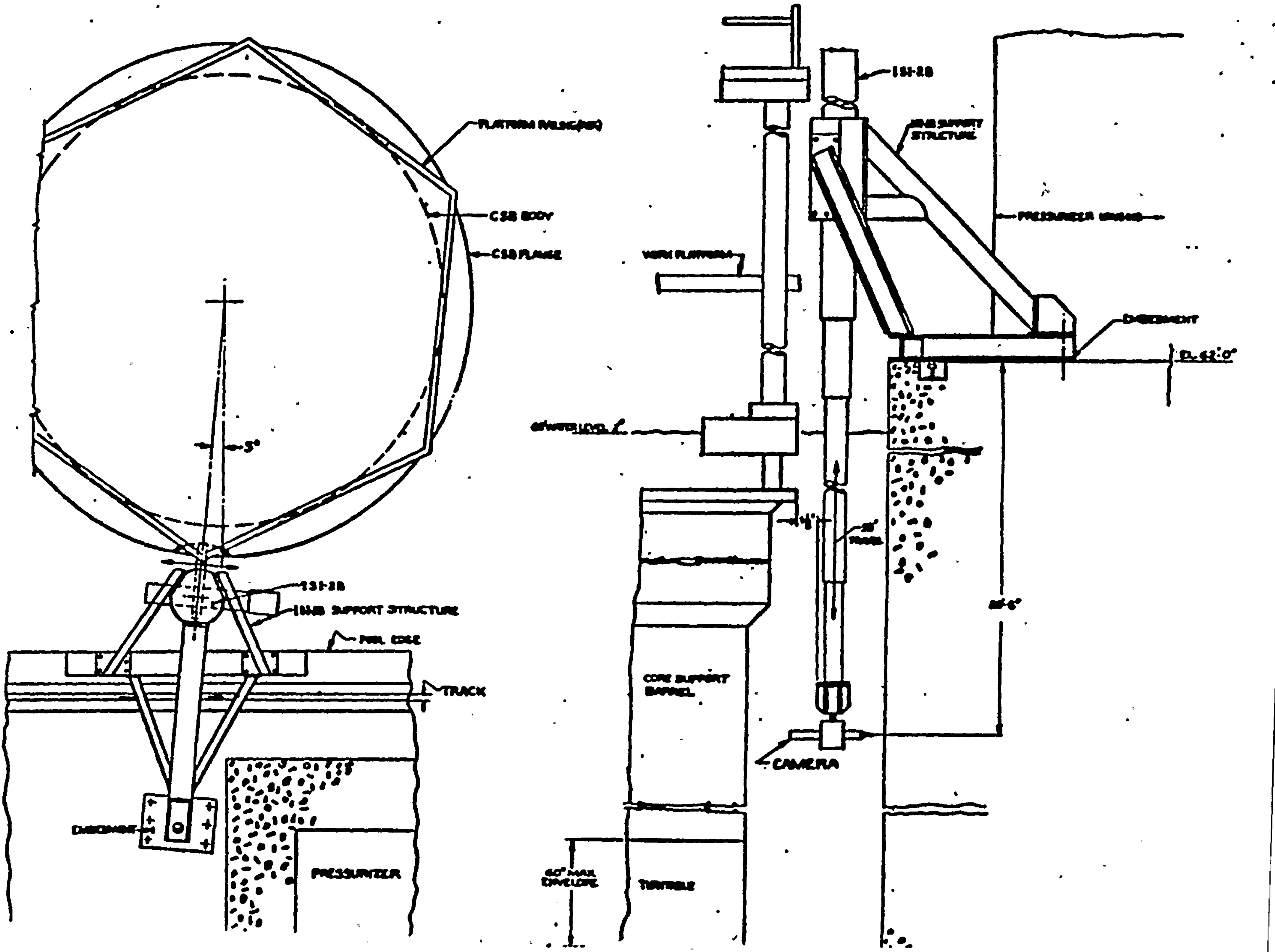

FIGURE 2 - ISI Positioner

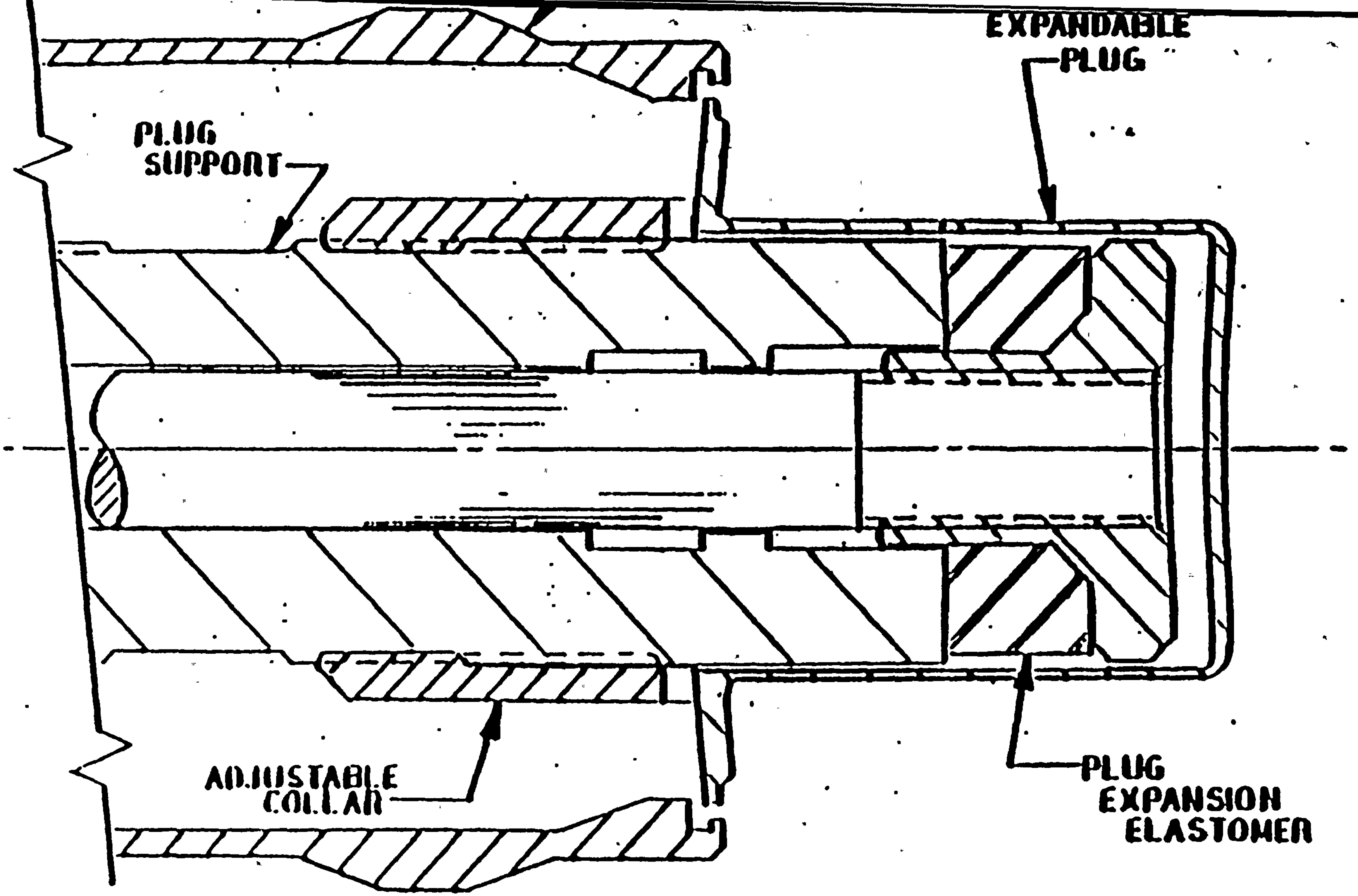

FIGURE 3
Plug Installation
Tool Flange Deflection Mechanism

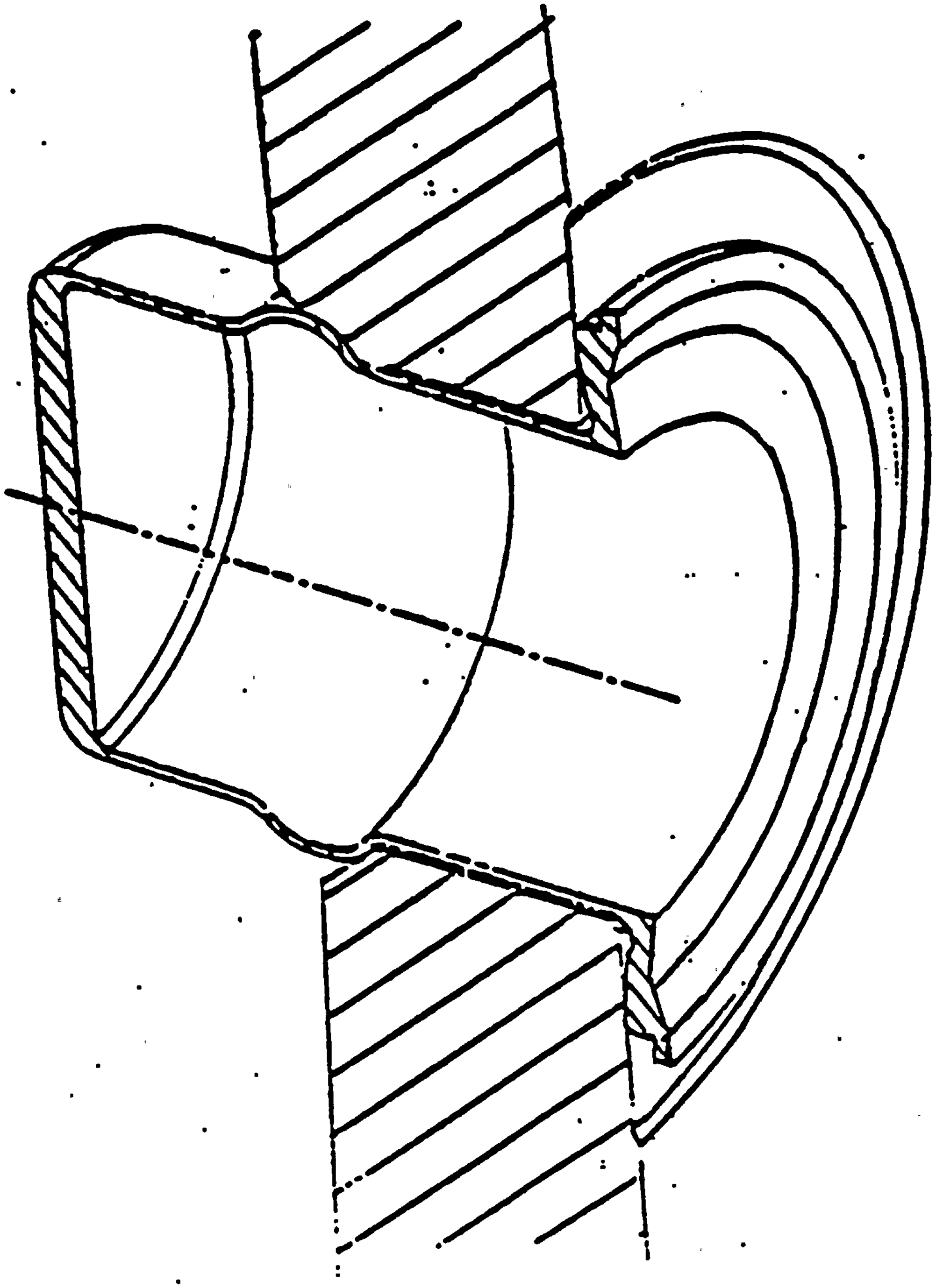

FIGURE 4

Installated Condition of
EXPANDABLE PLUG

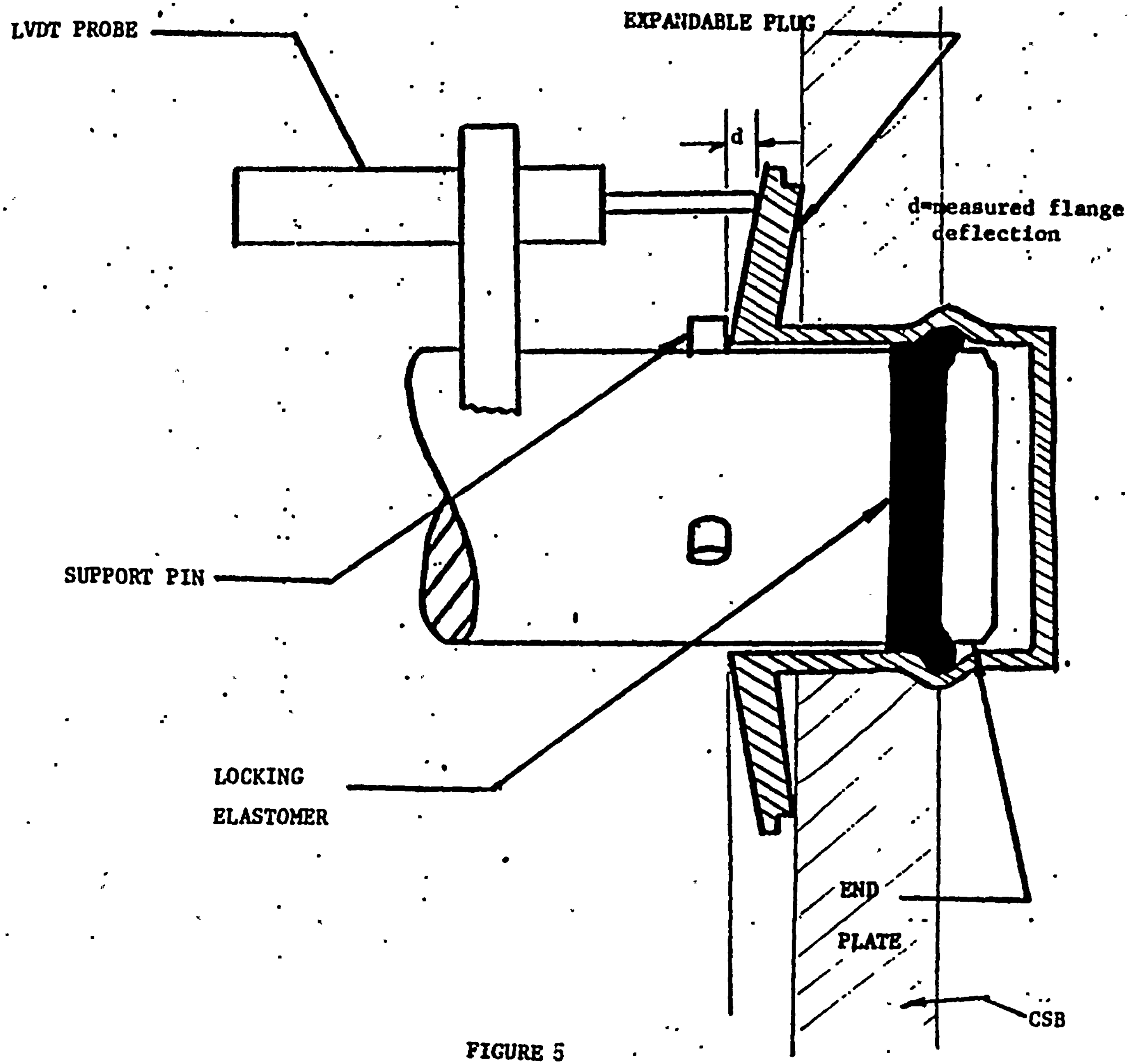

FIGURE 5

EXPANDABLE PLUG MEASURING TOOL INSTALLATION