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INVESTIGATION OF CHANNEL SEAL BLOW-BY PHENOMENON

JUNE 1966

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WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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TITLE

INVESTIGATION OF CHANNEL SEAL BLOW-BY PHENOMENON

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INVESTIGATION OF CHANNEL SEAL
BLOW-BY PHENOMENON

A. FOREWORD

Based on a recent XC-142 aircraft accident, it was established that the propeller pitch control actuator experienced a piston seal blow-by condition which caused the actuator to drive the propeller to the extreme low pitch position in flight causing the airplane to make an uncontrolled crash landing. Prior to this accident several incidents citing erratic behavior of the KC-135 airplane powered rudder control system were reported. In several of these incidents, the cause of erratic rudder responses could not be explained. Accordingly, since some similarity exists between the XC-142 actuator cap seal design and the channel seal design used in the KC-135 power rudder actuator, it was deemed advisable to conduct a test program to investigate channel seal blow-by phenomenon using KC-135 power rudder actuators. Secondly, if blow-by occurs, what modifications could be incorporated in the seal design to alleviate blow-by?

B. PURPOSE

The purpose of this program is to investigate channel seal blow-by phenomenon in KC-135 power rudder actuators and to record the results of these investigations.

C. TEST APPARATUS DESCRIPTION

The apparatus utilized for conducting the tests during this investigation is shown in Attachment Nrs. III, IV, and V. Referring to Attachment Nr. III, two actuators were installed in an 8-inch channel iron fixture with the actuator piston rods connected together. The channel iron fixture is shown in Attachment Nr. II. In this report, one of the actuators is referred to as the test unit and the other is the load unit. The load unit was modified wherein the actuator metering rod block (valve block) was removed and an adapter plate was added to allow direct porting to each side of the load unit piston. The adapter plate was also connected to a closed type fluid load system. The test unit load could be varied by adjusting the throttle valve to a pressure setting which corresponds to a simulated aircraft load. Four check valves are installed in the load system to permit high pressure fluid to flow from one side of the piston in the test unit through the throttle valve while the other side of the piston in the test unit is being refilled for the next stroke. An oil to water heat exchanger was used to prevent excessive fluid temperatures in the load system. The test unit was cycled by obtaining fluid under pressure from the supply system. This fluid entered the metering valve which ported the fluid to one side of the piston or the other depending on the position of the rudder slide position controller. This position controller could be moved through linkages either manually or by a variable speed electric motor (not shown in Attachment Nr. III). The amplitude or length of metering rod stroke could be varied by positioning a cam attached to the electric motor drive shaft. Four pressure transducers were installed in the test system, one on each side of the test unit and load unit pistons. Also, the stroke of the actuator piston and the position of the metering rod were electronically recorded by a visicorder not shown in Attachment Nr. III. Photographs of the test system are shown in Attachment Nr. IX. Included in these photographs are views of the variable speed motor and the visicorder.

Attachment Nr. IV is basically similar to Attachment Nr. III with the exception that the test unit piston rod is in a fixed position and that the test unit body is permitted to move. This installation is more representative of the actual KC-135 power rudder actuator installation and permits position feedback to occur.

Attachment Nr. V is an alternate load system which is connected to the load unit adapter plate in lieu of the load systems shown in Attachment Nrs. III and IV. This system permits load to be imposed on one side of the load unit piston rather than an alternating load as shown in Attachment Nrs. III and IV. The accumulator was precharged by nitrogen pressure and a hand pump was used to establish pressure loads on the load unit (actuator).

The electric motor used to vary the frequency and amplitude of the metering rod stroke was replaced with an MB Manufacturing Company, Inc. vibrator to obtain high frequency strokes for portions of this test program, since the electric motor was limited to producing frequencies only to 500 cycles per minute maximum.

An instrumentation list is shown in Attachment Nr. VII.

D. <u>TEST PROCEDURES</u>

Prior to any tests, both actuators were disassembled and inspected to determine if the channel seals were notched or damaged. Both systems as shown in Attachment Nrs. III and IV, as well as the alternate load system Attachment Nr. V, were utilized during this investigation. In general, the test procedure during this program was as shown below:

a. Adjust throttle valve on the load actuator to read 500 ± 50 PSI. Adjust throttle valve on the test actuator to read 1000 ± 50 PSI. Cycle rudder position slide control at various rates to determine if blow-by occurs.

b. Repeat above test with the following throttle valve adjustments:

Test Actuator	Load Actuator
1000 psi	900 psi
2500 psi	1500 psi
2500 psi	2000 psi
2500 psi	2400 psi
3000 psi	1000 psi
3000 psi	1500 psi
3000 psi	2000 psi
3000 psi	2500 psi
3000 psi	2900 psi

E. DISCUSSION OF RESULTS

Using the set-up shown in Attachment Nr. III, tests were started on 23 February 1966. Visicorder readings showed two instances where actuator channel seal blow-by may have occurred. More detailed evaluation of these readings led to the conclusion that these instances were not blow-by and were caused by moving the metering rod in an erratic manner. Attempts to obtain blow-by were unsuccessful using the load set-up shown in Attachment Nr. IV and the alternate load set-up (Attachment Nr. V) at various metering rod movement frequencies and amplitudes. An electric motor drive was used to move the metering rod after several days of attempts to obtain blow-by by manually positioning the metering rod. Blow-by phenomenon as defined for this program occurs when a large volume of fluid (approximately 3 gpm and above) under pressure passes across the piston seal for periods of tenths of a second to several seconds causing the actuator to become ineffective in performing its intended function during these intervals. Personnel representing Shamban made a visit to Wright-Patterson AFB on 2 March 1966 to discuss the test program objectives and assistance was obtained from these representatives. A total of 8 teflon channel seals; 4 with faces notched and 4 unnotched, were submitted by Shamban for this program. These seals were received on 10 March 1966. During this visit, the load actuator was removed to determine the condition of the channel seal as a result of the tests conducted as of that time. The channel seal in this actuator was in good condition and the actuator was assembled and reinstalled in the test system.

In an effort to obtain blow-by phenomenon, the clearance between the width of the teflon channel seal and the channel seal groove was varied during this test program as shown in Attachment Nr. VI. The seal/groove clearance of the test and load actuators as received through Air Force supply channels were .012 inches and .016 inches respectively. On 11 March 1966, these seals were removed from both actuators and negative clearance seals were installed and tested. After several days of testing, the load actuator was removed from the test set-up whereby the seal could be replaced with a seal enabling a seal/groove clearance of .000 inches. No blow-by occurrences were detected during these tests using the oversize channel seals. During disassembly of the load actuator, the piston with the oversize seal could not be pulled out of the housing and it was necessary to use a chain pull to remove the piston assembly. The channel seal was found to be cracked in many places across the circumferential face of the seal. During this portion of the test program, several 5000 psi pressure transducers failed on the test actuator. Pressure peaks exceeding 5000 psi were recorded on a hydrauliscope. Consequently, it was decided to continue the test program without recording pressures for the test actuator. No blow-by occurrences were detected on the zero clearance seal installed in the load actuator. New high pressure (7000 psi) transducers were installed on the test actuator on 21 March 1966. Also, the zero clearance seal from the load actuator was replaced with a seal having .025 inches seal/groove clearance. It was also necessary to use a chain pull to remove the piston with the zero clearance seal. This seal had several cracks in its circumferential face. The tests continued on these seals using the electric motor to cycle the metering rod of the actuator. During this interim, provisions were made to obtain a vibrator which could be used to investigate blow-by at high frequencies. The vibration equipment was adapted to this test stand on 24 March 1966. The metering rod was cycled at various amplitudes with frequencies from 0 to 20 cycles per second. No blow-by occurrences were detected during these tests.

Up to this time of the test program, all tests were conducted at ambient temperatures 70 ± 20°F. Accordingly, the actuators were packed in dry ice and allowed to cold soak for one hour at -40°F. No blow-by occurrences were detected during cycle tests following the low temperature soak. On 31 March 1966, the test actuator seal was replaced with a seal having a seal/groove clearance of .023. The piston assembly utilizing the negative clearance seal was removed without the use of a chain pull. This seal had cracks along its circumferential face. Evidently, this seal has been cycled sufficiently to cause it to wear to the degree where a chain pull was not required to remove the piston assembly from the actuator housing. The test actuator was removed from the test stand since no blow-by occurrences were detected and the .023 clearance seal was replaced with a double delta, turcon channel seal. The seal/groove clearance for the turcon seal was also .023 inches. The low temperature test was repeated on these actuator seals and no blow-by occurrences were detected. The turcon double delta channel seal was removed from actuator S/N 151 and an O-ring was machined to provide a cross-sectional thickness of .192 inches on a portion of its cross-sectional diameter. The test actuator utilizing the turcon seal was disassembled and the force required to move the piston assembly was between 30 to 35 pounds. Technical Order 9H17-3-2-3 for P/N 65-6511-15 actuators specifies a maximum force of 20 pounds to move the piston assembly. The machined O-ring was installed as the channel seal with two spiral back-up rings in actuator S/N 151. The actuator was installed in the test position of the stand and no blow-by occurrences were encountered other than slight leakage which can be expected with a worn O-ring seal. The actuator S/N 151 was removed from the test stand and the machined O-ring was removed from the channel seal groove. The actuator was reinstalled in the test stand with only the notched teflon channel seal in the groove. Testing indicated no blow-by with this seal arrangement other than slight leakage which is to be expected.

Attachment Nr. VIII is an idealized plot of a visicorder recording which presents data taken during this test program. The transient pressure surges are not shown in this plot. The actual visicorder recordings present continuous traces of each of the six readings simultaneously which makes the plot difficult to read. The traces incorporate timing lines (spaces), however, due to the nearness of the reading traces, a great amount of interpretation is required in analyzing the recorded results. To analyze the recorder traces, the recorder paper speed was varied from .1 inch/sec to 8 inches/sec, and the pressure transducers and the metering rod position sensor were disconnected temporarily to analyze individual traces during the test program.

If blow-by occurred during the test runs, an interruption would be noted in the piston position trace with abrupt changes in actuator pressures. These changes would be analyzed in conjunction with the metering rod position trace to determine if inadvertent movement of the metering rod occurred to cause the abrupt changes. Suspected blow-by incidents were attributed to this inadvertent rod movement. Also, abrupt changes could occur to the piston position trace if the metering rod was permitted to bottom against the actuator valve block. Since no blow-by occurrences were detected, no attempt was made to present the visicorder recording traces in this report. Also, the amount of recording paper utilized is too voluminous and difficult to reproduce to present readable traces which could be readily analyzed.

An Unsatisfactory Report Exhibit Actuator P/N 65-6511-15, S/N 332 was received on 11 April 1966 for evaluation test purposes. This actuator was installed in the test actuator position of the test set-up. The results of the test evaluation on the UR Exhibit actuator are not included in this report.

During this test program, it was noted that the test actuator valve metering control rod could be pushed far enough to permit a washer on the rod to enter the valve block a distance of approximately .125 inches. When this occurred, the actuator valve metering slide assumed a position which blocked fluid pressure and the actuator piston could not move unless the rod was retracted to approximately ¼ inch from its neutral center position. Investigations revealed that an incorrect size washer was installed on this actuator metering control rod. This washer had a smaller diameter as compared to the MS 15795-211, which is the correct washer to use for this installation. To correct this condition, the valve block which came with the load actuator replaced the test actuator valve block which had the small washer on the metering control rod. Inadvertently, the MS 15795-211 washer on the replaced valve block metering control rod was bent when the electric motor was started with an excessive speed setting during later phases of this test program. It was found that the bent washer would also protrude into valve block causing the actuator piston to assume a locked position. Investigations were made to determine if this metering control rod bottoming could occur in the KC-135 airplane rudder control system. Discussions with Boeing engineering personnel and maintenance personnel assigned to the 17th Bombardment Wing indicate that the washer installed on the metering control rod stops approximately ¼ inch from the valve block if the system is properly rigged. However, during the investigation procedures accomplished in regard to the UR Exhibit received from

Walker AFB, it was determined that it is difficult to determine if a washer on the metering control rod is bottoming on the valve block. Also, applicable Technical Order procedures do not specify checking procedures to determine if this washer can bottom against the valve block. Photographs are included in Attachment Nr. IX which show the three metering control rods tested during this program. The bent washer and the small washer are shown in this photograph. It is noted that the washer on the opposite end of the metering control rod can also bottom against the valve block. This was demonstrated by loosening the metering control rod nut to only about one thread engagement. To further substantiate that these washers can bottom out in KC-135 airplane rudder actuators, investigations of an operational hazard number 449, BW64-KC-135-4 which occurred at Kinchloe AFB, mentions a bent washer. However, the investigation report OCNCTQ-1 "MIP OC65-7000U1" dated 27 April 1965, states that it appears the washer was bent prior to installing the actuator in the airplane or before the actuator checkout by the investigator.

F. SUMMARY OF SIGNIFICANT FINDINGS

The channel seal design used in the KC-135 airplane power rudder actuator is not susceptible to blow-by occurrences. This is based on extensive testing over a two-month period whereby two actuators were utilized using seals exhibiting various seal/groove width clearances. The entire actuator load spectrum was investigated in conjunction with various input amplitudes and frequencies to the valve metering control rod. Tests were conducted with actuator ambient temperature below -40°F. Effects of hydraulic fluid temperatures up to 160°F were also investigated.

Over-travel of the metering control rod experienced in this test program could cause erratic rudder responses if this condition prevailed in a KC-135 airplane. Improper washer installations and bent washers installed on the metering control rod could permit over-travel in the airplane provided the rudder control linkages are not properly rigged.

The turcon double delta seal configuration presently being supplied in kits for the KC-135 power rudder actuator creates higher piston forces as compared to existing teflon channel seals. However, these increased piston forces are not magnified to an appreciable extent in pedal forces required to move the rudder.

G. RECOMMENDATIONS

It is recommended that the responsible activity at OCAMA take appropriate action to revise applicable Technical Orders to require KC-135 maintenance personnel to check both ends of the rudder metering control rod to determine if the washers bottom on the valve block body.

ATTACHMENT NR. I

Test Log Data

23 February 1966	Three instances of blow-by suspected
24 February 1966	No blow-by occurrence detected
28 February 1966	No blow-by occurrence detected
1 March 1966	No blow-by occurrence detected
2 March 1966	Shamban representatives viewed test set-up and procedures. Load actuator was removed from fixture and was disassembled for inspection of channel seal. Seal appeared to be in satisfactory condition.
3 March 1966	No blow-by occurrence detected
4 March 1966	No blow-by occurrence detected
7 March 1966	No blow-by occurrence detected
8 March 1966	No blow-by occurrence detected
9 March 1966	No blow-by occurrence detected
10 March 1966	Test stand was down due to excessive leakage in stand noise suppressor. Stand was repaired by removing suppressor from system.
11 March 1966	Both actuators removed from fixture. Unnotched oversize teflon channel seals received from Shamban were installed in the actuators and the actuators were reinstalled in the test stand.
14 March 1966	No blow-by occurrence detected
15 March 1966	No blow-by occurrence detected. However, pressure transducers failed during cycle tests.

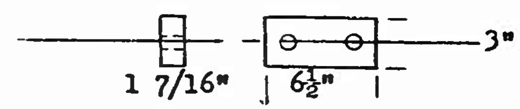
	Three transducers failed in the past 10 hours of tests. All failed units were installed on the test actuator. Oscilloscope traces show pressure peaks exceeding 5000 psi. Tests continued during which only the load pressure values were recorded.
16 March 1966	The load actuator oversize channel seal was replaced with a new channel seal having a seal/groove clearance of zero. Test stand was down for this day since a leaking relief valve needed repair.
17 March 1966	No blow-by occurrence detected
18 March 1966	Tests were not conducted. New high pressure transducers installed on test actuator
21 March 1966	Tests were not conducted
22 March 1966	No blow-by occurrence detected
23 March 1966	No blow-by occurrence detected
24 March 1966	Test stand was down to enable vibration test equipment to be installed in the test set-up
25 March 1966	No blow-by occurrence detected. Frequencies up to 20 cps were investigated
28 March 1966	No blow-by occurrence detected.
29 March 1966	No blow-by occurrence detected.
30 March 1966	The test actuator fixture was packed in dry ice and the temperature was allowed to stabilize at $-40^{\circ}F$ for approximately 1 hour. No blow-by occurrence during this test.
31 March 1966	A new channel seal was installed in the test actuator. This seal was unnotched and its width was reduced to enable a maximum seal/groove clearance of .025 inches. No blow-by occurrences during these test cycles.

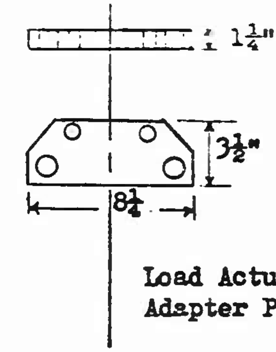
1 April 1966	Movement of the metering rod manually indicated that the actuator valve spool could lock pressure in the piston chamber when the rod travel was at a maximum in one direction. The valve block was replaced on the test actuator. Also, a turcon double delta channel seal was installed in the test cylinder. No blow-by occurrence. Examination of removed valve block indicated that a smaller size washer was installed on the rod permitting the washer to enter the boss on the valve block causing the metering spool to over-travel its design limit.
4 April 1966	No blow-by occurrence detected
5 April 1966	Low temperature test repeated - No blow-by occurrence detected
6 April 1966	No blow-by occurrence detected
7 April 1966	No blow-by occurrence detected
8 April 1966	No blow-by occurrence detected
11 April 1966	Removed test actuator (S/N 151) from stand and installed actuator received from Walker AFB (S/N 332). The actuator performed satisfactorily during these tests. Actuator S/N 332 was removed from the test stand and was disassembled to inspect the channel seal. Fifteen pounds of pull were required to move piston. The channel seal was found to be split circumferentially. Photographs were taken of the damaged channel seal installed on the piston of the actuator.
12 April 1966	Actuator S/N 332 was reassembled with the split channel seal and was subjected to static pressure checks up to 3000 psi. No appreciable leakage was observed across the split seal during these test checks. The pull forces an actuator S/N 151 which utilized the turcon double delta

	channel seal measured 30 to 35 pounds. Actuator rigging procedures were discussed with maintenance personnel assigned to 17th Bombardment Wing
13 April 1966	Blow-by tests were not conducted since efforts were being made to determine causes of excessive rudder pedal forces reported by Walker AFB personnel.
14 April 1966	No blow-by testing accomplished.
15 April 1966	Actuator S/N 151 installed in test position with .192 inch O-ring and 2 spiral back-up rings. No blow-by occurrence. O-ring removed from S/N 151 and this actuator was tested with only the teflon channel seal in piston seal groove. No blow-by occurrence.
18 April 1966	Actuator S/N 332 was installed in the test position of the test stand for endurance tests. Using a $\pm \frac{1}{4}$ inch metering rod stroke at 128 cycles per minute, inlet pressure 2500 psi, and load pressure from 0 to 2300 psi, loaded in both directions of the piston stroke, the actuator rod broke after 83,815 cycles on 19 April 1966.
19 April 1966	Photographs were taken of the failed actuator and arrangements were made with the RTD Materiels Laboratory to investigate the causes of rod failure from a material properties viewpoint.

ATTACHMENT NR. II

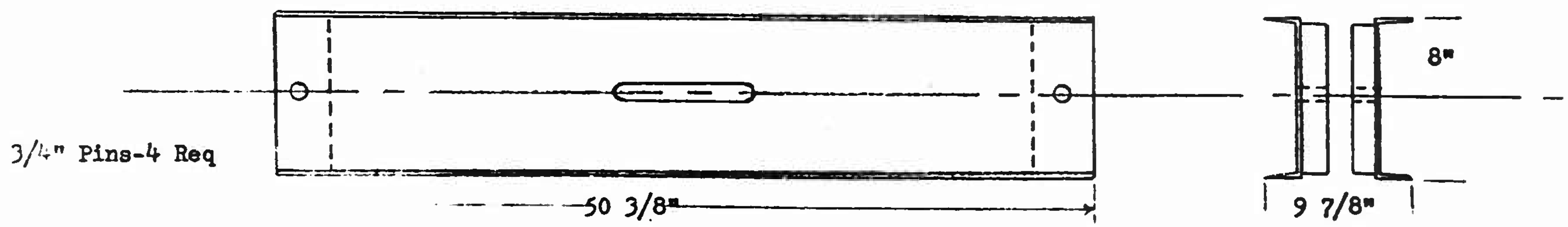
FIXTURE SLIDING BLOCKS - 2 REQ.



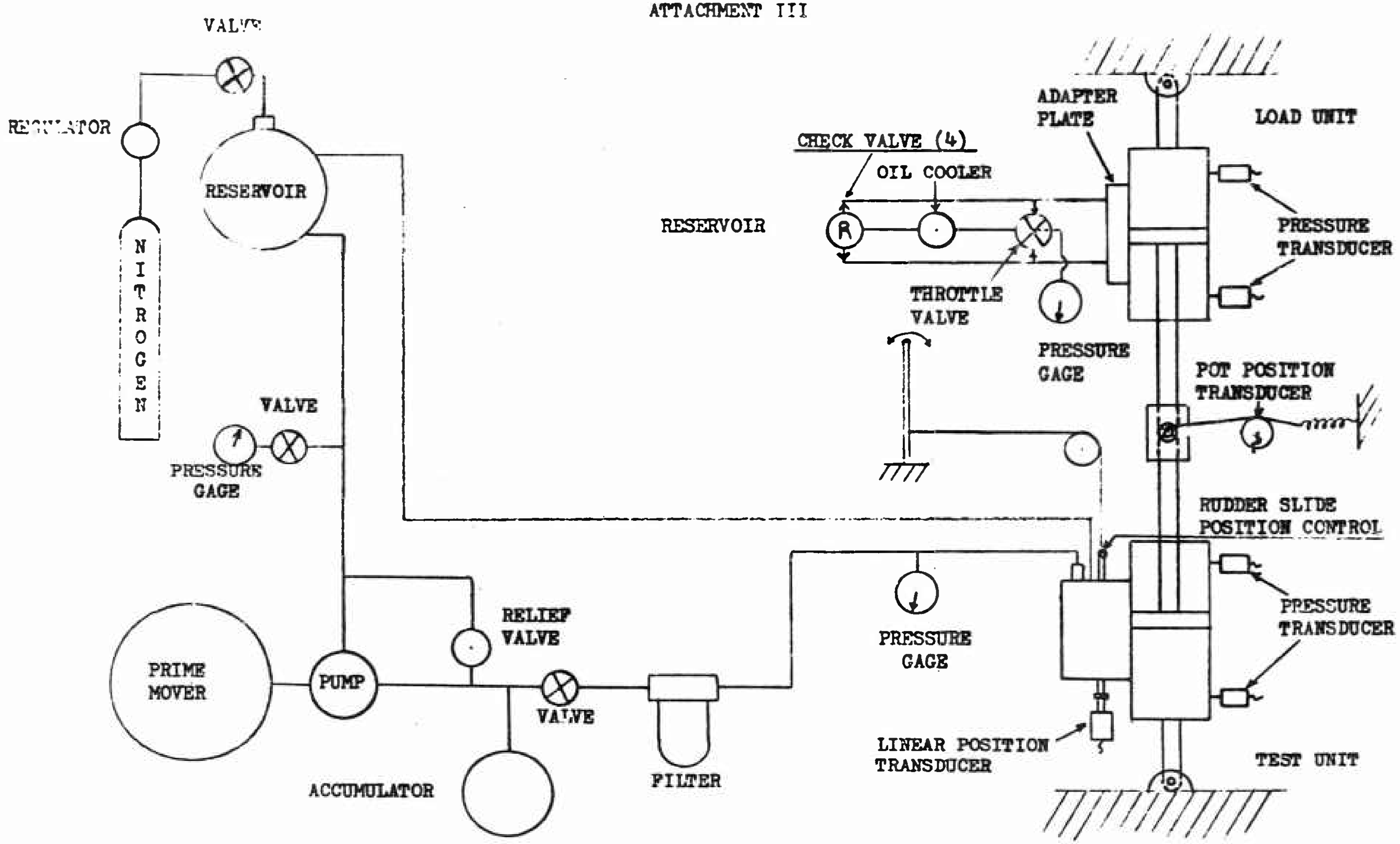


Load Actuator
Adapter Plate

CHANNEL IRON FIXTURE



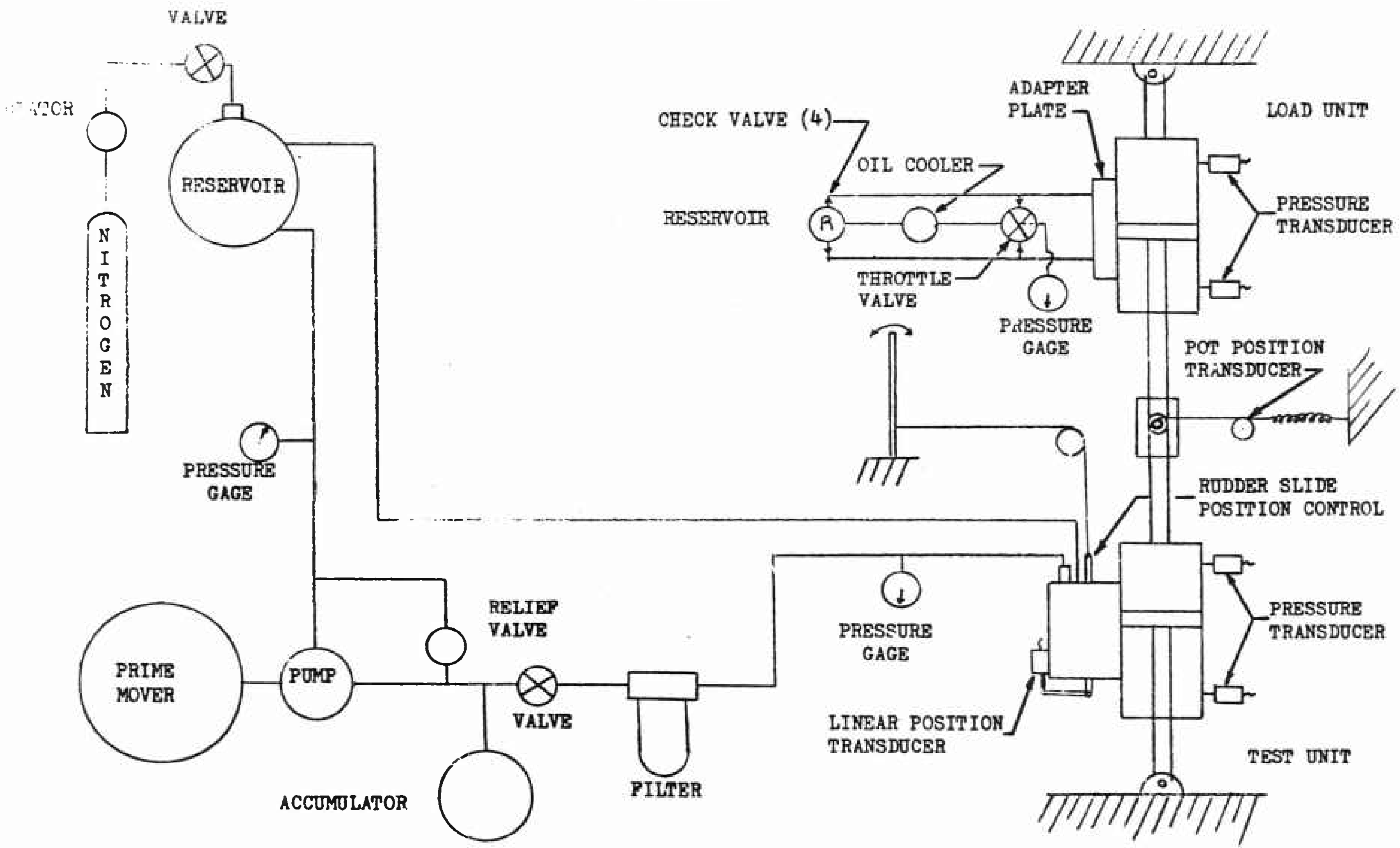
ATTACHMENT III



RUDDER POWER CONTROL TEST

SCHEMATIC NR. 1

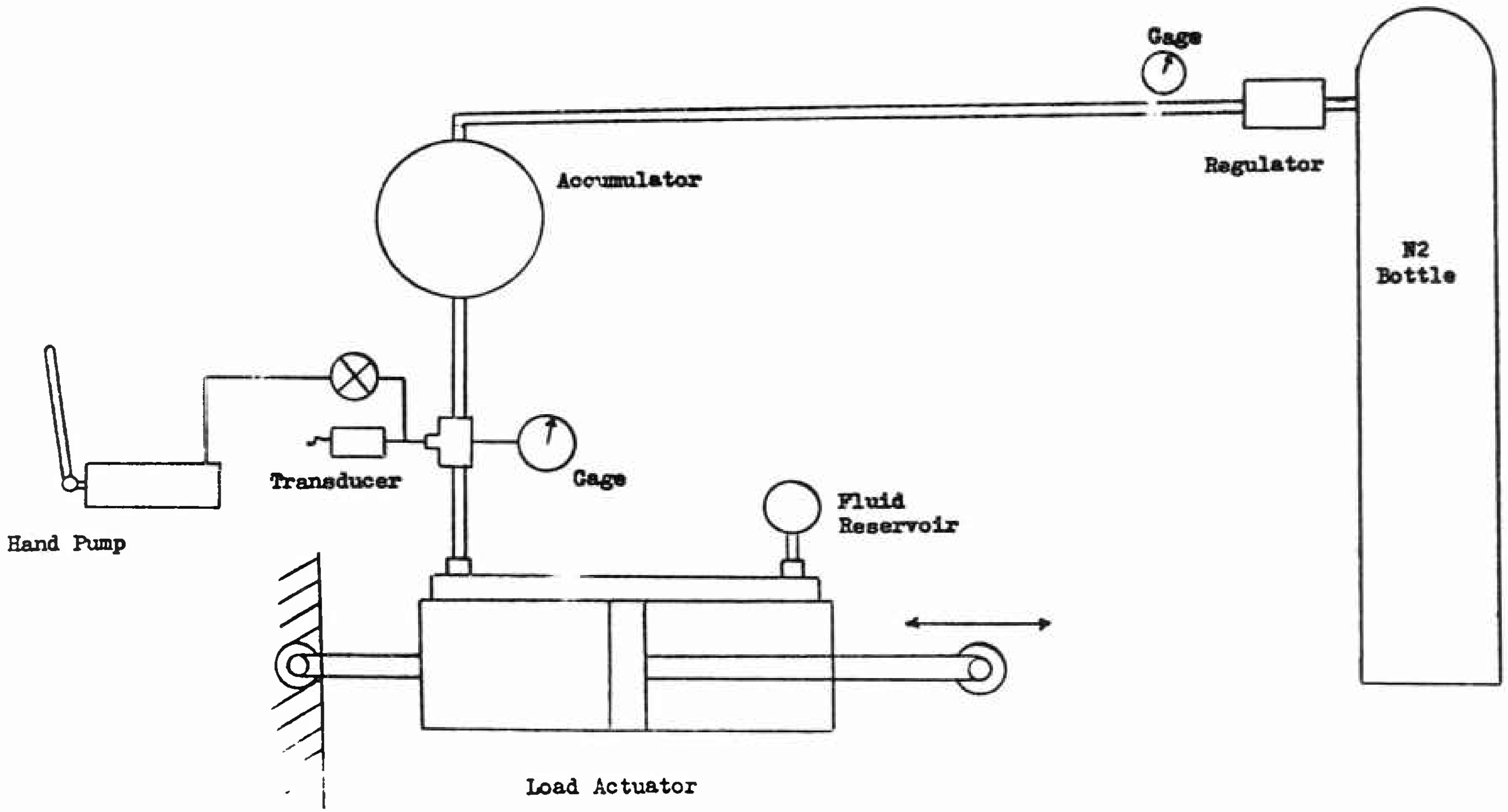
ATTACHMENT IV



RUDDER POWER CONTROL TEST
SCHEMATIC NR. 2

ATTACHMENT NR. V

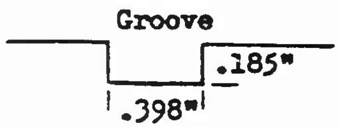
ALTERNATE LOAD SYSTEM SCHEMATIC



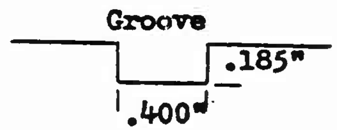
ATTACHMENT NR. VI

CHANNEL SEAL DIMENSIONS

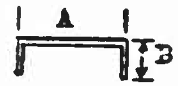
Test Actuator



Load Actuator



Seal



Channel Seal Configuration	Dimension "A"	Dimension "B"	Actuator Installation	Seal/Groove Clearance
1	-	-	Test	.012"
2	-	-	Load	.016"
3	.4075	.183	Test	-.0095"
4	.408	.183	Load	-.008"
5	.400	.183	Load	.000"
6	.375	.183	Load	.025"
7	.375	.183	Test	.023"
8 (turcon) double ▲	.375	.151	Test	.023"
9	.408	.183	Test	-.010" (No O-ring)

ATTACHMENT NR. VII

Instrumentation List

2 Pressure Transducers (0 - 5000 psi); Statham PG 246TC-5M-350

1 Pressure Transducer (0 - 10,000 psi); Norwood S/N 3537

1 Pressure Transducer (0 - 10,000 psi); Control Engineering S/N 768

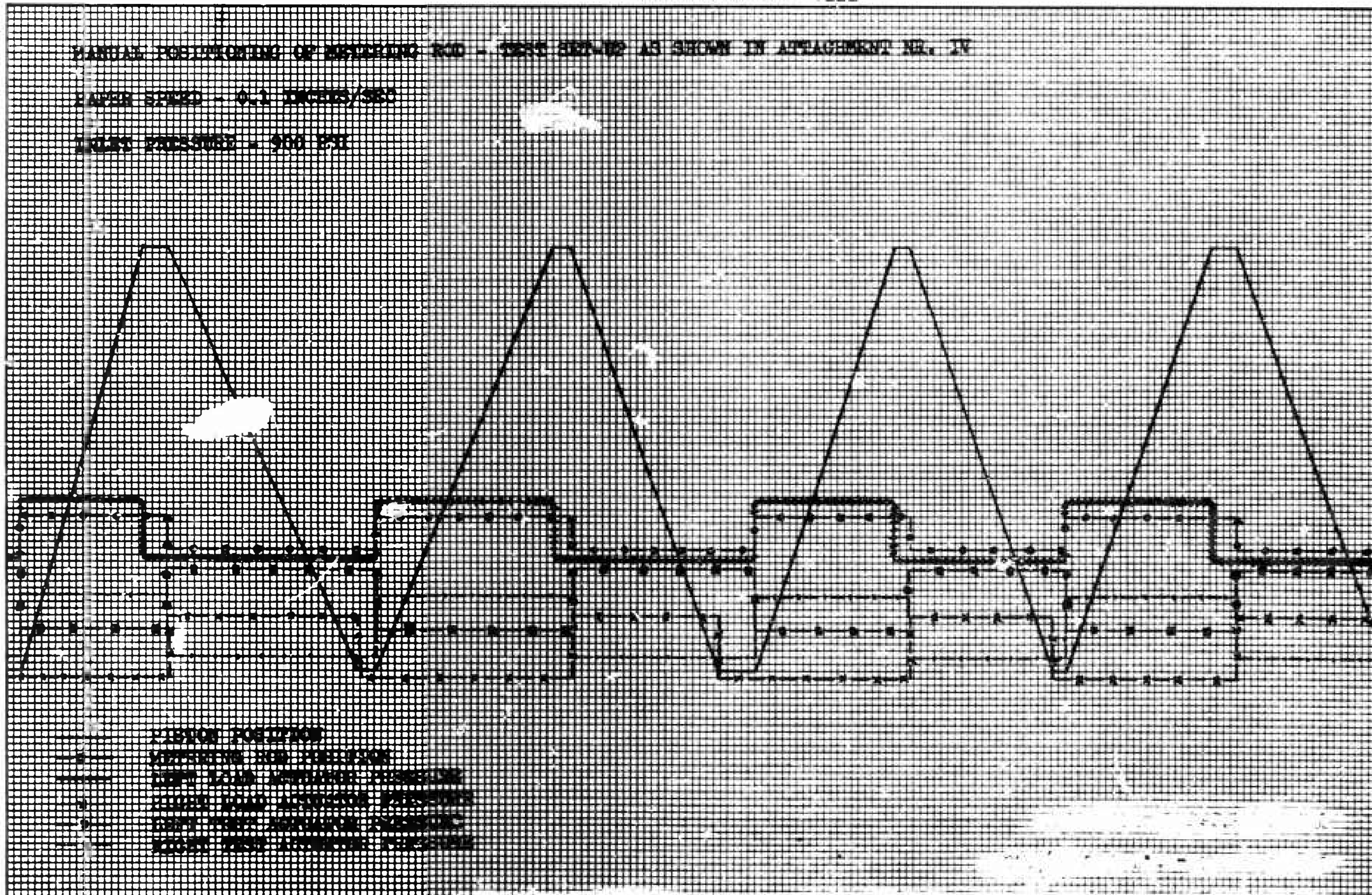
1 Visicorder, Honeywell Model 1508

1 Vibration Test Set; MB Manufacturing Company, Inc. Model CID

1 Linear Position Transducer (2 inch travel); Link Aviation Inc., P/N 245103, 50 Kr, 1163A

1 Rotary Pot (4 inch circumference); Spectrol Electronics Corporation, Model 200490, 500 r

ATTACHMENT NR. VIII



VISICORDER RECORDING OF TEST DATA (IDEALIZED PLOT)

ATTACHMENT NR. IX

List of Photographs

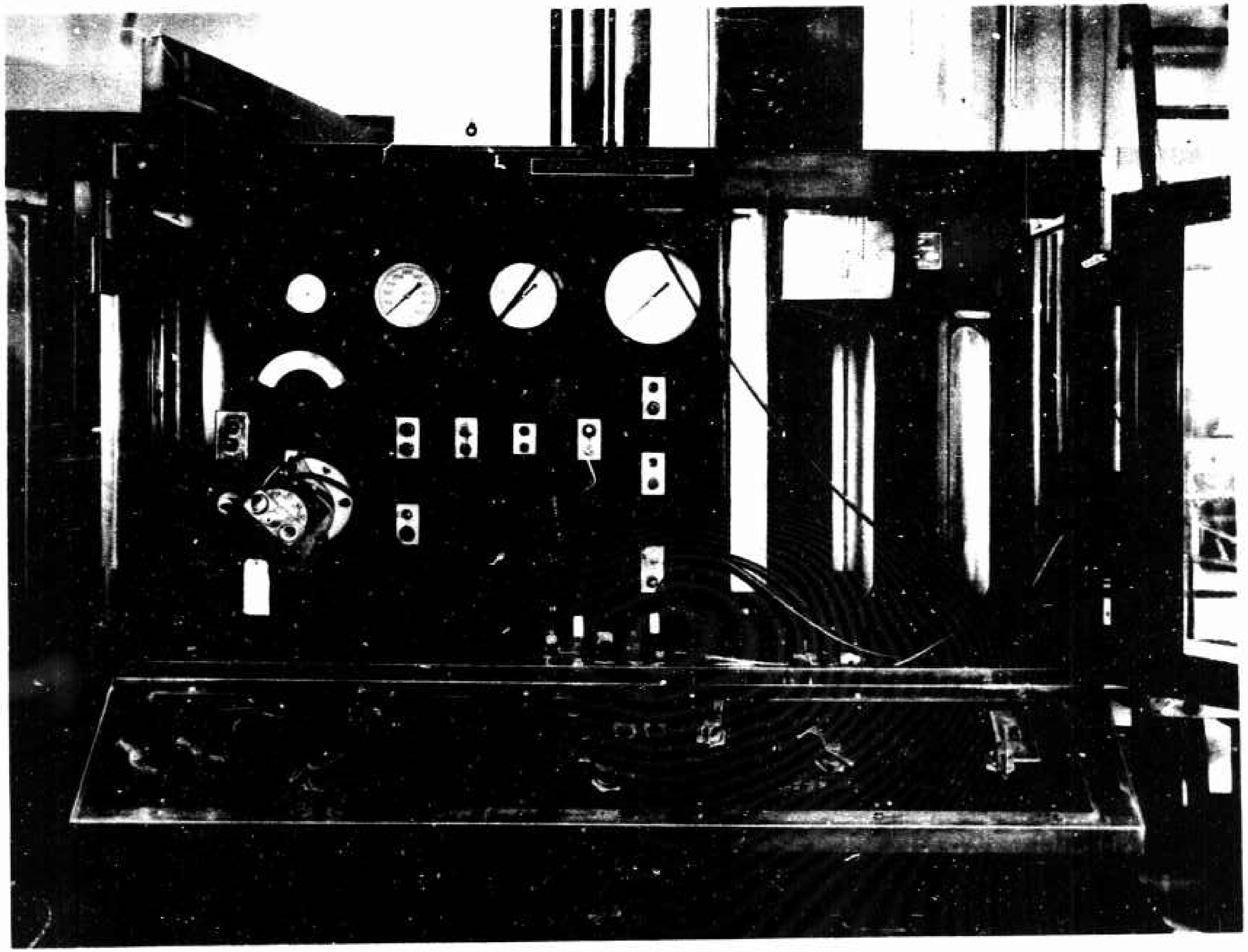


FIGURE 1 FLUID POWER SUPPLY APPARATUS

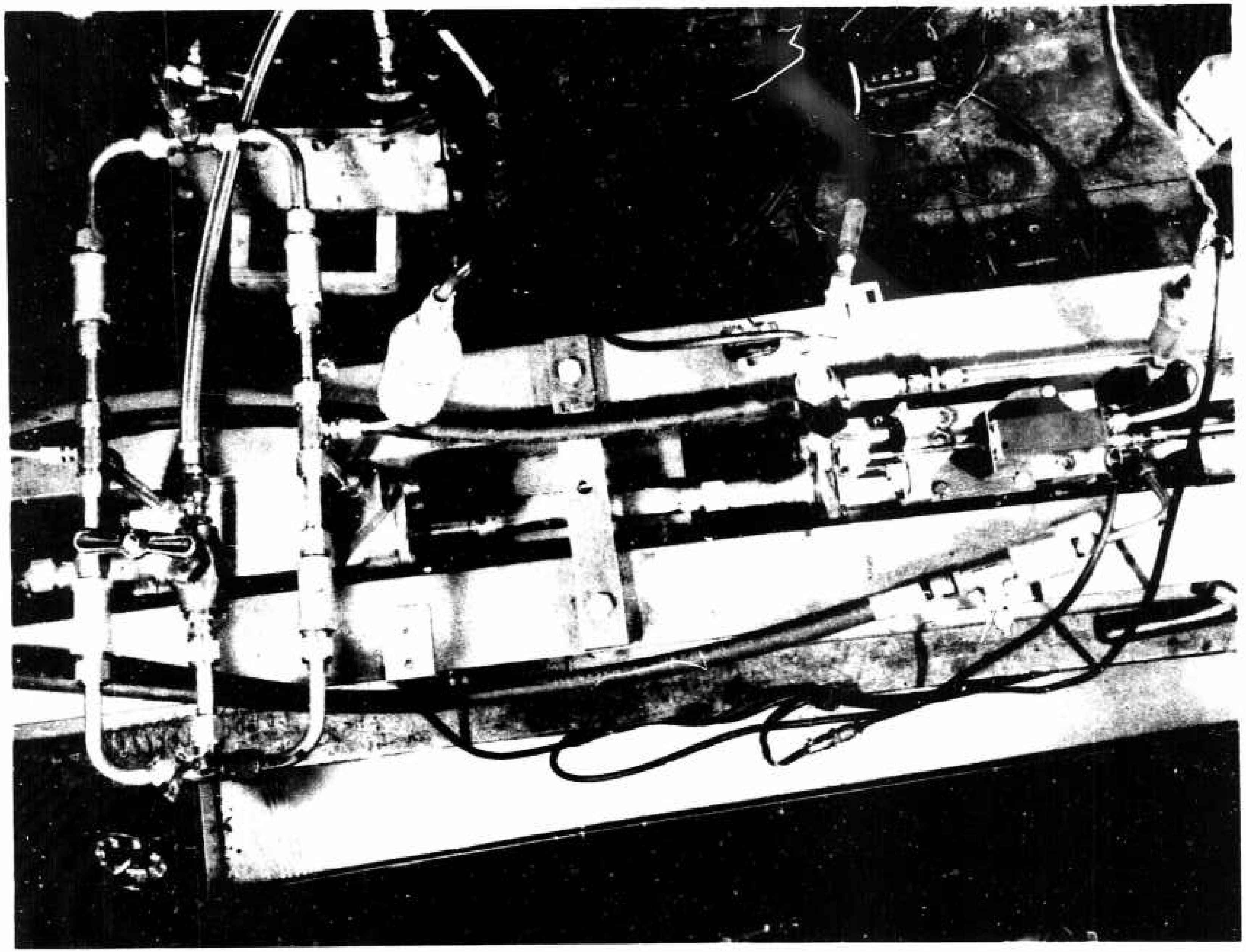


FIGURE 2 TEST FIXTURE WITH ACTUATORS INSTALLED

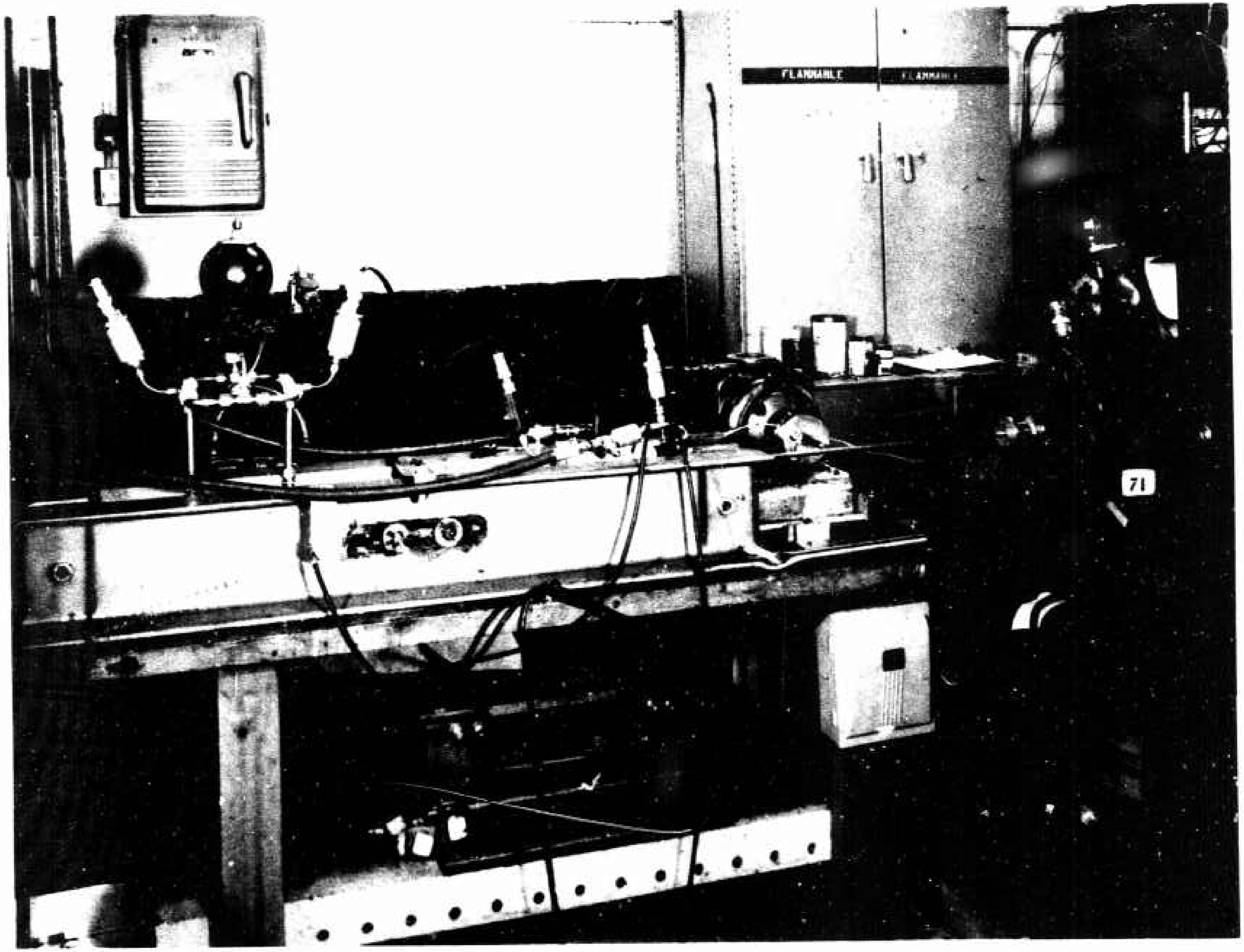


FIGURE 3   TEST CIRCUIT APPARATUS

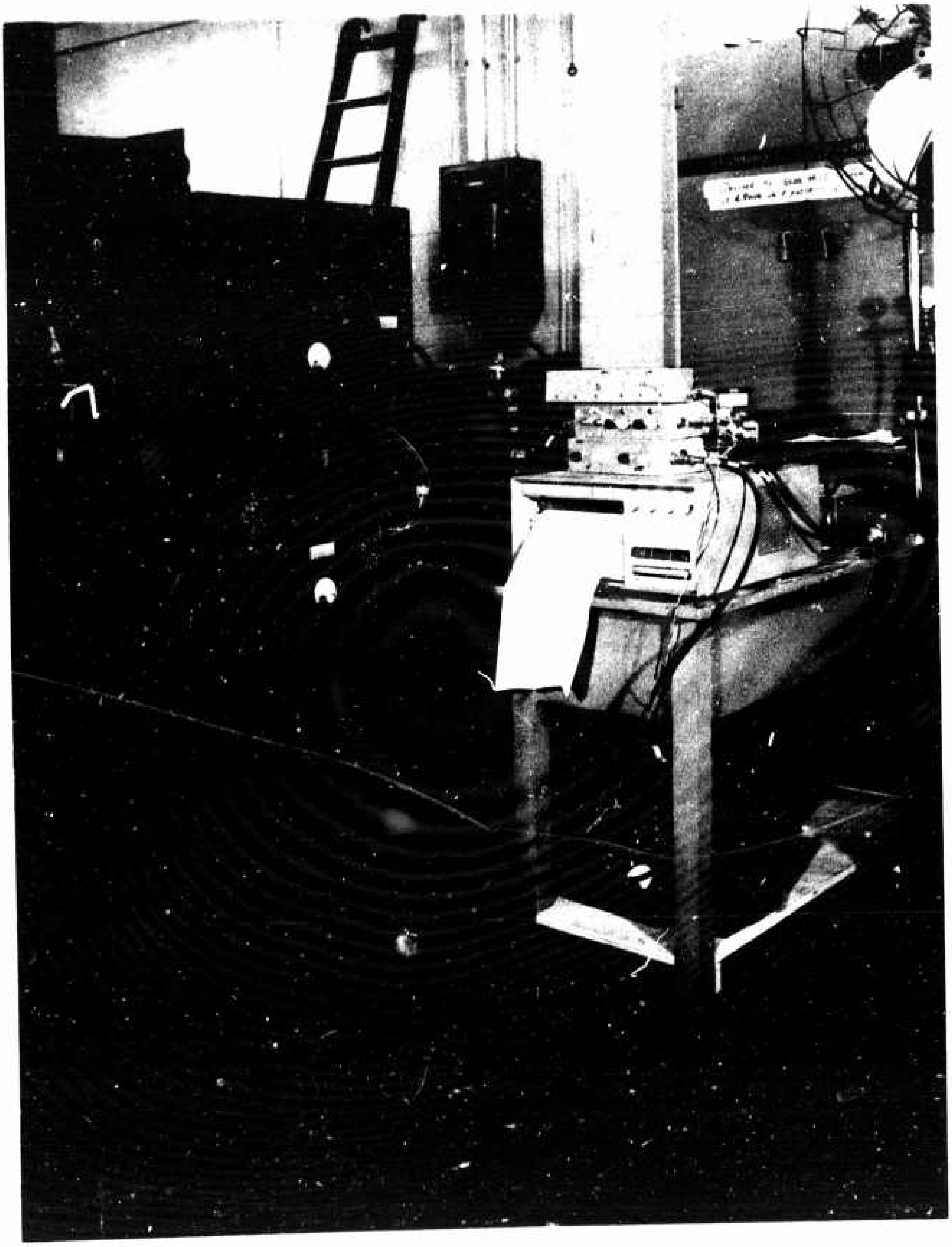


FIGURE 4 VIBRATOR CONTROL AND VISICORDER

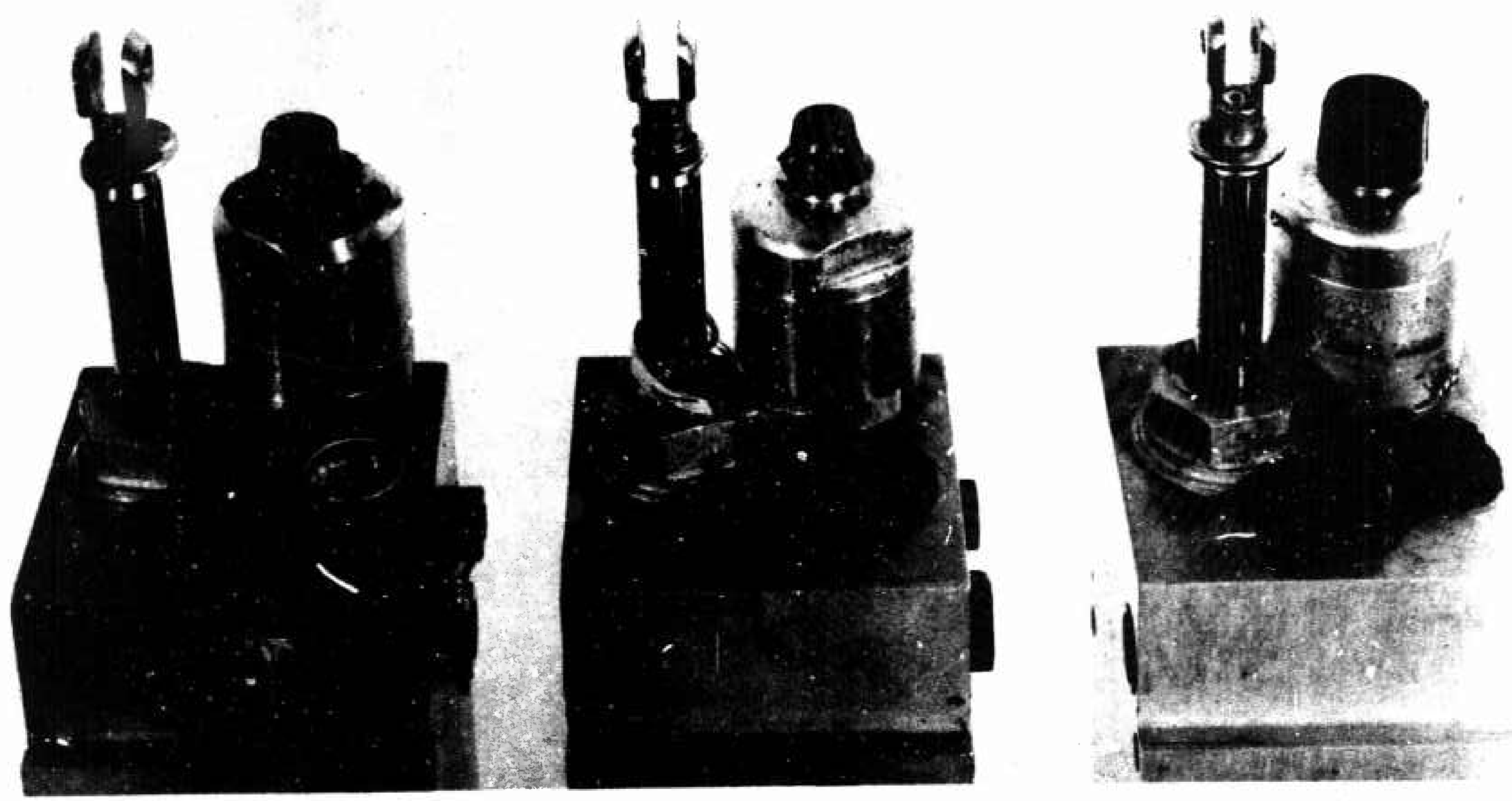


FIGURE 5 VIEWS OF METERING CONTROL VALVE FACE

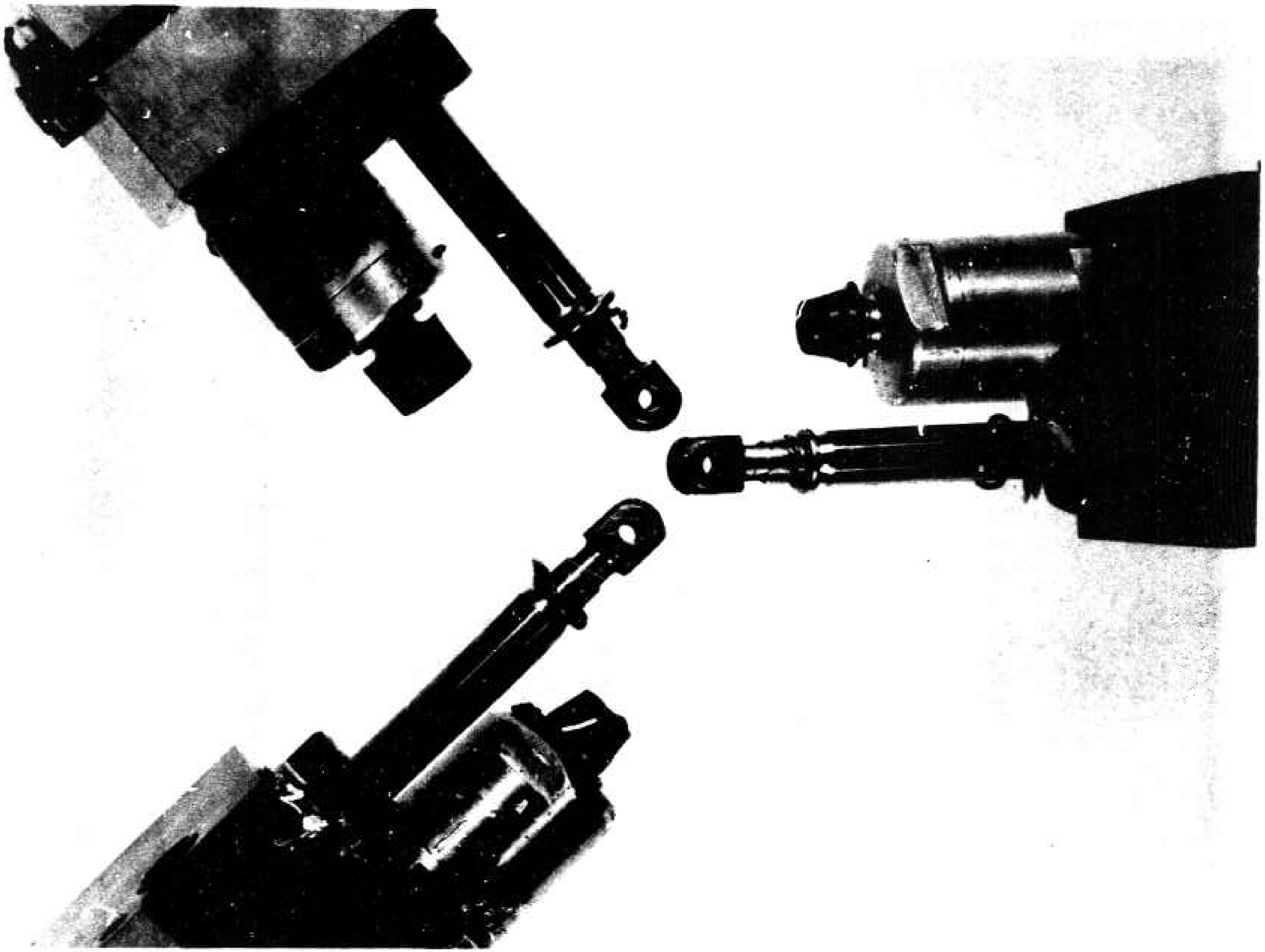


FIGURE 6 WASHER INSTALLATIONS ON METERING CONTROL ROD

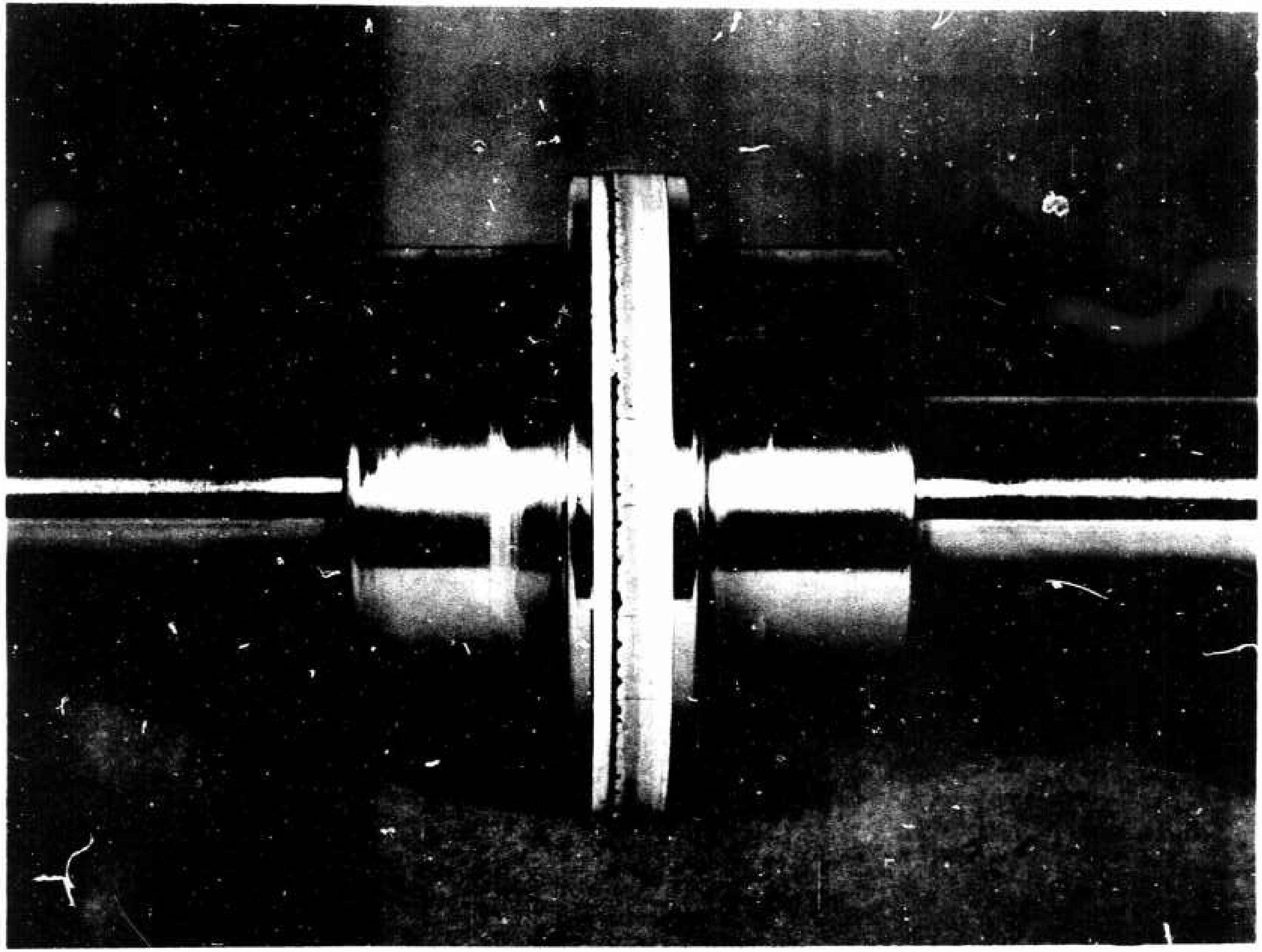


FIGURE 7 DAMAGED TEFLON CHANNEL SEAL REMOVED FROM UR EXHIBIT ACTUATOR

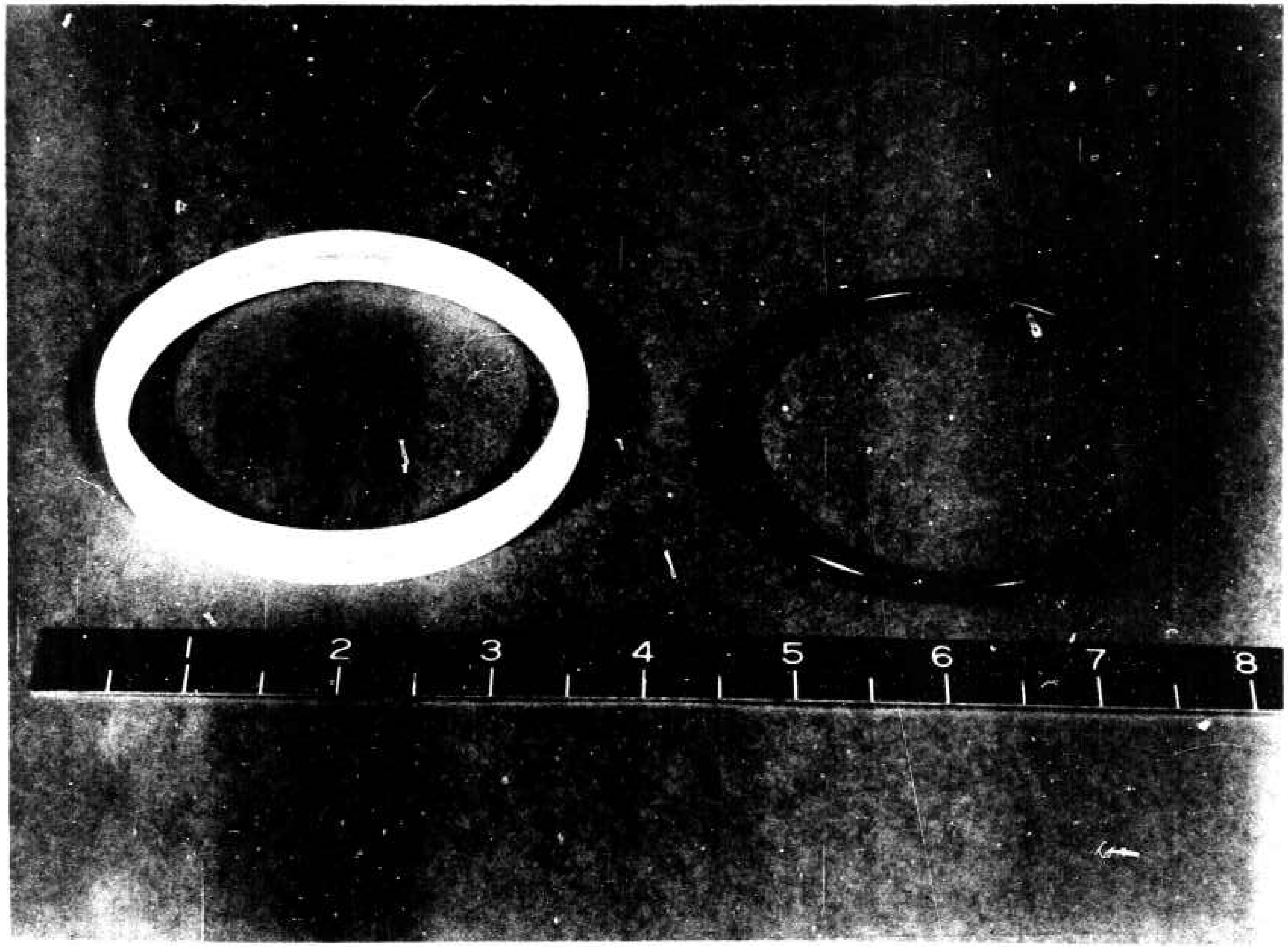


FIGURE 8 VIEW OF THE TEFLON CHANNEL SEAL CONFIGURATION

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13. ABSTRACT This report covers results of tests accomplished in investigating blow-by phenomenon utilizing the channel seal configuration installed in KC-135 airplane power rudder actuators. Various channel seal/groove clearances dimensions were investigated at different loads and applications of metering control rod movements.

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14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Piston Channel Seals						
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