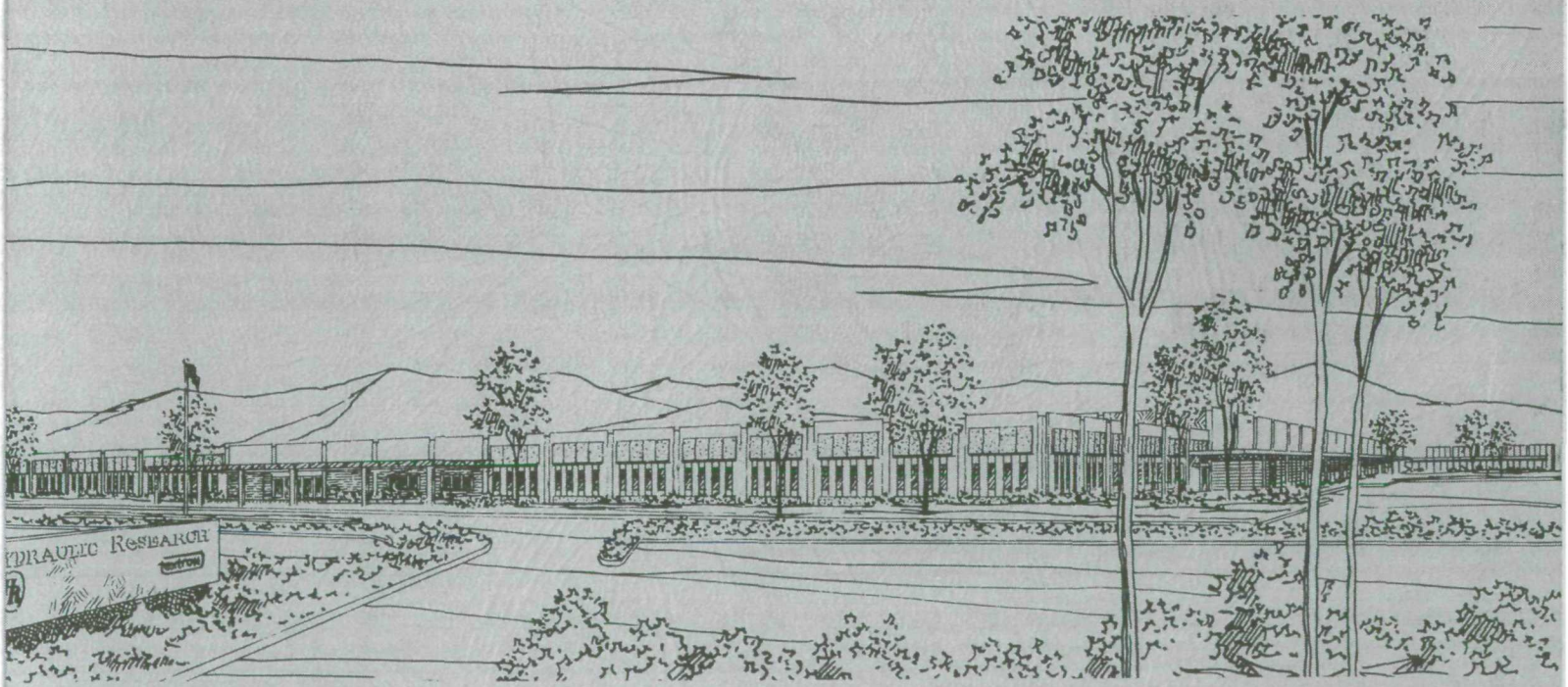
(NASA-CR-124025) MODIFICATION, STATIC TESTING AND DELIVERY OF ONE SERVOACTUATOR Final Report (Hydraulic Research and Mfg. Co.) 122 p HC $8.25 CSCL 13I
N73-20524
Unclas
G3/15 62032

FINAL REPORT
FOR
NASA CONTRACT NO. NAS 8-27928
MODIFICATION, STATIC TESTING AND DELIVERY OF ONE SERVOACTUATOR



HYDRAULIC RESEARCH
and MANUFACTURING COMPANY
A textron COMPANY

HR 7370006

25200 WEST RYE CANYON ROAD • VALENCIA, CALIFORNIA 91355

FINAL REPORT
FOR
NASA CONTRACT NO. NAS 8-27928
MODIFICATION, STATIC TESTING AND
DELIVERY OF ONE SERVOACTUATOR

HR 73700067

HYDRAULIC RESEARCH
and MANUFACTURING COMPANY
textron company
25200 WEST RYE CANYON ROAD • VALENCIA, CALIF. 91355
(805) 259-4030 TWX 910-336-1438
CODE IDENT 81873

REPORT NO. HR 73700067
HR&M JOB NO.
CONTRACT NAS 8-27928
NO. PAGES 106
DATE June 6, 1972
REV.

FINAL REPORT

FOR

NASA CONTRACT No. NAS 8-27928

Modification, Static Testing and

Delivery of one Servoactuator

PREPARED BY Kenneth E. Hart DATE 6-6-72
CHECKED BY _____ DATE _____
APPROVED BY _____ DATE 6-6-72
APPROVED BY _____ DATE _____
APPROVED BY _____ DATE _____

EG 055 (REV. 4-69)

CONTENTS

Paragraph		Page
1.	Scope.	6
2.	Statement of Work.	6
3.	Conclusions & Recommendations.	7
4.	S-1C Modification Description.	11
4.1	30004610 TVC Servoactuator Design Description.	11
4.2	Hydraulic Logic Module Design Description.	15
5.	Total System Operation Description	22
5.1	Hydraulic Logic Operation.	22
5.1.1	Operate Mode	22
5.1.2	Fail-Operate Mode.	24
5.1.3	Fail-Center Mode	24
5.2	Pressure System Supply Selector Valve Operation.	24
5.3	System Test Setup.	27
6.	Test Data Discussion	27
6.1	Linearity and Hysteresis	30
6.1.1	Hydraulic Logic System 1 (Operate Mode).	30
6.1.2	Hydraulic Logic System 2 (Fail-Operate Mode).	36
6.2	Threshold.	42
6.2.1	Hydraulic Logic System 1 (Operate Mode).	42
6.2.2	Hydraulic Logic System 2 (Fail-Operate Mode).	42
6.3	Frequency Response	42
6.3.1	Hydraulic Logic System 1 (Operate Mode).	43
6.3.1.1	Secondary Control Loop	43
6.3.1.1.1	Secondary Control Loop System Loop Gain Calculation.	45

CONTENTS (Continued)

Paragraph		Page
6.3.1.2	Total System.	47
6.3.2	Hydraulic Logic System 2 (Fail-Operate Mode)	50
6.3.2.1	Secondary Control Loop.	50
6.3.2.1.1	Secondary Control Loop System Loop Gain Calculations	52
6.3.2.2	Total System.	53
6.4	Failure Switching Transients.	55
6.4.1	Hydraulic Logic System 1 (Operate Mode) .	55
6.4.2	Hydraulic Logic System 2 (Fail-Operate Mode)	68
7.	Test Data Comparison.	81
7.1	Linearity and Hysteresis.	81
7.2	Total System Frequency Response	84
7.3	Sine Wave Response.	88
7.4	Step Response (Square Wave)	91
8.	Test Equipment Description.	94
9.	System Design Problem Areas	98
10.	Continuation of Development Testing	.103

Appendices

A: HR 73700065 Test Procedure. 105

B: HR 73600003 Hydraulic Research Redundant Thrust Vector Control Servoactuator Development Program. . .106

CONTENTS (Continued

TABLES

Page

Table 1. Linearity and Hysteresis - Hydraulic Logic System 1. 30
Table 2. Linearity and Hysteresis - Hydraulic Logic System 2. 36
Table 3. Failure Switching Transients - Hydraulic Logic System 1. 57
Table 4. Failure Switching Transients - Hydraulic Logic System 2. 69

FIGURES

Figure 1. 30004610 TVC Servoactuator Electrical and Hydraulic Schematic 13
Figure 2. 301100 S-1C Servoactuator Hydraulic Schematic 14
Figure 3. Photographs of 30004610 Unit. 16
Figure 4. Photographs of 30004610 Unit. 17
Figure 5. 33000660-3 Redundant Servoactuator (Minilogic) Schematic 18
Figure 6. 30004610 Total System Block Diagram 19
Figure 7. Pressure System Supply Selector Valve Assembly Schematic. 25
Figure 8. 30004610 Hydraulic Test Setup 28
Figure 9. 30004610 Dynamic Test Setup 29
Figure 10. 1% Linearity and Hysteresis Plot - Hydraulic Logic System 1. 31

CONTENTS (Continued)

FIGURES Page

Figure 11. 5% Linearity and Hysteresis Plot - Hydraulic Logic System 1. 32
Figure 12. 20% Linearity and Hysteresis Plot - Hydraulic Logic System 1. 33
Figure 13. 100% Linearity and Hysteresis Plot - Hydraulic Logic System 1. 34
Figure 14. 1% Linearity and Hysteresis Plot - Hydraulic Logic System 2. 37
Figure 15. 5% Linearity and Hysteresis Plot - Hydraulic Logic System 2. 38
Figure 16. 20% Linearity and Hysteresis Plot - Hydraulic Logic System 2. 39
Figure 17. 100% Linearity and Hysteresis Plot - Hydraulic Logic System 2. 40
Figure 18. Frequency Response - System 1 Control Loop. . . .44
Figure 19. Block Diagram - Control Loop. 46
Figure 20. Frequency Response - Total System (System 1 Active) 48
Figure 21. Block Diagram - Total System. 49
Figure 22. Frequency Response - System 2 Control Loop. . . .51
Figure 23. Frequency Response - Total System (System 2 Active) 54
Figure 24. Calibration Sheet 58
Figures 25.- 33. Hardover Command Signals to Servovalves (System 1). . . . . .59 - 67

CONTENTS (Continued)

FIGURES

Page

Figures
34. - 43. Hardover Command Signals to Servovalves (System 2). . . . . 71 - 80
Figure 44. 30004610 Linearity and Hysteresis 82
Figure 45. 301100 Linearity and Hysteresis 83
Figure 46. 30004610 System 1 Frequency Response. 85
Figure 47. 301100 Frequency Response (Amplitude Ratio) . . 86
Figure 48. 301100 Frequency Response (Phase Angle) 87
Figure 49. 30004610 Line Wave Response 89
Figure 50. 301100 Line Wave Response 90
Figure 51. 30004610 Step Response. 92
Figure 52. 301100 Step Response. 93
Figure 53. Photographs of Test Equipment 96
Figure 54. Photographs of Test Equipment 97
Figure 55. Actuator Null Adjustment. 99
Figure 56. 3-Stage Servovalve Feedback Spring Springrate Adjustment 102

1. SCOPE

This final report documents in detail all work performed under National Aeronautics and Space Administration Contract Number NAS 8-27928 (modification, static testing and delivery of one servoactuator). Work documented includes the following: S-1C modification description, total system operation description, test data discussion including analyses, test procedure and test data, conclusions and recommendations. Included also are photographs, test equipment description and additional test data to comprehensively describe the unit operation and test results.

All development and testing has been accomplished with a modified 301100 S-1C Servoactuator, designated 30004610 Thrust Vector Control Servoactuator (operate/fail-operate/fail-center), utilizing a 33000660-3 Redundant Servoactuator (minilogic) as a hydraulic logic module.

2. STATEMENT OF WORK

The following is the statement of work as defined in NASA Contract No. NAS 8-27928.

The contractor shall modify and static test one government furnished Hydraulic Research Model 301100 S-1C type servoactuator according to the following:

(1) Modify the existing actuator body to incorporate three servovalves driving a common power spool in such a manner that fail-operate/fail-safe redundant operation is obtained. Provisions shall be made to incorporate three separate hydraulic power sources with switching valves to switch out a failed source.

(2) Assemble and perform static testing on the modified actuator to determine baseline performance data.

3. CONCLUSIONS AND RECOMMENDATIONS

The modification design approach which HYDRAULIC RESEARCH elected to pursue involved rework to the HR&M P/N 301100 S-1C servoactuator body such that an active-standby self-monitoring type redundant system is utilized as a hydraulic logic module. The 30004610 TVC servoactuator when combined with the 33000660-3 redundant servoactuator (minilogic) as the hydraulic logic module provides an operate/fail-operate/fail-center system capability. A test procedure has been developed (see Appendix A) and used as a basis for all development testing. In addition to standard acceptance testing the major categories of development testing and those which are discussed in the report are: Linearity and Hysteresis, Threshold, Frequency Response and Failure Switching Transients. Very favorable testing results have been obtained for linearity and hysteresis, threshold and frequency response.

Comparisons have been made between the 30004610 (modified) unit and the 301100 S-1C unit (prior to modification) for linearity and hysteresis, frequency response and system response (sine wave and step responses). Results show slight variations in each category although when considering the design approach and method of modification the results are very encouraging.

Failure switching transient testing involved the application of hardover positive and negative signals to each servovalve in both actuator extend and retract stroke directions. Failure switching transient times in the range of 9.0 - 20.0 milliseconds have been obtained for the first failure (fail-operate mode) and 30.0 - 115.0 milliseconds for the second failure (fail-center mode). Large times in the fail-operate mode are caused by several system variables some of which are: Command signal amplitude, position of actuator at the time of failure, type of failure and secondary actuator centering springs.

Failure switching transient times obtained are well within those anticipated for operation with the active-standby self-monitoring type control system as designed and with the type of modification utilized.

Test results obtained from the modification and testing program can be interpreted for the 33000660-3 active-standby self-monitoring type control system only. All S-1C modification, development testing with test results and final report fulfill the statement of work defined in NASA Contract No. NAS 8-27928 (modification, static-testing and delivery of one servoactuator).

The 30004610 TVC servoactuator has been designed to operate with both the 33000660-3 Redundant Servoactuator (minilogic) and 34000220 servoactuator (electronic model) as hydraulic control modules. System operation with the 34000220 unit is described in the HYDRAULIC RESEARCH Report No. HR 73600003 included in Appendix B.

Development testing thus far has provided baseline performance data for the total system (as designed) when subjected to the operating and failure mode conditions as defined in the test procedure HR 73700065 (Appendix A). Performance characteristics could be extensively improved with a continuation in development testing conducted on the 30004610 unit utilizing both 33000660-3 and 34000220 units as hydraulic logic modules. Continuation of testing under a variety of failure modes with variations in loop gain, amplitude and frequency is recommended. A list of recommended testing is included in paragraph 10.

During the course of the modification program HYDRAULIC RESEARCH has conducted trade studies on several types of redundant control system designs which are directly applicable to thrust vector control servoactuator systems. The trade studies involved consideration of all the following: System design configuration, reliability, cost and weight. Basically the following are the major design requirement categories used for system configuration design:

(1) System Redundancy: Fail-operate/fail-safe (center)

(2) Supply Pressure Sources: Three separate independent pressure sources

(3) Command Inputs: Minimum of three separate and independent command inputs

(4) Switching Logic: Hydro-mechanical

(5) Feedback Mechanism: Mechanical or Hydro-mechanical

The resultant optimum system design configuration (per the trade study) is a single closed loop hydraulic comparator intersystem - monitoring active-standby type system. System design description is as follows:

The system is provided with three separate independent two-stage flapper-nozzle type high flow rate mechanical feedback servovalves which control directly the main actuator piston. Each servovalve is supplied with a separate individual pressure system and command input signal. A combination of comparator valves, shutoff valves and engage valve provide for the active-standby intersystem monitoring capability. Servovalves # 1 and 2 are the active and standby systems respectively where servovalve # 3 is utilized as a monitor.

Complete system isolation is obtained for the unit to the engage valve and main actuator only. Any combination of failures (command input, servovalve hardover and softover, pressure, etc.) are automatically sensed and system control is automatically switched within the unit. Final fail-safe (center) mode operation is provided for by a combination of control valve, centering link and pressure switching valves. Mechanical feedback is provided from the main actuator piston directly to all

three servovalves. Also dynamic load damping is provided for load damping under load resonant conditions. Failure indication readout is obtained through separate pressure switches.

4. S-1C MODIFICATION DESCRIPTION

4.1 30004610 TVC Servoactuator Design Description

The objective of the program was to modify and statically test a government furnished HYDRAULIC RESEARCH Model 301100 S-1C Servoactuator as described in Paragraph 2. "Statement of Work". Very early in the program HYDRAULIC RESEARCH had taken exception to the "three servovalve driving a common spool" portion of the work statement with the approval of NASA-MFSC. In place of the three servovalves requirement a four servovalve active-standby self-monitoring type hydraulic logic has been utilized. (Reference Paragraph 4.2).

Modification of the 301100 S-1C Servoactuator, which had been designated 30004610 Thrust Vector Control Servoactuator (operate/fail-operate/fail-center), is shown schematically in Figure 1. and in block diagram form in Figure 6. Complete unit installation, assembly and schematics can be found on drawing 30004610, sheets 1 through 3. For comparison, a schematic of the original non-modified 301100 S-1C Servoactuator is shown in Figure 2.

As shown in Figure 1 and on 30004610 drawings, the 301100 S-1C Servoactuator has been modified as follows:

(1) Three-stage servovalve torque motor replaced by a mechanical input.

(2) Summing link added along with a bias spring (to bias all excess linkage clearances).

(3) Added also are two secondary actuators (modulating pistons) connected by a whiffletree link and provided with centering springs and an LVDT (utilized for closing the control loop). Secondary actuators are operated by the hydraulic logic module described in Paragraph 4.2.

(4) Pressure system supply selector valve assembly is provided as a separate unit connected to the S-1C body by flexible tubing.

All hardware described in (1), (2) and (3) has been designed to attach directly onto the existing torque motor access cover mounting pad. Very little rework to the S-1C body has been required.

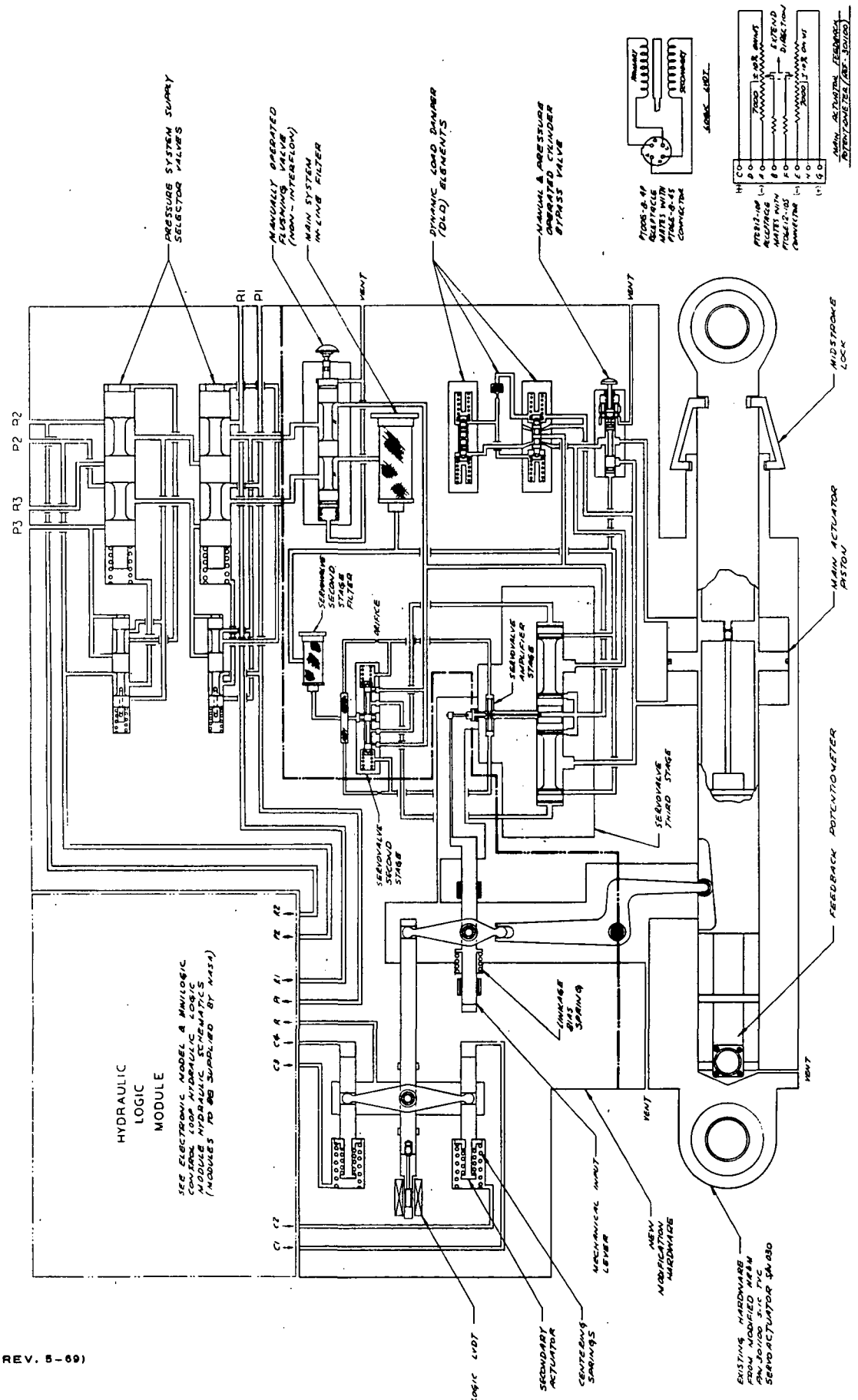


Figure 1. 30004610 TVC Servoactuator Electrical and Hydraulic Schematics (Modified 301100 S-1C Servoactuator)

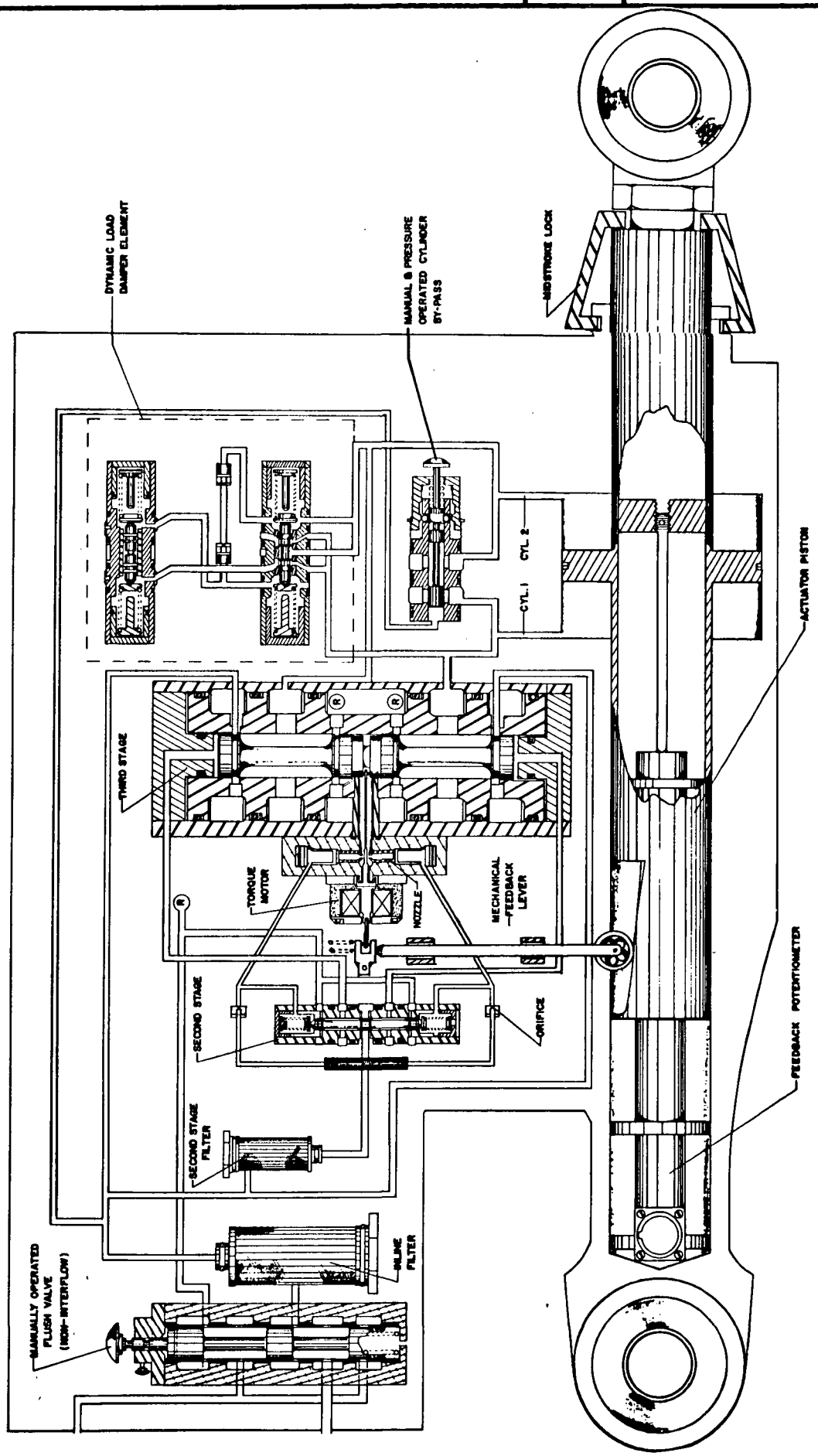


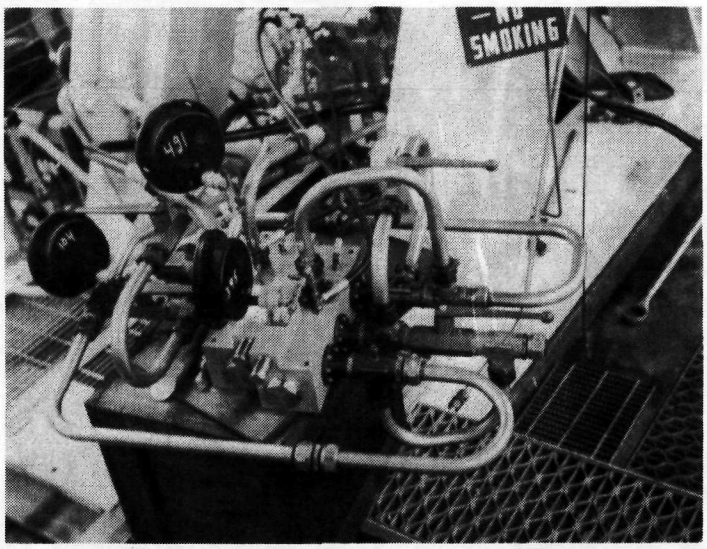
Figure 2. 301100 S-1C Servoactuator
Hydraulic Schematic

The pressure system supply selector valve assembly has been provided to satisfy the work statement (Paragraph 3) requirement of incorporation of "three separate hydraulic power sources with switching valves to switch out any two failed sources" while maintaining one normal source to the 30004610 unit. Installation of the valve assembly can be seen in a photograph in Figure 4. with operation description found in Paragraph 5.2.

The 30004610 unit has been designed to accomodate the 33000660-3 Redundant Servoactuator (minilogic), shown in Figure 5, as the hydraulic logic module to satisfy the requirement operate/fail-operate/fail-safe (center). The 33000660-3 hardware mounted on the 30004610 unit can be seen in the photograph in Figure 3. with operation description found in Paragraph 4.2.

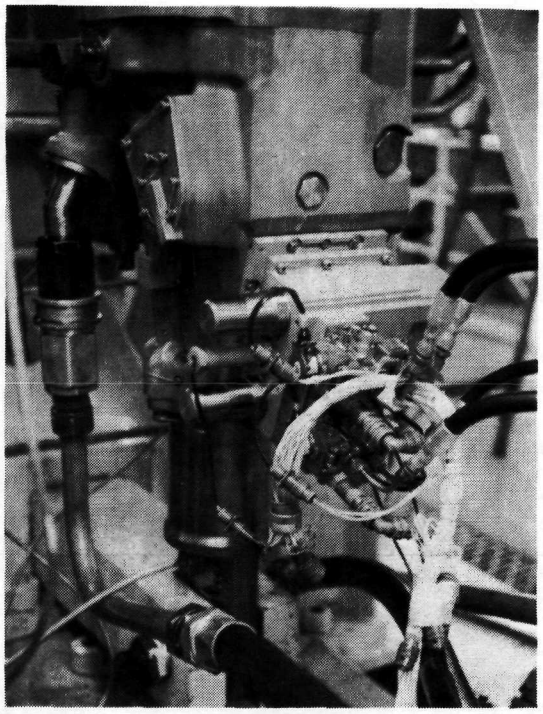
4.2 Hydraulic Logic Module Design Description

As described previously and shown in Figure 5., the 33000660-3 Redundant Servoactuator (minilogic) has been utilized as a hydraulic logic module for use with the 30004610 unit. The 33000660-3 unit together with the 30004610 unit are shown in block diagram from in Figure 6. The following is a description of the individual components in the 33000660-3 unit only with operation as a complete logic module found in Paragraph 4.

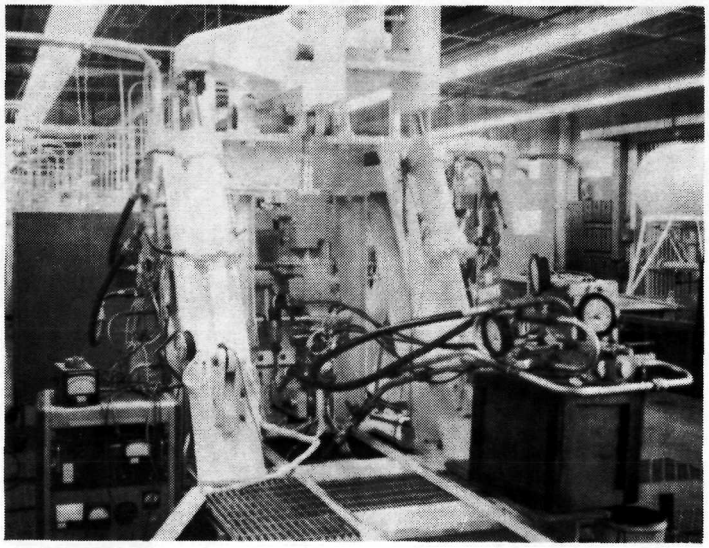


Pressure System Supply
Selector Valve
Assembly

Figure 3. Photograph of 30004610 Unit



33000660 Redundant Servoactuator (mini-logic) Installed



30004610 Unit Installed on Load Simulator

Figure 4. Photographs of 30004610 Unit

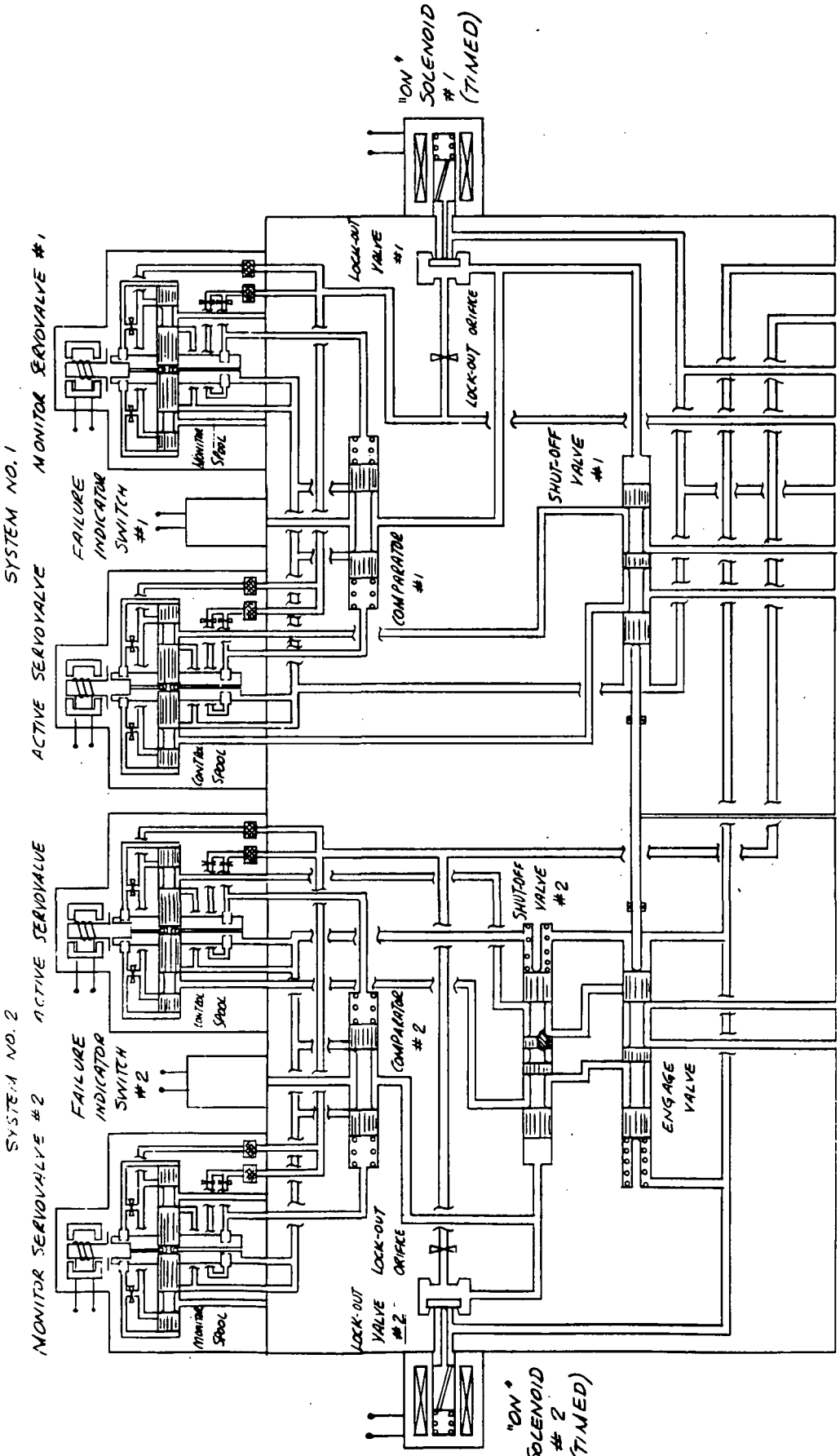
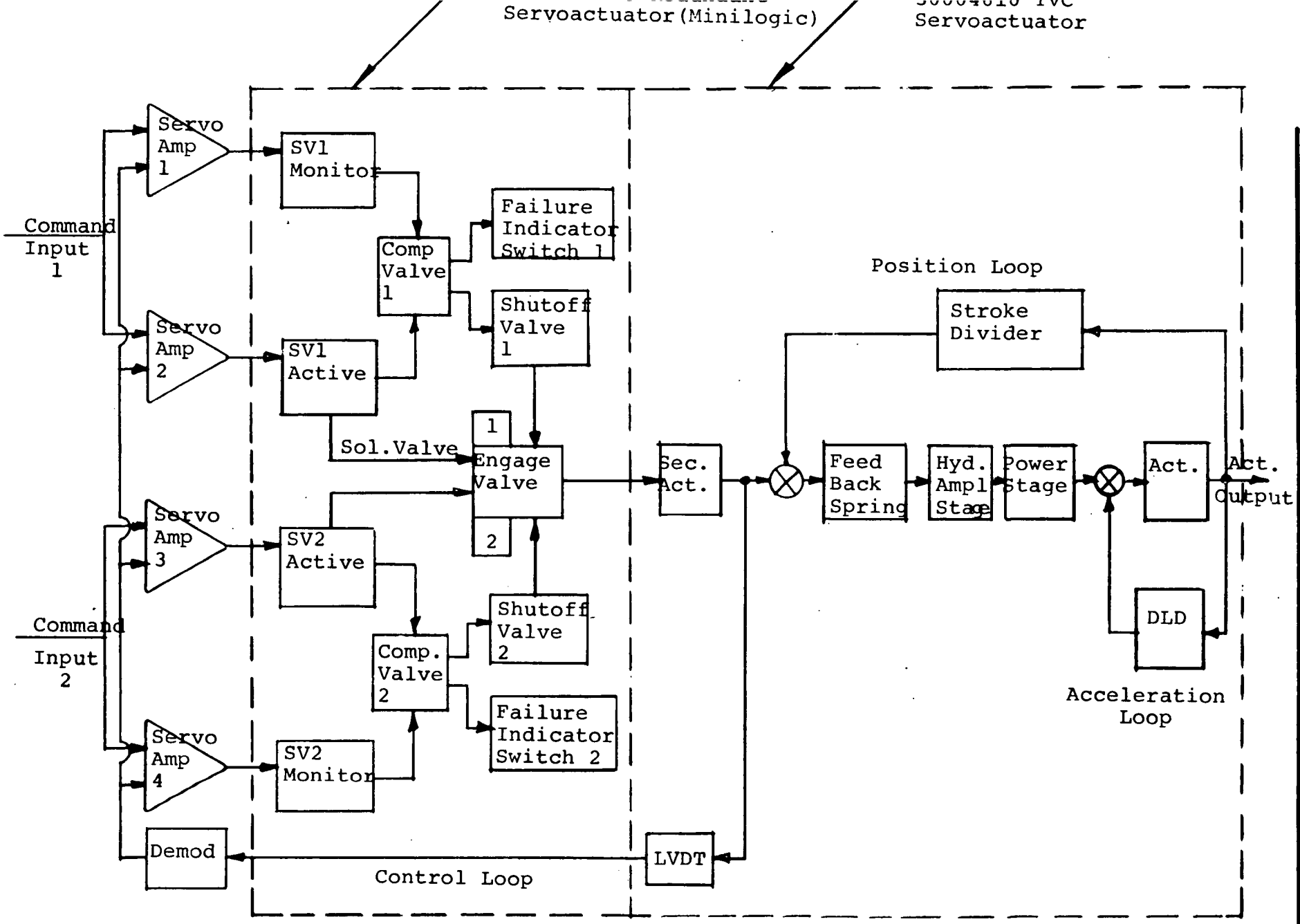


Figure 5. 33000660-3 Redundant Servoactuator (Minilogic) Schematic



NOTE: SV - Electrohydraulic Servovalve

Figure 6. 30004610 Total System Block Diagram

HYDRAULIC RESEARCH and MANUFACTURING COMPANY
25200 WEST RYE CANYON ROAD • VALENCIA, CALIFORNIA 91355
Unitron COMPANY
REV.
REPORT NO. HR 73700067
PAGE NO. 19
PART NO.

The 33000660-3 unit is configured as a active-standby self-monitoring type redundant system which, when installed onto the 30004610 TVC Servoactuator, provides for an operate/fail-operate/fail-center system capability. Each system (No. 1 and 2) has two servovalves which receive equally matched, within acceptable tolerances, command signals. Spool position of each pair of servovalves is compared hydromechanically by a separate comparator spool. Each end of the comparator spool senses nozzle pressure from an additional nozzle-flapper circuit attached directly to the servovalve spool. A channel failure (command signal, servovalve hardover, etc) will manifest itself as a difference in spool position thus a difference in nozzle pressure is sensed at the comparator spool. When this difference exceeds a preset failure threshold level, the comparator spool shifts, porting shutoff valve 1 pressure to return. The engage and shutoff 1 valves then shift switching control from the active system to standby system. Active system cylinders C3 and C4 are then interconnected with cylinders C1 and C2 ported to active servovalve 2.

The solenoid valves in each system are pulsed for system startup and are held in the engage position by system pressure. When electrically de-energized, the solenoid valve senses loss in its system pressure (at a preset pressure failure threshold level) at which point it ports shutoff valve pressure to return. The engage and shutoff 1 valves then shift switching control from the active system to the standby system. Upon a command

failure or pressure loss in the standby system, shutoff valve 2 shifts, thus interconnecting cylinders C1 and C2.

The failure indicator switches are utilized to indicate each system failure by supplying an electrical signal for instrumentation readout.

5. TOTAL SYSTEM OPERATION DESCRIPTION

The 30004610 unit, Figure 1., with the 33000660-3 unit Figure 5., combine to form a totally redundant active-standby self-monitoring type Thrust Vector Control Servoactuator assembly. An operate/fail-operate/fail-center capability is the result whereby two electrical, two hydraulic or any two electrical/hydraulic failures can be sustained by the unit prior to failing to the fail-center mode of operation. The following is a description of each mode of operation of the unit.

5.1 Hydraulic Logic Operation

5.1.1 Operate Mode

When pressurized (P1, P2 and P3) and with all electrical components energized, the total system will operate on active system 1 and pressure P1 prior to any failures. Active Servovalve 1 operates one secondary actuator (modulating piston) through cylinders C3 and C4. Since the standby system active servovalve 2 is disengaged from operation and cylinders C1 and C2 are interconnected, the second secondary actuator is spring centered to the mechanical null position providing a rigid pivot point for the whiffletree link. A commanded input signal to servovalve 1 is transmitted through the whiffletree link to the summing link, thereby providing an error input signal to the three-stage servovalve

feedback spring. As shown in the block diagram, Figure 6., servovalve 1 control loop is closed through the secondary actuator LVDT (electrical feedback) and actuator position loop is closed through the main actuator stroke divider (mechanical feedback). Two separate loops, one electrical feedback and the other mechanical feedback, are required to operate the total system as modified.

The 33000660-3 unit has been designed to sense an electrical or pressure failure as follows:

(1) Servovalve switching current (failure threshold level) set at 5.5 $\pm$1.0 ma. Compared to 16 ma rated current this amounts to 34.4% failure threshold level.

(2) Solenoid valve (1 and 2) sensing pressure set at 59000 $\pm$3690 newton/meter^2 (1600 $\pm$100 psi).

(3) Shutoff valve (1 and 2) sensing pressure set at 53500 newton/meter^2 (1450 psi) max.

(4) Failure Indicator Switch (1 and 2) opening pressure set at 33200 $\pm$7380 newton/meter^2 (900 $\pm$200 psi).

Therefore if the command signal to the active or monitor servovalve (in either system) differs more than 5.5 $\pm$ 1.0 ma, system switching will be initiated with the above component switching sequence (1, 2, 3 and 4) taking place.

5.1.2 Fail-Operate Mode

Upon sensing a channel 1 electrical or pressure (P1) failure, the hydraulic logic system (as described in Paragraph 4.2) will switch to the standby system 2 with operation on active servovalve 2 and system pressure P2. When switching occurs, cylinders C3 and C4 are interconnected, thus allowing the centering springs to center the secondary actuator to mechanical null position. Centering the piston will provide a rigid pivot point for the whiffletree link whereupon the standby secondary actuator will become operational. Operational sequency is the same as described in Paragraph 5.1.1.

5.1.3 Fail-Center Mode

Upon sensing a channel 2 electrical or pressure P2 failure, the hydraulic logic system will switch cylinders C1 and C2 to interconnect whereupon the secondary actuator will automatically be spring centered to the mechanical null position. Main actuator mechanical null centering will therefore be initiated through the linkage, three-stage servovalve and mechanical feedback mechanisms.

5.2 Pressure System Supply Selector Valve Operation

The pressure system supply selector valve assembly, as shown in Figure 7, consists of two power spools (1 and 2) which are each controlled by a separate

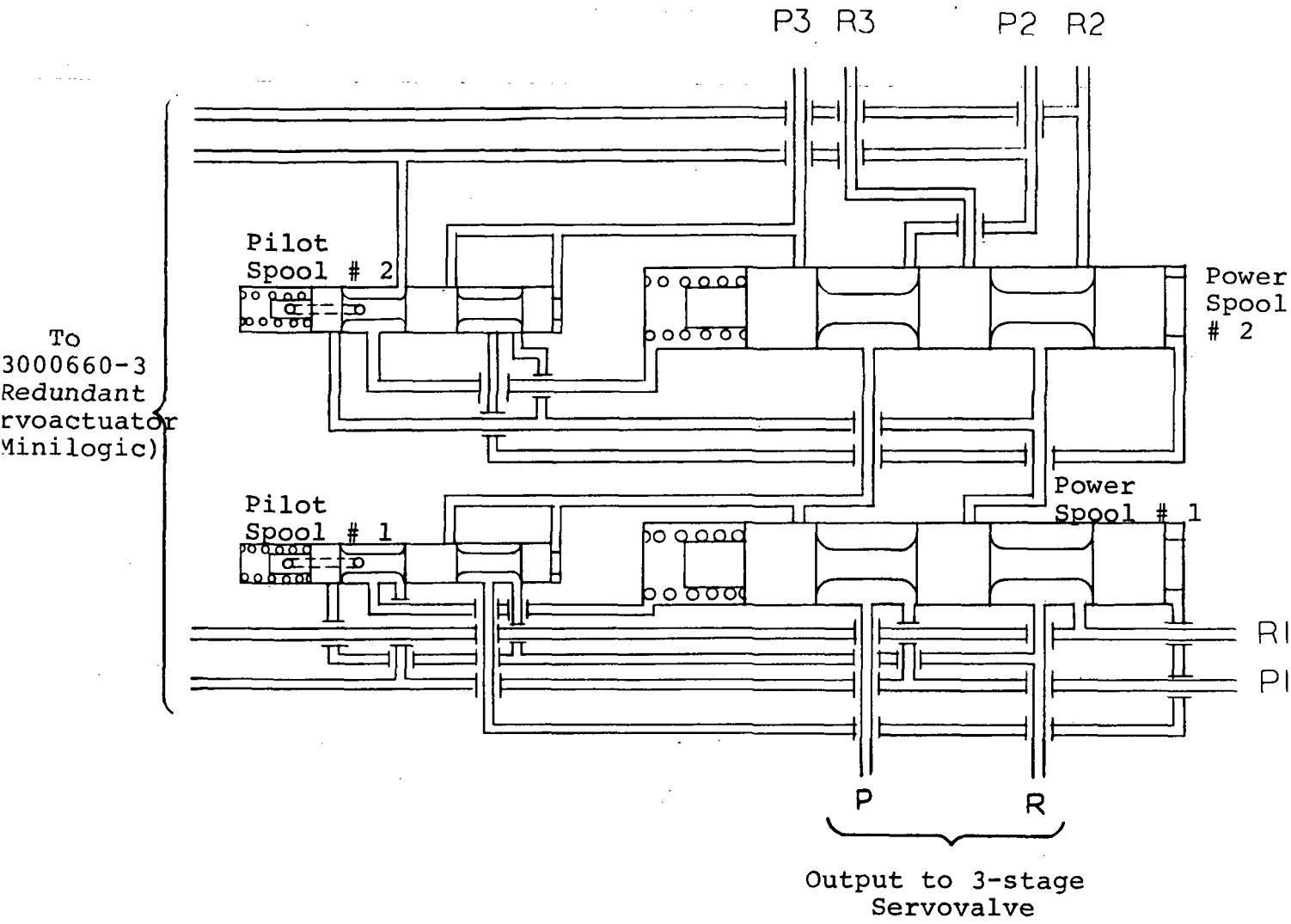


Figure 7. Pressure System Supply Selector Valve Assembly Schematic

pilot spool (1 and 2). Under normal conditions, with all system pressures (P1, P2 and P3) operating, the output pressure to the 3-stage servovalve is P1. Under these conditions the power spools are pressurized to their open position with the pressurizing pressure being ported through the pilot spool. Upon decrease of pressure P1 to 40600 newton/meter^2 (1100 psi) pilot spool 1 will shift against the spring load. When shifted, pilot spool 1 ports pressure P2 to power spool 1 thus shifting it and porting pressure P2 to the output.

Upon sensing a decrease in pressure P2 to 40600 newton/meter^2 (1100 psi), the pilot spool 2 will shift thus porting pressure P3 to power spool 2, thus shifting it. Pressure P3 is then ported to the output.

The pilot spools are designed such that re-engagement of a failed pressure will not automatically occur. Each failed pressure source is blocked and cannot be re-engaged if any one of three pressures is normally operating. Re-engagement requires the decrease of all pressures (P1, P2 and P3) to a level below 40600 newton/meter^2 (1100 psi) and sequentially pressurizing P1, P2 and P3.

The valve assembly, as described, will sense any combination of two pressure failures while maintaining a normal pressure at the output. An operate/fail-operate/fail-operate capability is therefore maintained.

5.3 System Test Setup

All development testing has been accomplished with the system hydraulic test setup per Figure 8. In addition, all system test data has been recorded with the unit installed and operating on the engine dynamic load simulator as shown in Figure 9.

6. TEST DATA DISCUSSION

A complete 30004610 TVC Servoactuator test procedure including all test data, report no. HR 73700065, is included in Appendix A. Data results, as required, have been repeated in the following discussion for clarification of presentation. Four categories of test data are discussed and are as follows: (1) Linearity and Hysteresis (2) Threshold (3) Frequency Response and (4) Failure Switching Transients.

As indicated in test procedure HR 73700065, hydraulic logic control system loop gain values have been established by specifying a servoamplifier gain of 54.0 ma/v and an LVDT-Demodulator gain of 1.338 v/cm (3.40 v/in). Loop gain calculations are included in Paragraph 6.3.

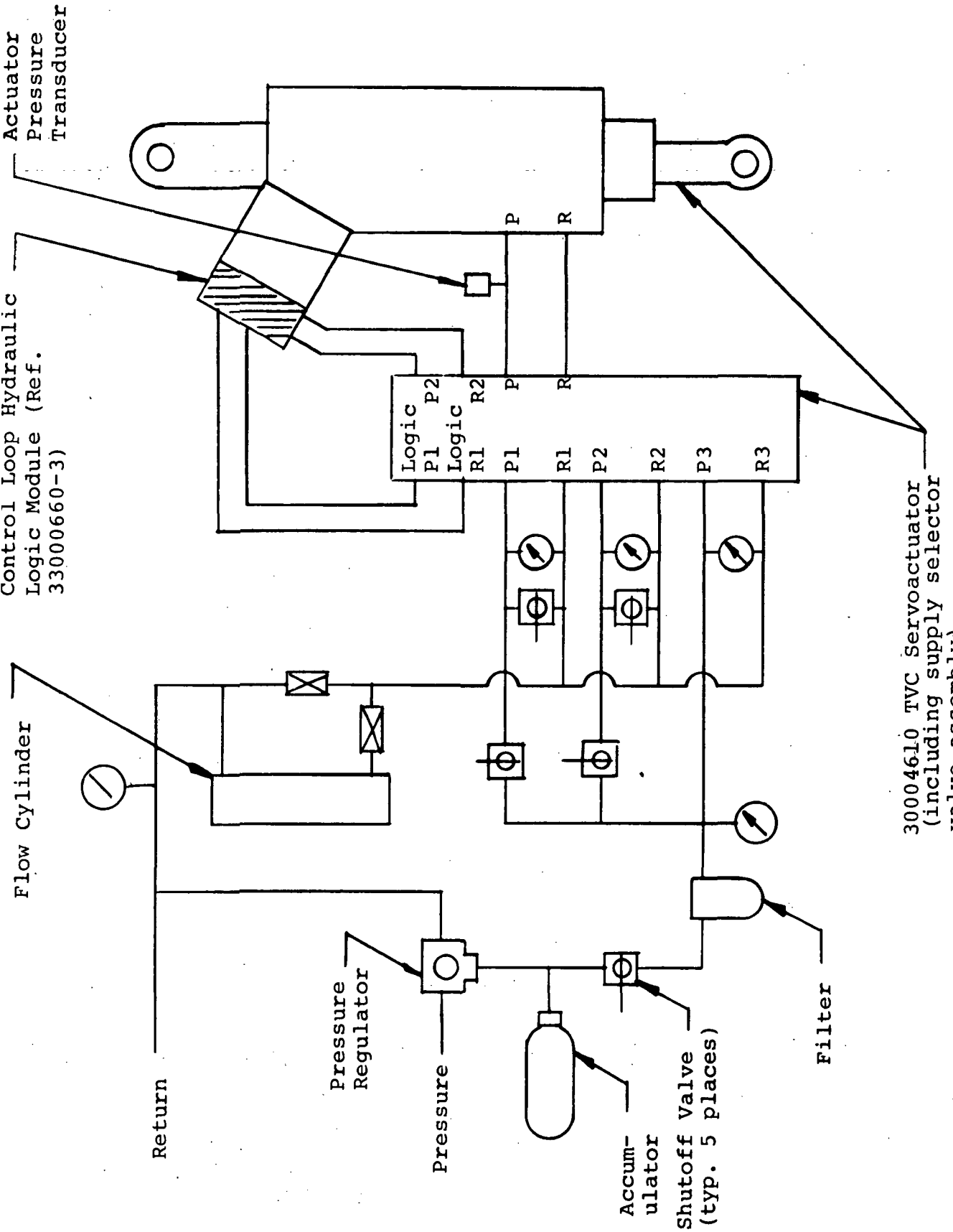


Figure 8. 30004610 Hydraulic Test Setup

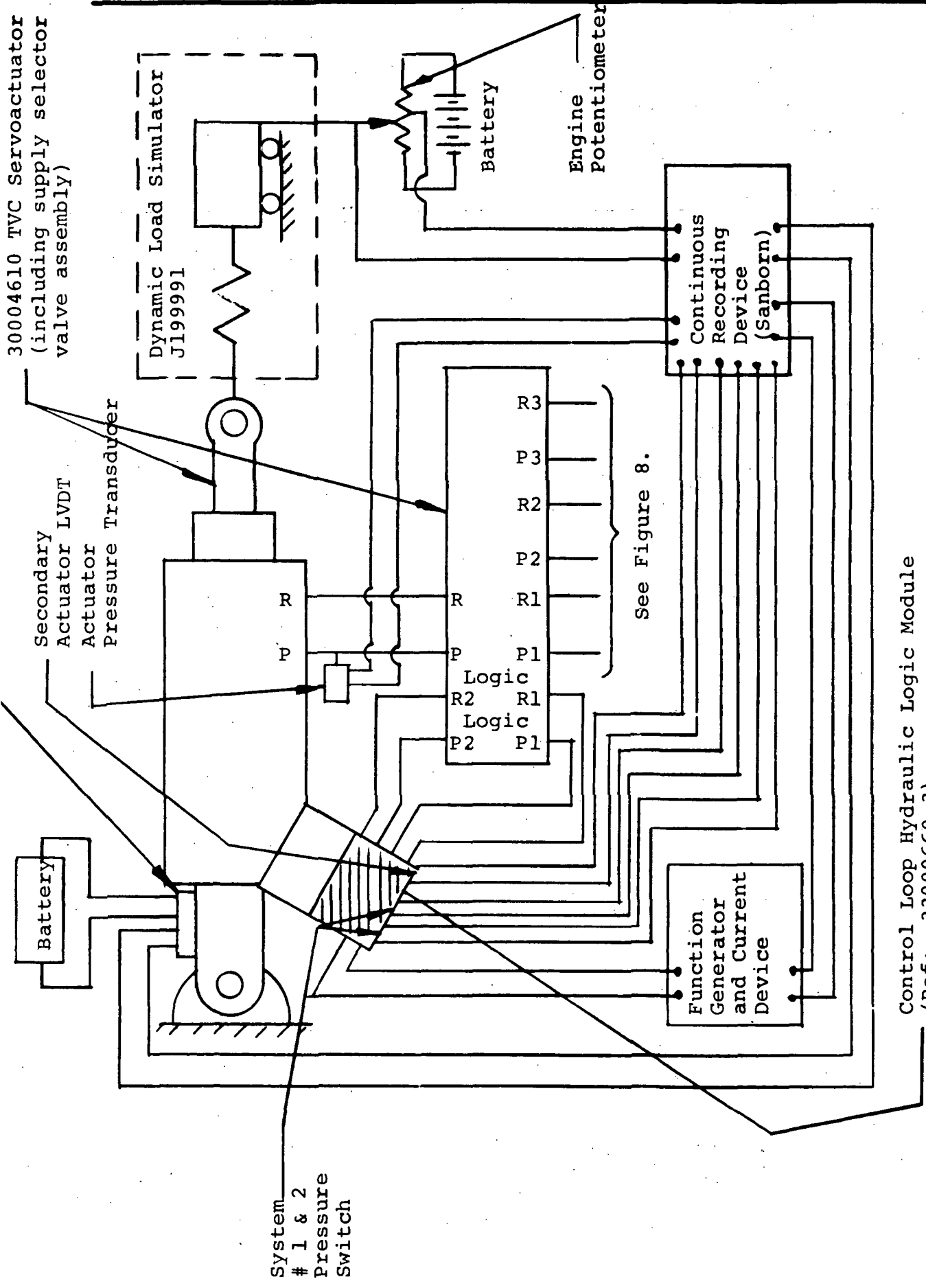


Figure 9. 30004610 Dynamic Test Setup

6.1 Linearity and Hysteresis

6.1.1 Hydraulic Logic System 1 (Operate Mode)

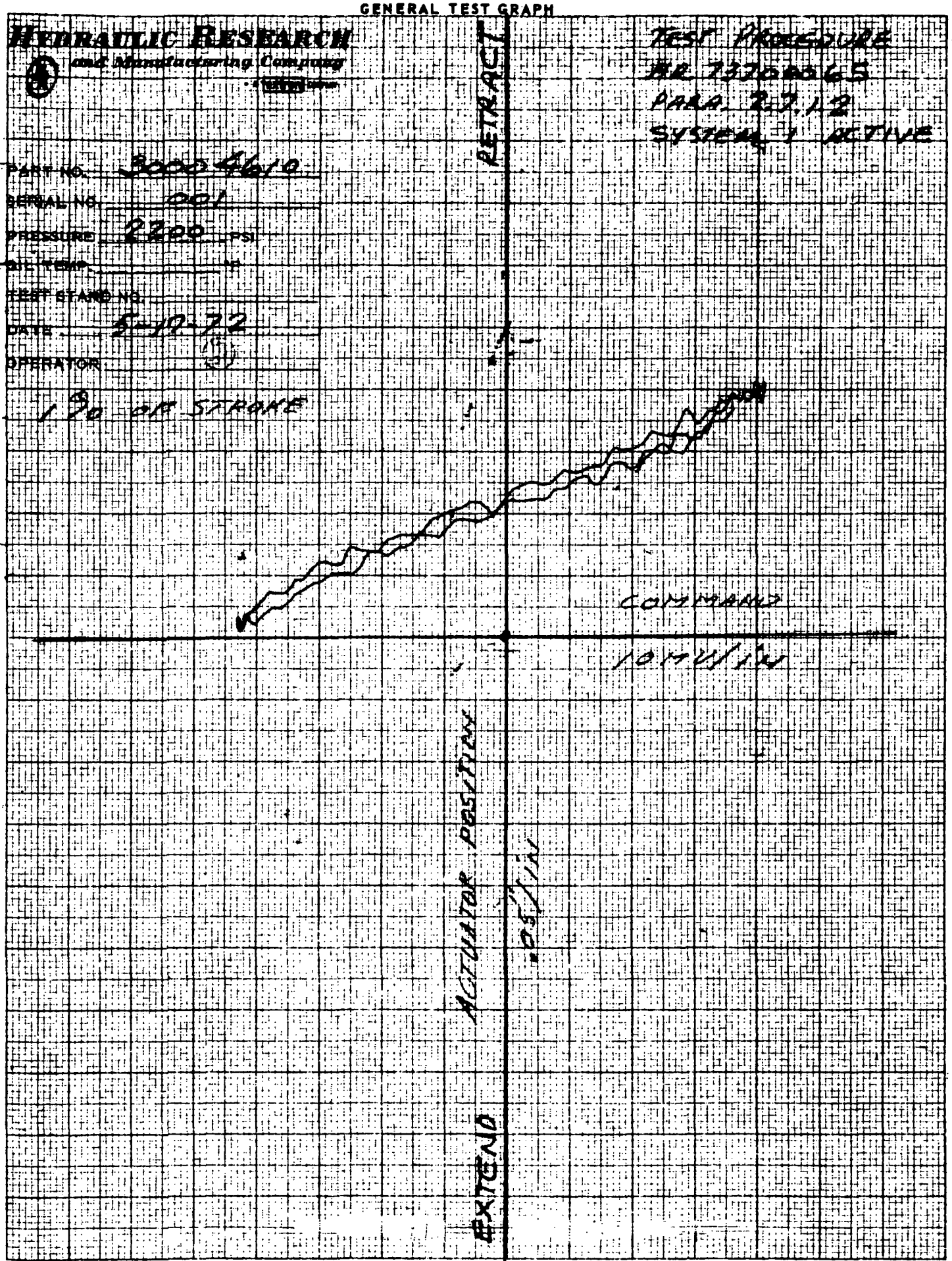
With the unit operating on active system 1, linearity and hysteresis were plotted with test data shown in Figures 10, 11, 12 and 13. Strokes of 1%, 5%, 20% and 100% of full stroke were plotted at a system pressure P1 of 81200 newton/meter^2 (2200 psi).

The plotted data has been reduced and tabulated on Table 1 as numerical % rated command input signal.

HYDRAULIC LOGIC SYSTEM 1 (Operate Mode)		
Percent Full Stroke	Linearity % Rated Command Input Signal	Hysteresis % Rated Command Input Signal
1%	7.6	9.5
5%	6.7	14.4
20%	7.1	13.5
100%	2.33	4.07
Note: Actuator Full Stroke 29.82 cm (11.74 in)		

TABLE 1. Linearity and Hysteresis - Hydraulic Logic System 1

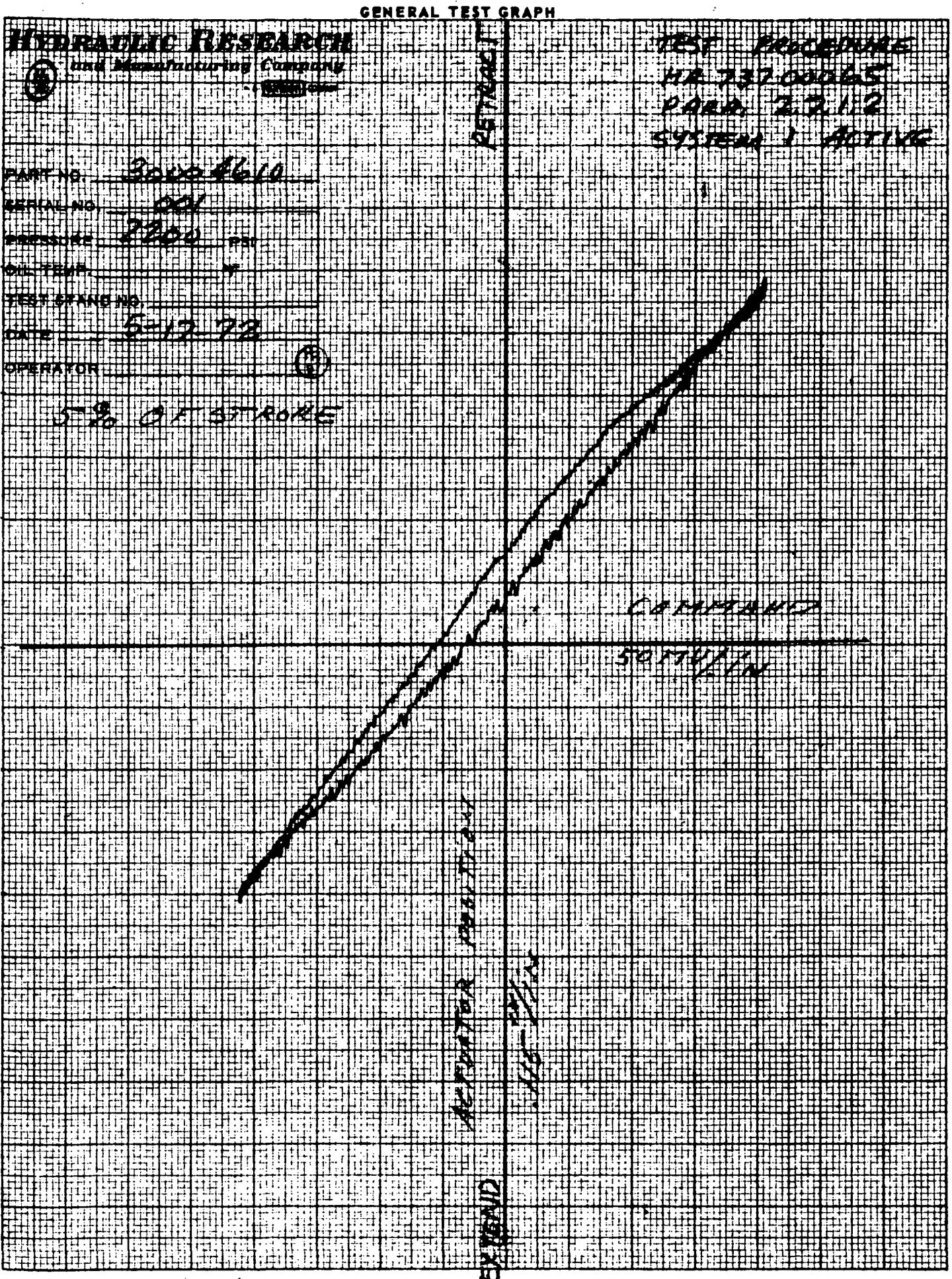
GENERAL TEST GRAPH



1% Linearity and Hysteresis Plot

Figure 10. Hydraulic Logic System 1

EL 009



EL 009

Figure 11. 5% Linearity and Hysteresis Plot - Hydraulic Logic System 1

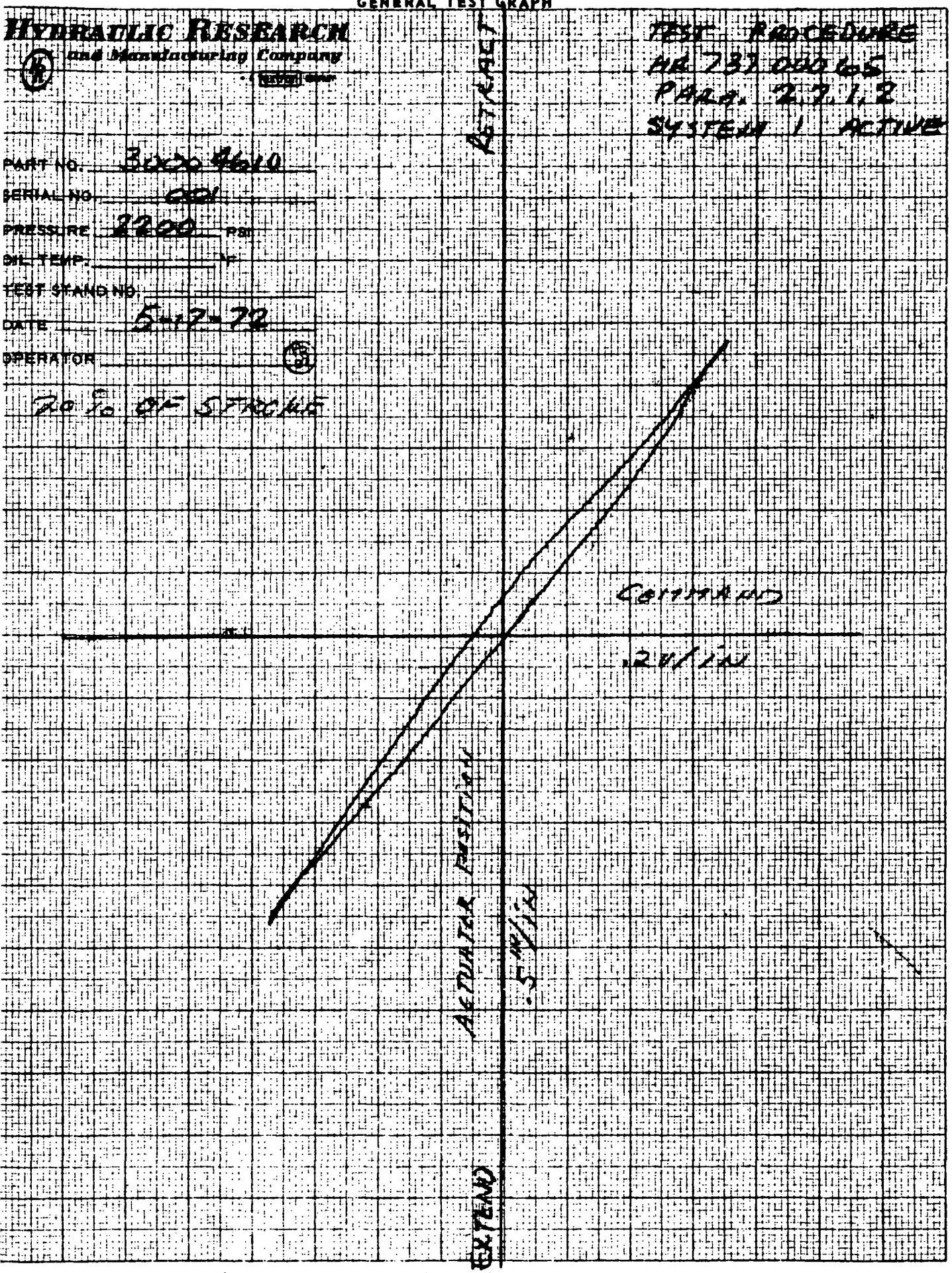


Figure 12. 20% Linearity and Hysteresis Plot - Hydraulic Logic System 1

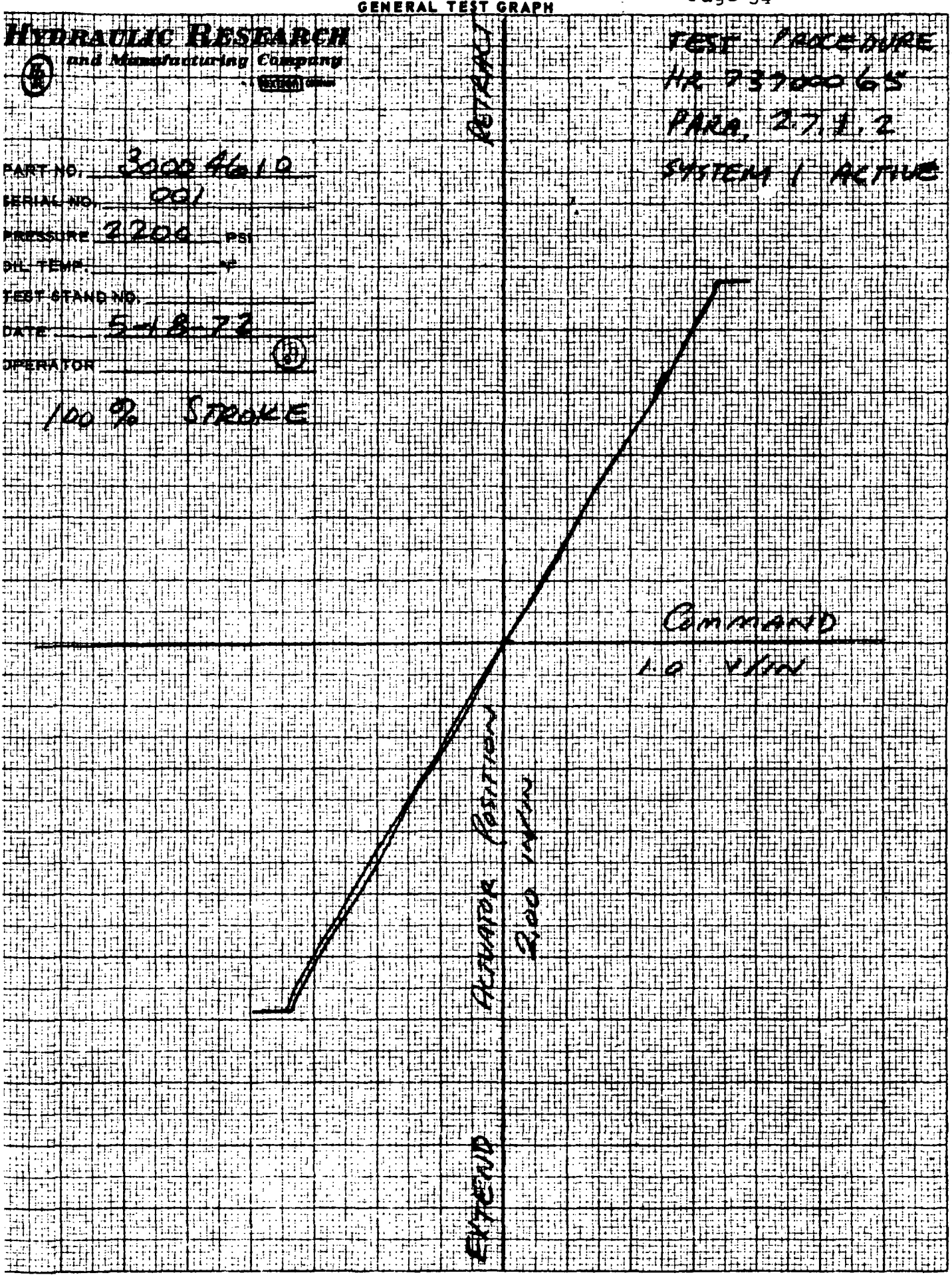


Figure 13. 100% Linearity and Hysteresis Plot - Hydraulic Logic System 1

The linearity and hysteresis values at 100% stroke are compared to that tested on the 301100 S/N 030 S-1C Servoactuator prior to modification (reference Paragraph 7.2). Comparison is as follows:

Unit	Linearity	Hysteresis
301100 (non-modified)	2.05%	1.23%
30004610 (system 1)	2.33%	4.07%

The reason for increased 30004610 (system 1) unit hysteresis can be attributed primarily to the two separate closed loop system design. Whereas the linearity increase in the 30004610 (system 1) unit is caused mainly by the mechanical linkage in each of the two closed loops (reference Figure 1.). Two loop servocontrol systems in general have wider linearity band characteristics. The 301100 unit in comparison is a single closed loop system with no mechanical linkage.

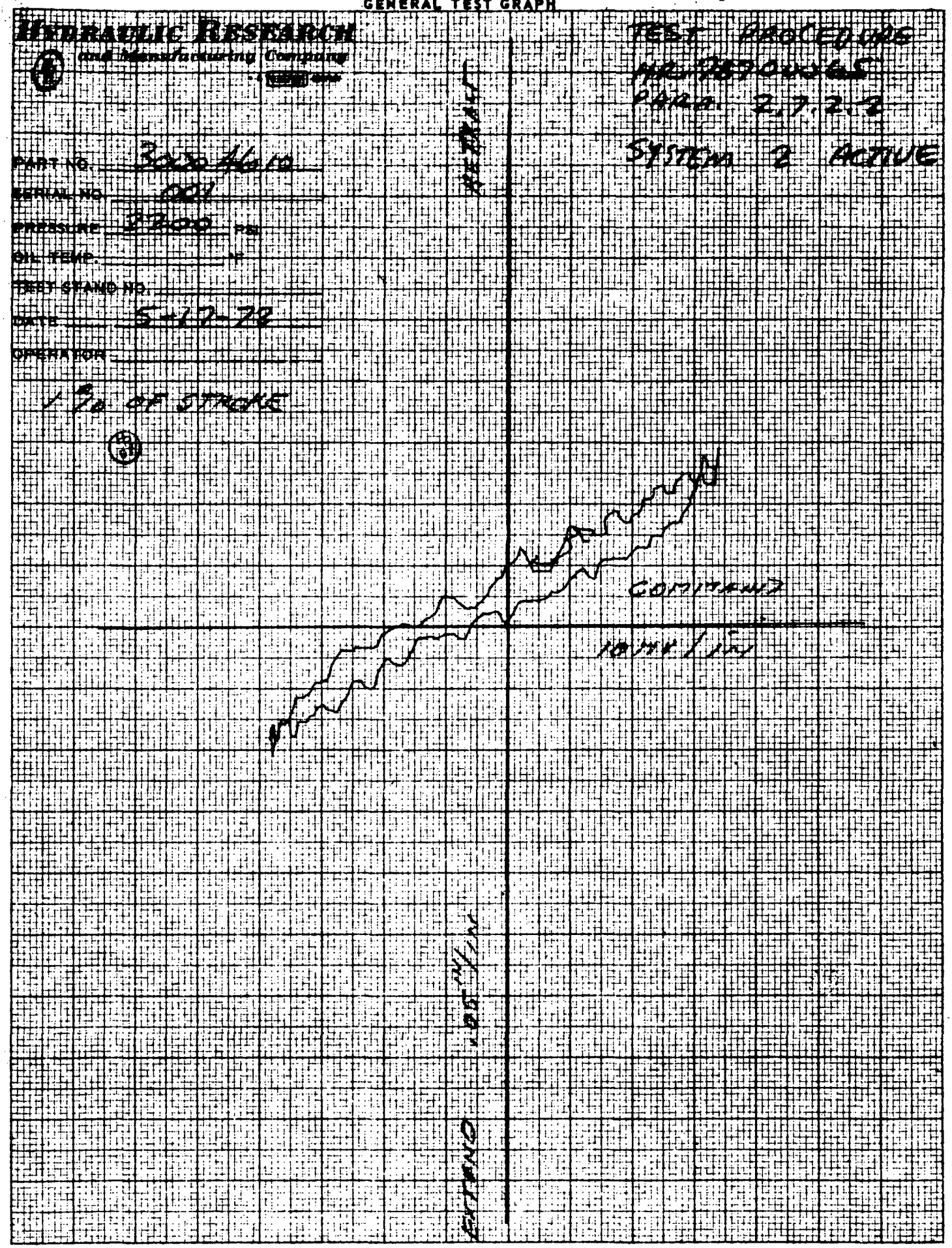
6.1.2 Hydraulic Logic System 2 (Fail-Operate Mode)

With system 1 failed and standby system 2 in control of the unit, linearity and hysteresis were plotted with test data shown in figures 14, 15, 16 and 17. Strokes of 1%, 5%, 20% and 100% of full stroke were plotted at a system pressure P2 of 81200 newton/-meter^2 (2200 psi).

The plotted data was also reduced and tabulated on Table 2 as numerical % rated command input signal.

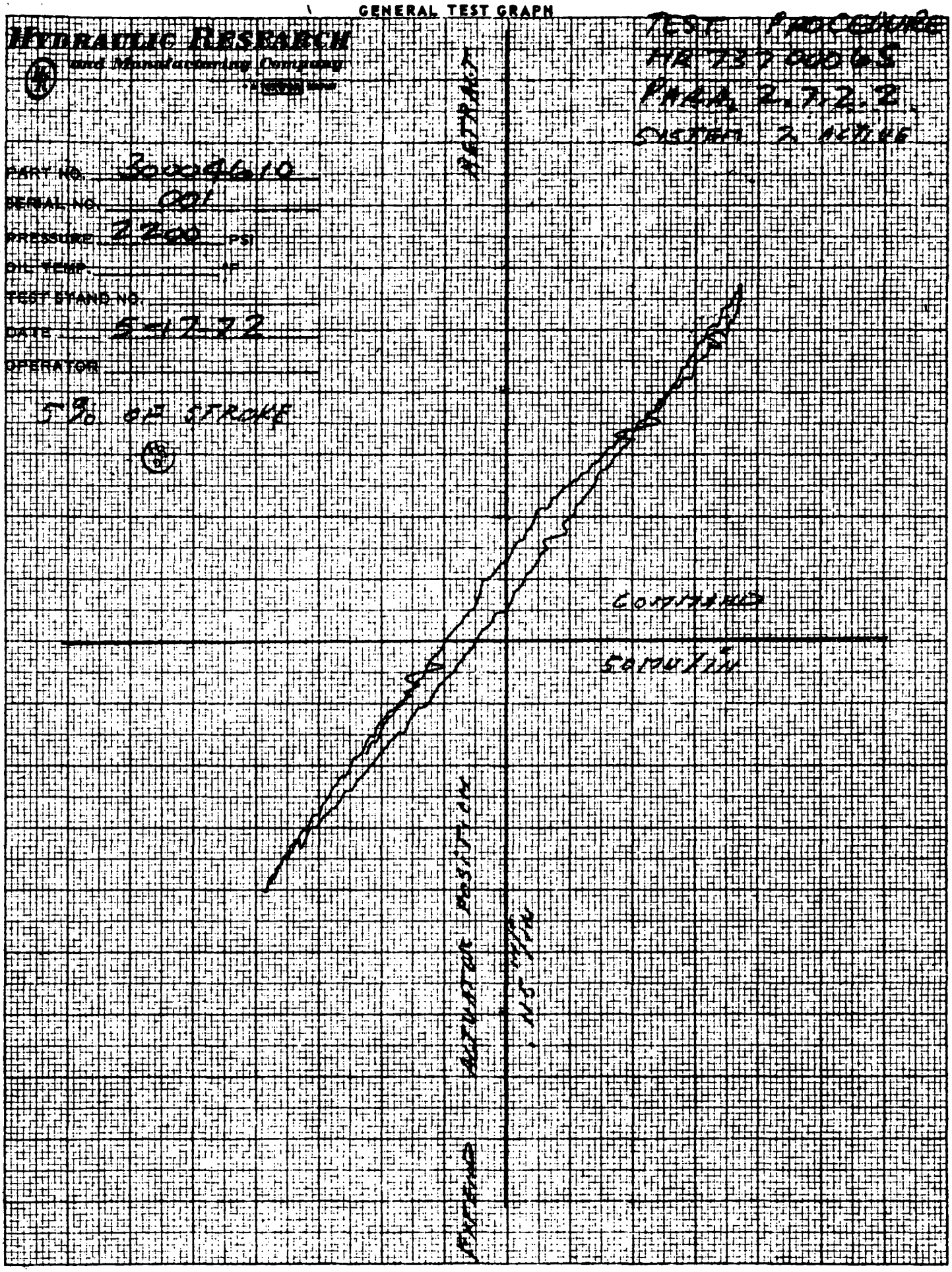
HYDRAULIC LOGIC SYSTEM 2 (Fail-Operate Mode)		
Percent Full Stroke	Linearity % Rated Command Input Signal	Hysteresis % Rated Command Input Signal
1%	16.7%	22.2%
5%	8.4%	15.2%
20%	6.4%	10.7%
100%	2.38%	4.17%
Note: Actuator Full Stroke 29.82 cm (11.74 in)		

TABLE 2. Linearity and Hysteresis - Hydrologic Logic System 2



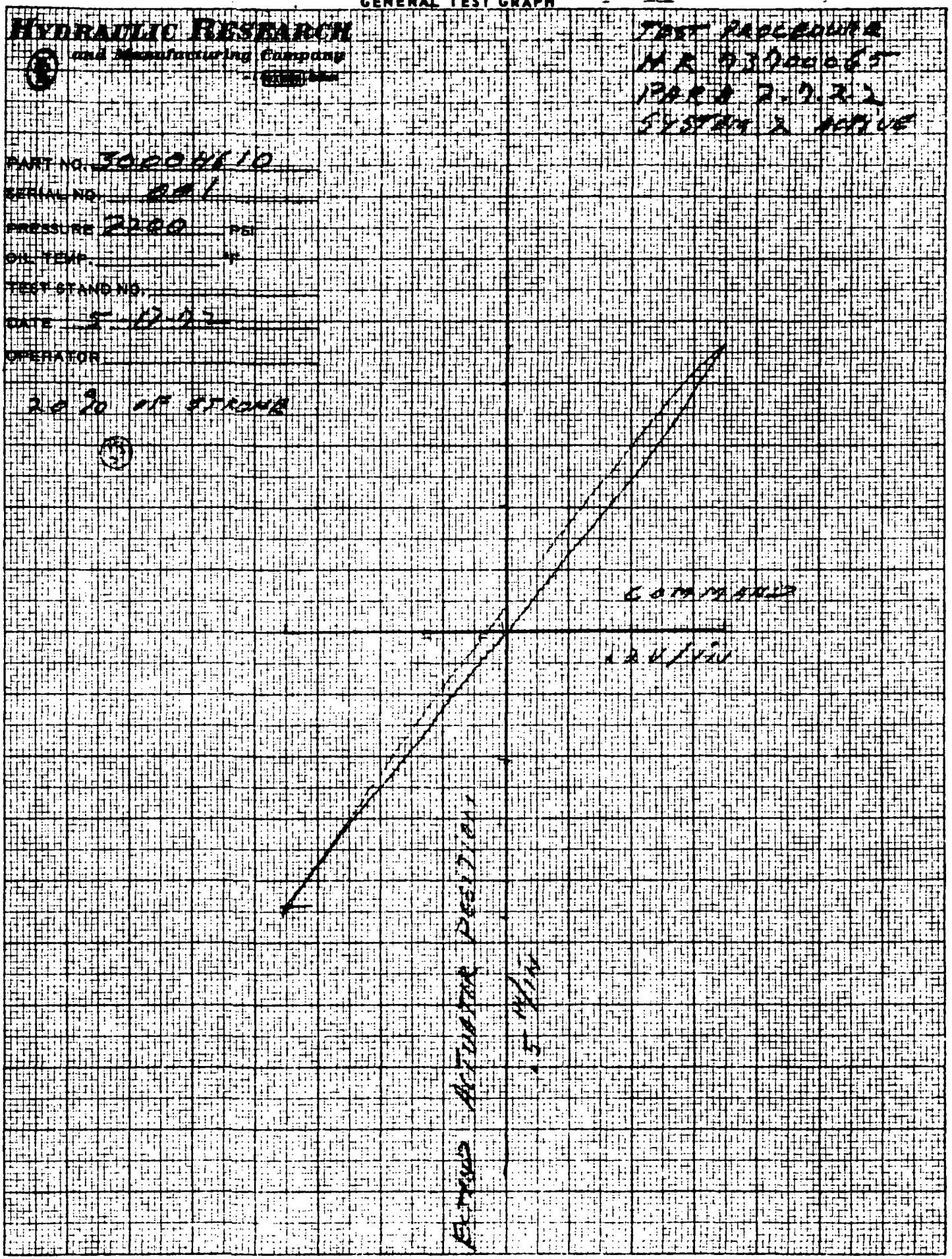
EL 009

Figure 14. 1% Linearity and Hysteresis Plot - Hydraulic Logic System 2



EL 009

Figure 15. 5% Linearity and Hysteresis Plot - Hydraulic Logic System 2



EL 009

Figure 16. 20% Linearity and Hysteresis Plot - Hydraulic Logic System 2

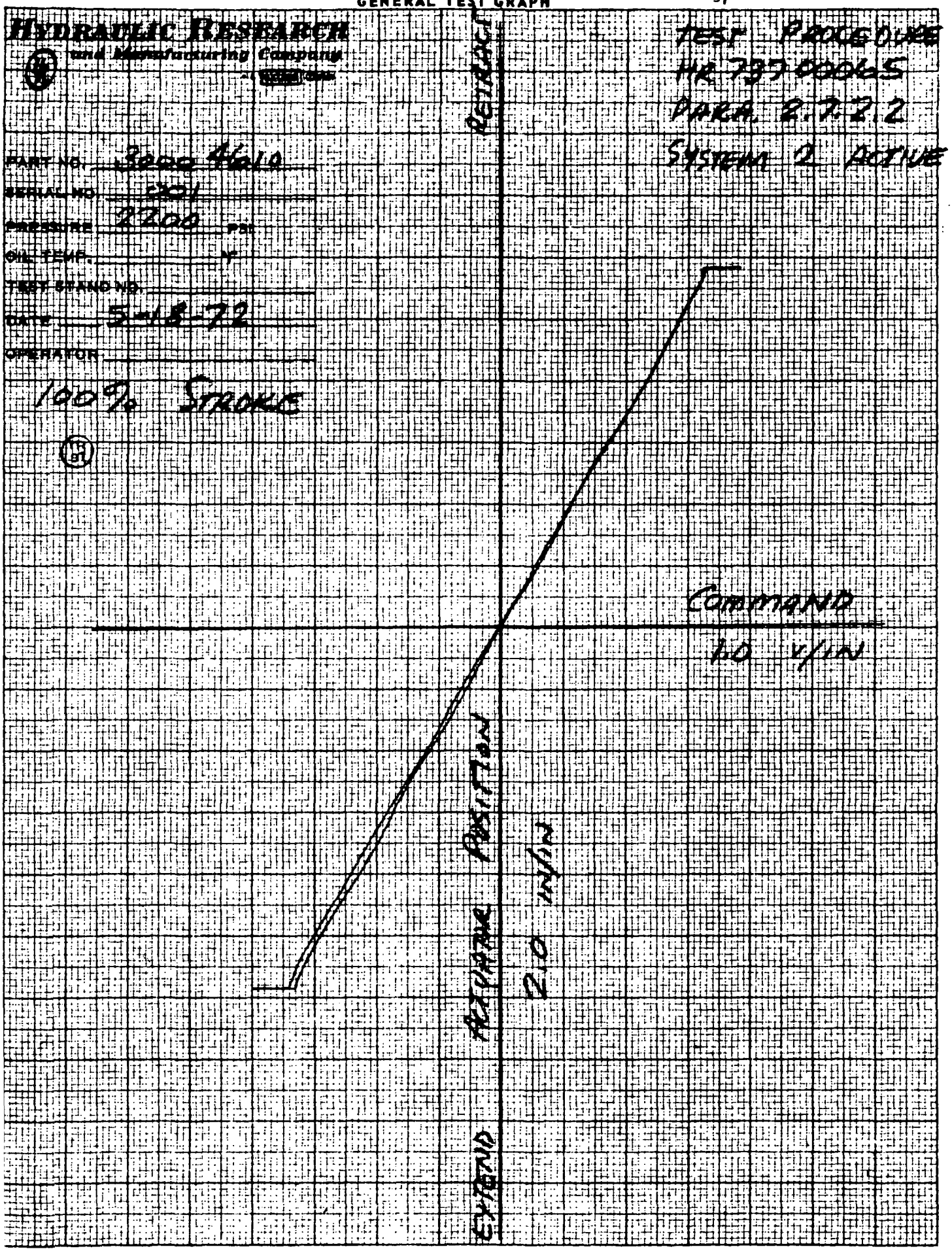


Figure 17. 100% Linearity and Hysteresis Plot - Hydraulic Logic System 2

EL 009

The linearity and hysteresis values at 100% stroke are also compared to the 301100 S/N 030 S-1C servoactuator prior to modification and are as follows:

Unit	Linearity	Hysteresis
301100 (non-modified)	2.05%	1.23%
30004610 - system 2	2.38%	4.17%

Reasoning for increases in linearity and hysteresis for the 30004610 (system 2) unit is as described in Paragraph 6.1.1.

6.2 Threshold

6.2.1 Hydraulic Logic System 1 (Operate Mode)

With the unit operating on active system 1, the maximum threshold signal for piston movement to occur is .010 vdc. When compared with the total voltage required to drive the actuator piston full stroke, the threshold is .64%. Low threshold valves, such as in this case, are a function of the relatively high total system loop gain.

6.2.2. Hydraulic Logic System 2 (Standby Mode)

With the system 1 failed and standby system 2 in control of the unit, the maximum threshold signal for piston movement to occur is .013 vdc. When compared with the total voltage required to drive the actuator piston full stroke, the threshold is .82%. The low threshold is also a function of the relatively high total loop gain.

Differences in threshold between system 1 and system 2 are largely caused by differences in active servo-valve (1 and 2) pressure and flow gain.

6.3 Frequency Response

6.3.1 Hydraulic Logic System 1 (Operate Mode)

6.3.1.1 Control Loop

With the unit operating on active system 1, the control loop frequency response was plotted and is shown in figure 18. Secondary actuator LVDT output versus command input was plotted at a main actuator piston stroke (amplitude) of approximately 1% (.110 inch). As shown in the amplitude ratio plot, the first order system break occurring at -3.0 db, is 20 cps or 125.7 rad/sec. System control loop gain, read directly from the plot, is therefore 125.7 rod/sec. Phase log at -3.0 db is approximately 110°.

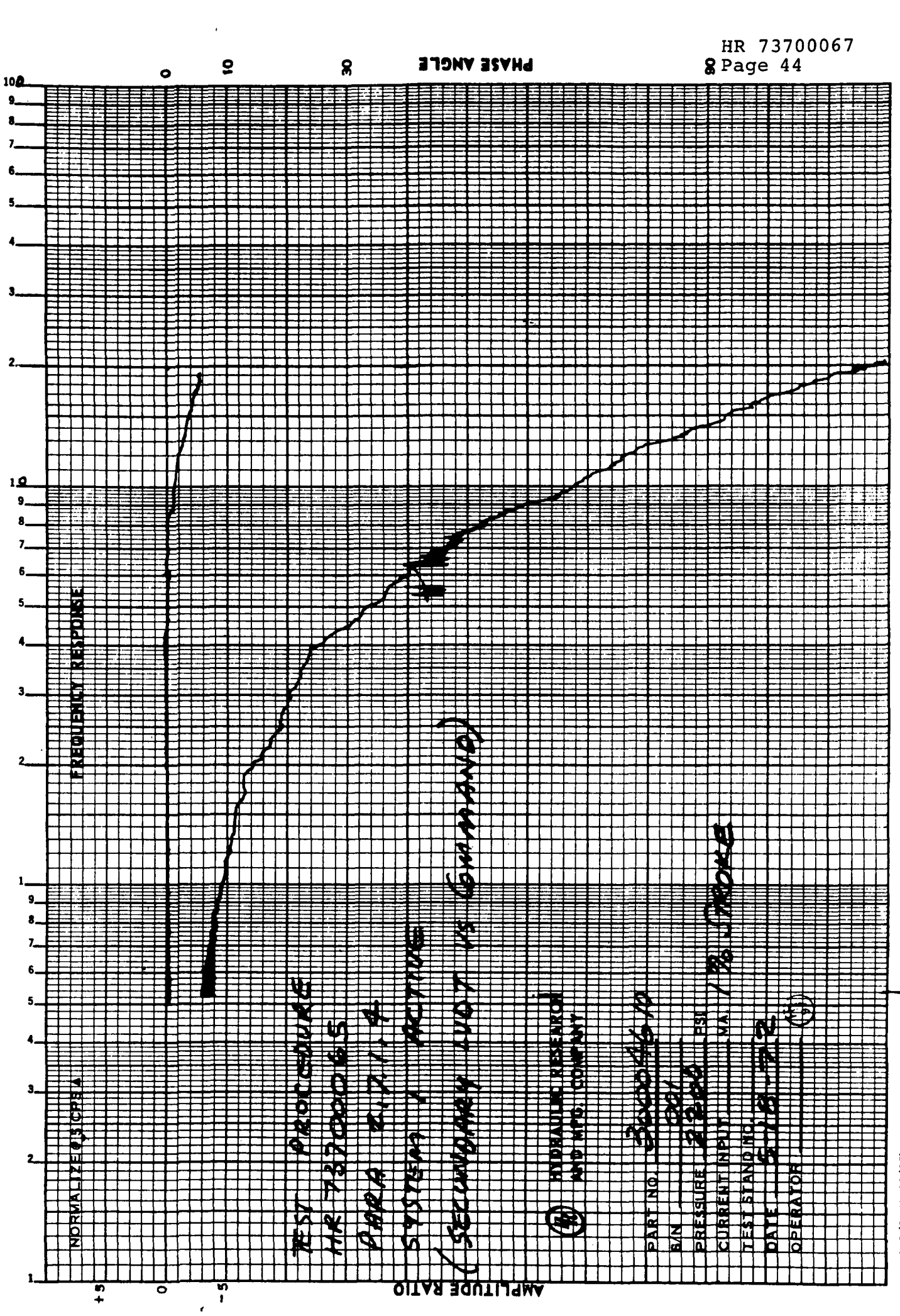


Figure 18. Frequency Response - System 1 Control Loop

6.3.1.1.1 Secondary Control System Loop Gain Calculation

As shown in the control system loop block diagram, Figure 19, the following is the system loop gain calculation:

Where: Servoamplifier Gain = K_1 = 54.0 ma/v

Servovalve 1 Gain = $K_2 = \frac{66.0 \text{ cm}^3/\text{sec}}{16.0 \text{ ma}} =$

$$\frac{(1.044 \text{ gpm})(3.85 \text{ m}^3/\text{sec/gpm})}{16.0 \text{ ma}}$$

$$K_2 = 4.12 \frac{\text{cm}^3/\text{sec}}{\text{ma}}$$

$$(.251 \frac{\text{in}^3/\text{sec}}{\text{ma}}$$

Actuator Gain = $K_3 = \frac{1}{a} = \frac{1}{1.78\text{cm}^2} = \frac{1}{.276 \text{ in}^2}$

$K_3 = .562/\text{cm}^2$ $(3.63/\text{in}^2)$

LVDT-Demodulator Gain = H_1H_2 = 1.338 v/cm (3.40 v/in)

Loop Gain = $K = K_1K_2K_3 (H_1H_2)$

$K = (54.0 \text{ ma/v})$

$(4.12 \text{ cm}^3/\text{sec/ma})(.562/\text{cm}^2)$

(1.338 v/cm)

$K = 167.5$ rad/sec or 26.7 cps

Differences between system loop gain values read from the amplitude ratio plot (125.7 rad/sec) and calculated (167.5 rad/sec) can be attributed largely to frequency analyzer calibration, dynamics in the servoamplifier and phase shift in the demodulator.

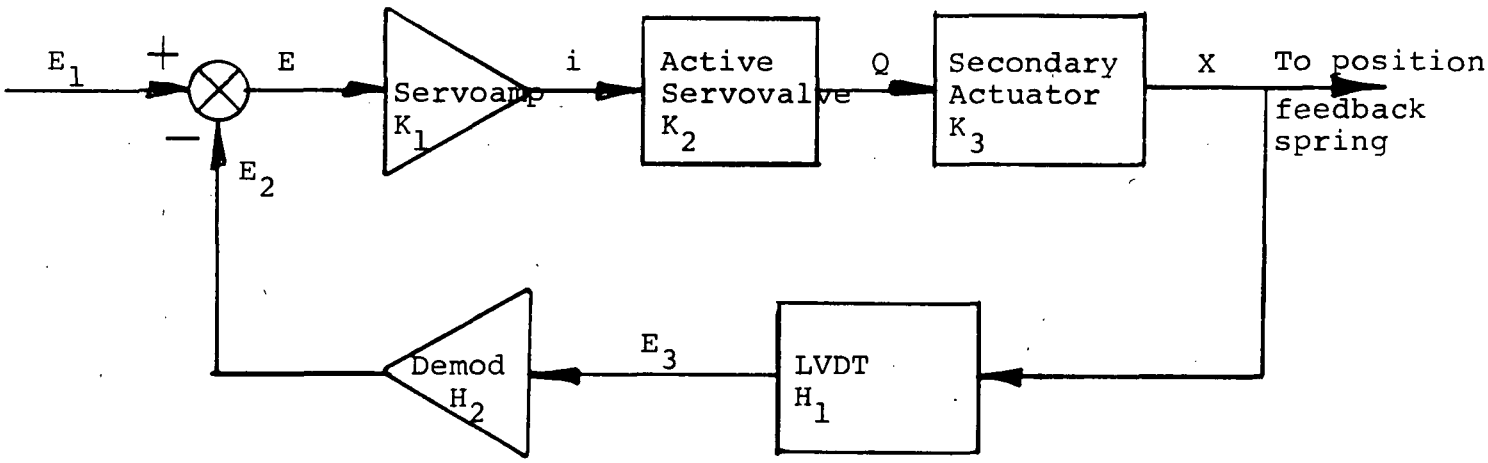


Figure 19. Block Diagram - Control Loop

6.3.1.2 Total System

With the unit operating on active system 1, the total system frequency response was plotted and is shown in Figure 20. Main actuator potentiometer output versus command input was plotted at a main actuator piston stroke (amplitude) of approximately 1% (.298 cm -.110 in). As shown on the amplitude ratio plot, peaking at -90° phase lag and +4.0 db indicates a second order type system with a damping ratio (ζ) of approximately 0.3.

The block diagram of the total system is shown in Figure 21.

At frequencies above 8.2 cps, as shown in Figure 20, the frequency response amplitude ratio plot experiences an erratic deviation from the normal second order type amplitude ratio curve. At this time the cause of the deviaiton is unexplained. Reasoning may be the fact that the load simulator has an inherent 7 - 8 cps load resonant frequency and due to changes in system loop gain (from the original 301600 unit) the system frequency response is affected. The original 301100 unit frequency response (Figure 47) did not indicate any deviation up to 10 cps. A continuation in the testing program (reference Paragraph 10.) for the 30004610 unit would allow for proper system frequency response evaluation.

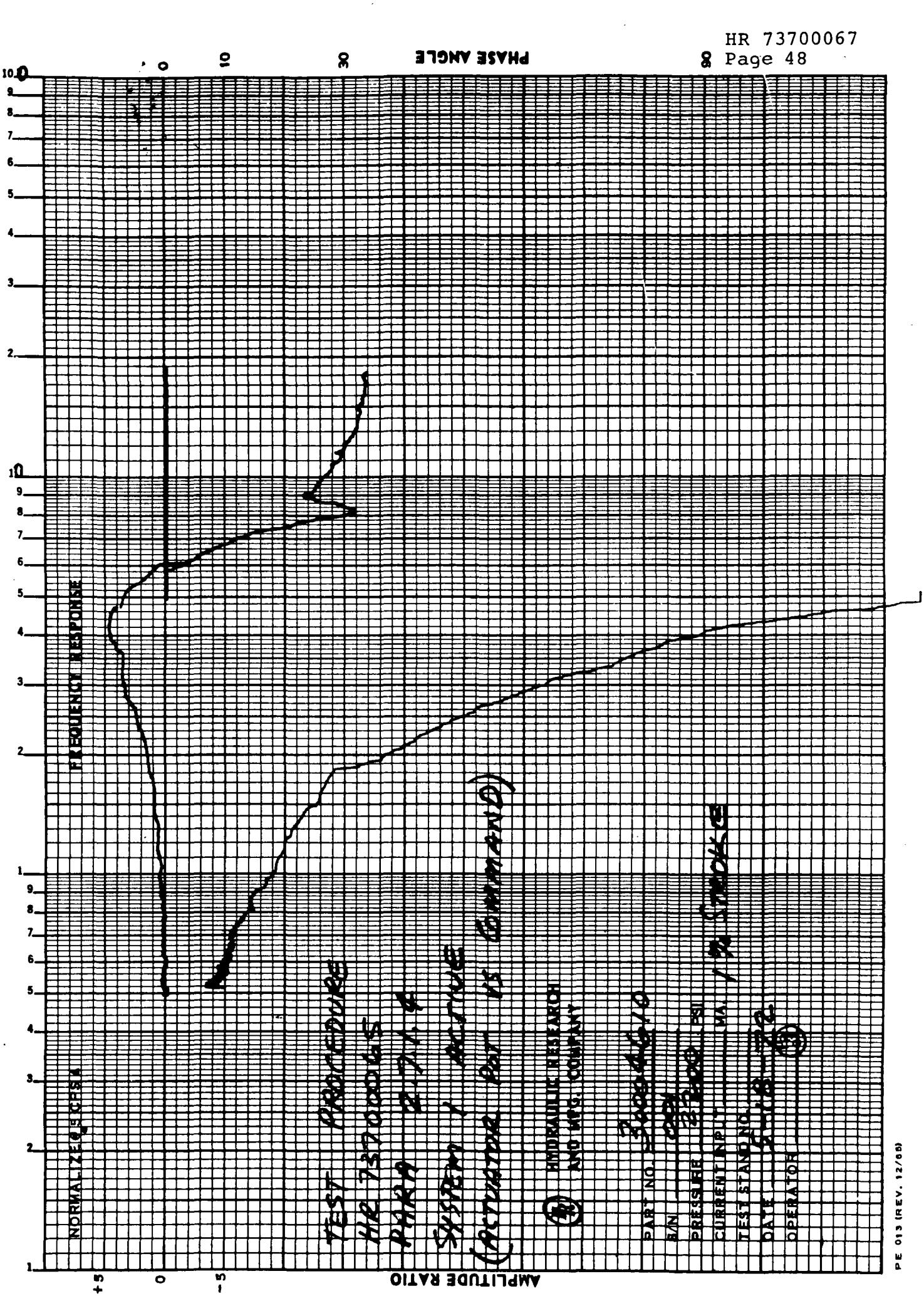


Figure 20. Frequency Response - Total System (System 1 Active)

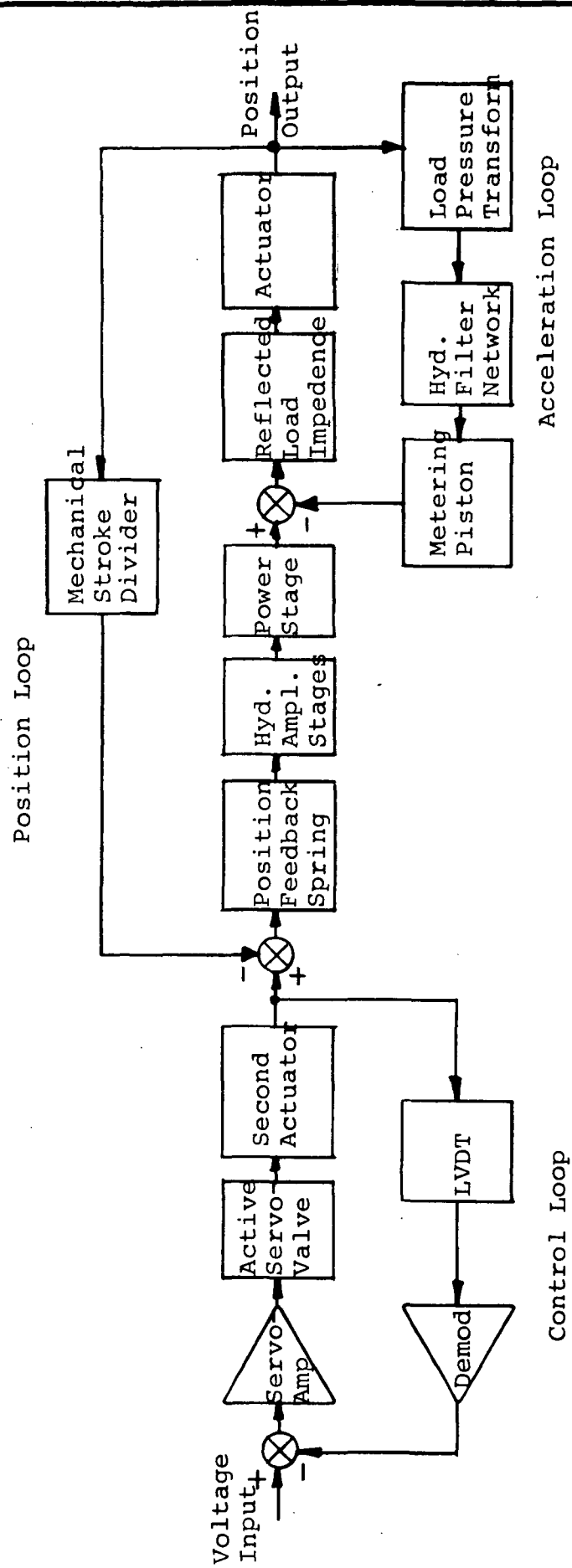


Figure 21. Block Diagram - Total System

6.3.2 Hydraulic Logic System 2 (Fail-Operate Mode)

6.3.2.1 Secondary Control Loop

With system 1 failed and standby system 2 in control of the unit, the control loop frequency response was plotted and is shown in Figure 22. Secondary actuator LVDT output versus command input was plotted at an main actuator piston stroke (amplitude) of approximately 1% (.298 cm -.110 in). As shown in the amplitude ratio plot, the first order system break occurring at -3.0 db, is 16.0 cps or 101.0 rad/sec. System control loop gain, read directly from the plot, is therefore 101.0 rad/sec. Phase log at -3.0 db is approximately 110°.

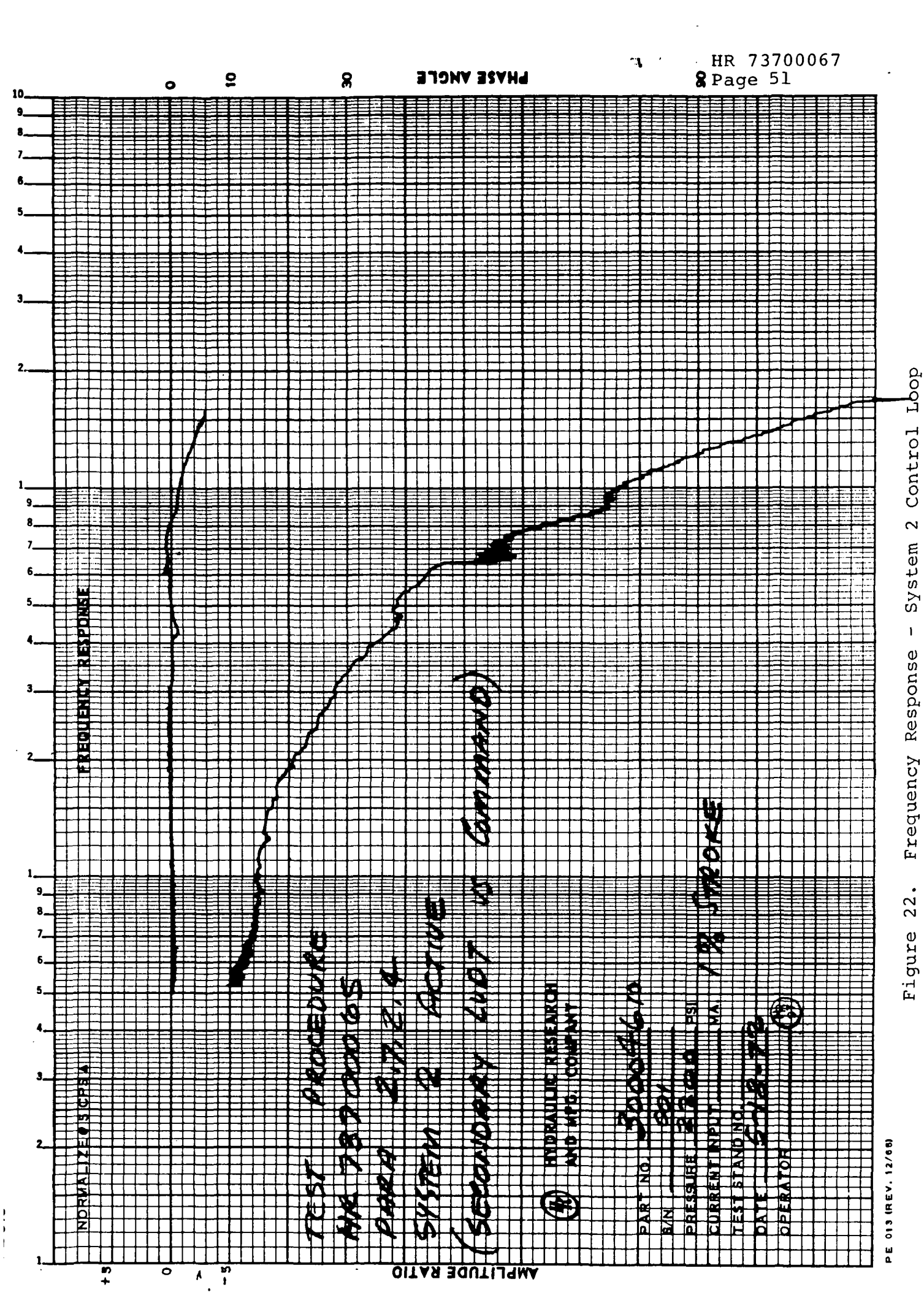


Figure 22. Frequency Response - System 2 Control Loop

6.3.2.1.1 Secondary System Loop Gain Calculation

As shown in the control system loop block diagram, Figure 19, the following is the system loop gain calculation:

Where:

Servoamplifier Gain = K_1 = 54.0 ma/v

Servovalve 2 Gain = $K_2 = \frac{59.7 \text{ cm}^3/\text{sec}}{16 \text{ ma}}$

$$= \frac{(.944 \text{ gpm})(3.85 \text{ in}^3/\text{sec/gpm})}{16 \text{ ma}}$$

$$K_2 = 3.73 \frac{\text{cm}^3/\text{sec}}{\text{ma}} \quad \left(.227 \frac{\text{in}^3/\text{sec}}{\text{ma}}\right)$$

Actuator Gain = $K_3 = \frac{1}{a} = \frac{1}{1.78 \text{ cm}^2} = \frac{1}{.276 \text{ in}^2}$

$$K_3 = .562/\text{cm}^2 \ (3.63/\text{in}^2)$$

LVDT-Demodulator Gain = H_1H_2 = 1.338 v/cm (3.40 v/in)

Loop Gain = $K = K_1K_2K_3 \ (H_1H_2)$

$$K = (54.0 \text{ ma/v}) \left(3.73 \frac{\text{cm}^3/\text{sec}}{\text{ma}}\right) (.562/\text{cm}^2)$$

$$\left(1.338 \frac{\text{v}}{\text{cm}}\right)$$

$$K = 151.3 \text{ rad/sec} = 24.1 \text{ cps}$$

Differences between the system loop gain read from the amplitude ratio plot (101.0 rad/sec) and calculated (151.3 rad/sec) can be attributed largely to frequency analyzer calibration, dynamics in the servoamplifier, and phase shift in the demonulator.

6.3.2.2 Total System

Operating on system 2, the total system frequency response was plotted and is shown in Figure 23. Main actuator potentiometer output versus command was plotted at main actuator piston stroke (amplitude) of approximately 1% (.298 cm -.110 in). As shown on the amplitude ratio plot, peaking at -90° phase log and +3.5 db indicates a second order type system with a damping ratio (ζ) of approximately 0.35.

The block diagram of the total system is shown in Figure 21.

As indicated in Paragraph 6.3.1.2 at frequencies above 8.2 cps (Figure 23) the frequency response amplitude ratio plot experiences an erratic deviation from the normal second order type amplitude ratio curve. At this time the cause of the deviation is unexplained. Reasoning may be the fact that the load simulator has an inherent 7-8 cps load resonant frequency and due to changes in system loop gain (from the original 301100 unit) the system frequency response is affected. The original 301100 unit frequency response (Figure 47) did not indicate any deviation up to 10 cps. A continuation in the testing program (reference Paragraph 10.) for the 30004610 unit would allow for proper system frequency response evaluation.

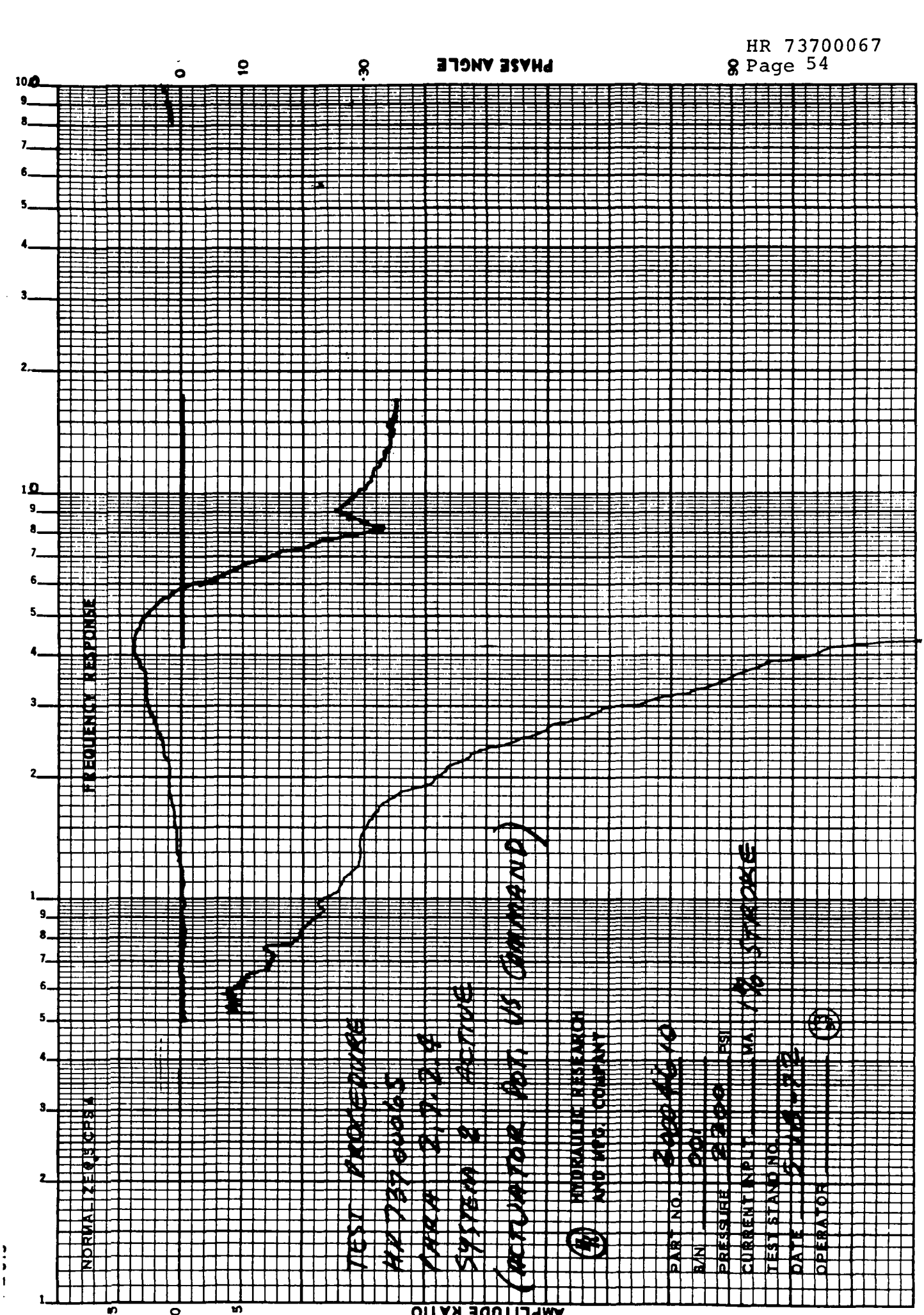


Figure 23. Frequency Response - Total System (System 2 Active)

6.4 Failure Switching Transients

6.4.1 Hydraulic Logic System 1 (Operate Mode)

With the unit operating on active system 1 and hydraulic pressure P1, failure switching transient data was plotted under specific test conditions as indicated in Figures 25 through 33 (reference test procedure HR 73700065 Appendix A). As shown, the following data was simultaneously plotted during each test:

(1) Secondary actuator LVDT (voltage output)

(2) Command Input Signal (voltage input)

(3) System # 1 Failure Indicator Switch

(4) Actuator Potentiometer Position

(5) Engine Potentiometer Position

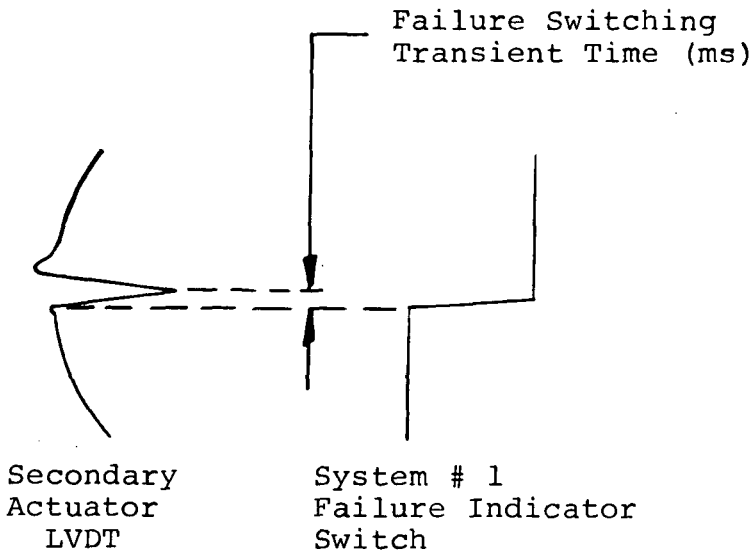
(6) System # 2 Failure Indicator Switch

(7) Actuator Pressure Transducer

(8) Timing Lines (1.0 second intervals)

Failure switching transient time was then determined for each test condition and tabulated as shown on Table 3. To eliminate any reference or correlation to system loop gain valves, the failure switching transient time measurement method was selected as follows:

Time is measured (on the secondary actuator LVDT plot) from the time system # 1 failure indicator switch disengages to the point at which system 2 active servovalve starts initiation of the secondary actuator return to the commanded position. For example:



As can be seen from Table 3, the failure switching transient time is a function of the type of hardover failure whether positive or negative (extend or retract) and to which servovalve the failure applied.

Test Procedure HR 73700065 Paragraph No.		Failure Switching Transient Time * (milliseconds)	Figure No.
2.7.1.5.3	Hardover Command Signal to Active Servovalve 1 (+) extend	10.0	25
	(+) retract	25.0	26
	(-) extend	20.0	27
	(-) retract	10.0	28
2.7.1.5.4	Hardover Command Signal to Monitor Servovalve 1 (+) extend	13.0	29
	(+) retract	11.0	30
	(-) extend	11.0	31
	(-) retract	9.0	32
2.7.1.5.5	Pressure 1 failure	11.0	33

*Time is measured (on the secondary actuator LVDT plot) from the time system 1 failure indicator switch disengages to the point at which system 2 active servovalve starts initiation of the secondary actuator return to the commanded position.

TABLE 3. Failure Switching Transients - Hydraulic Logic System 1

HYDRAULIC RESEARCH and MANUFACTURING COMPANY
25200 WEST RYE CANYON ROAD • VALENCIA, CALIFORNIA 91355
Textron COMPANY

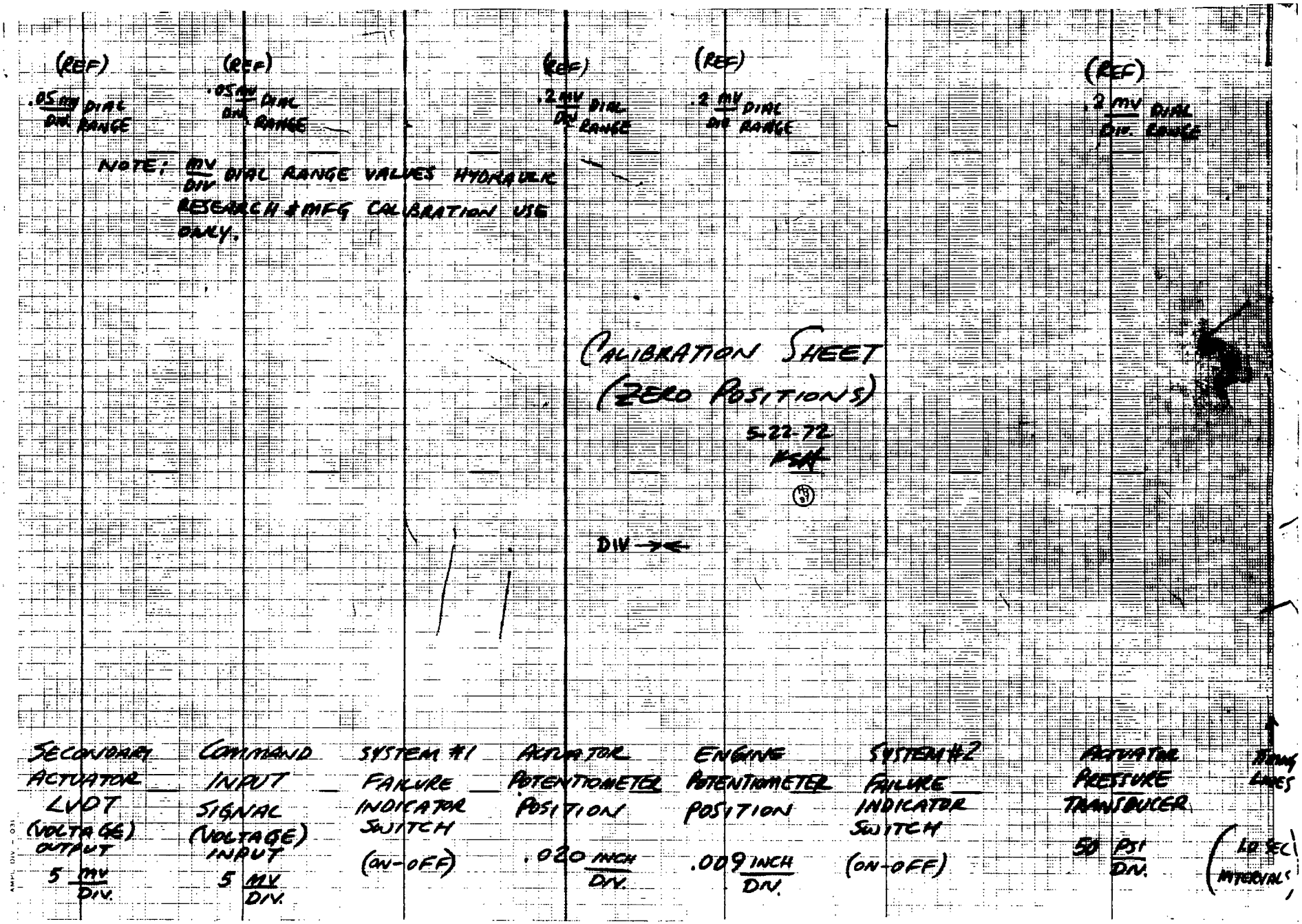


Figure 24. Calibration Sheet

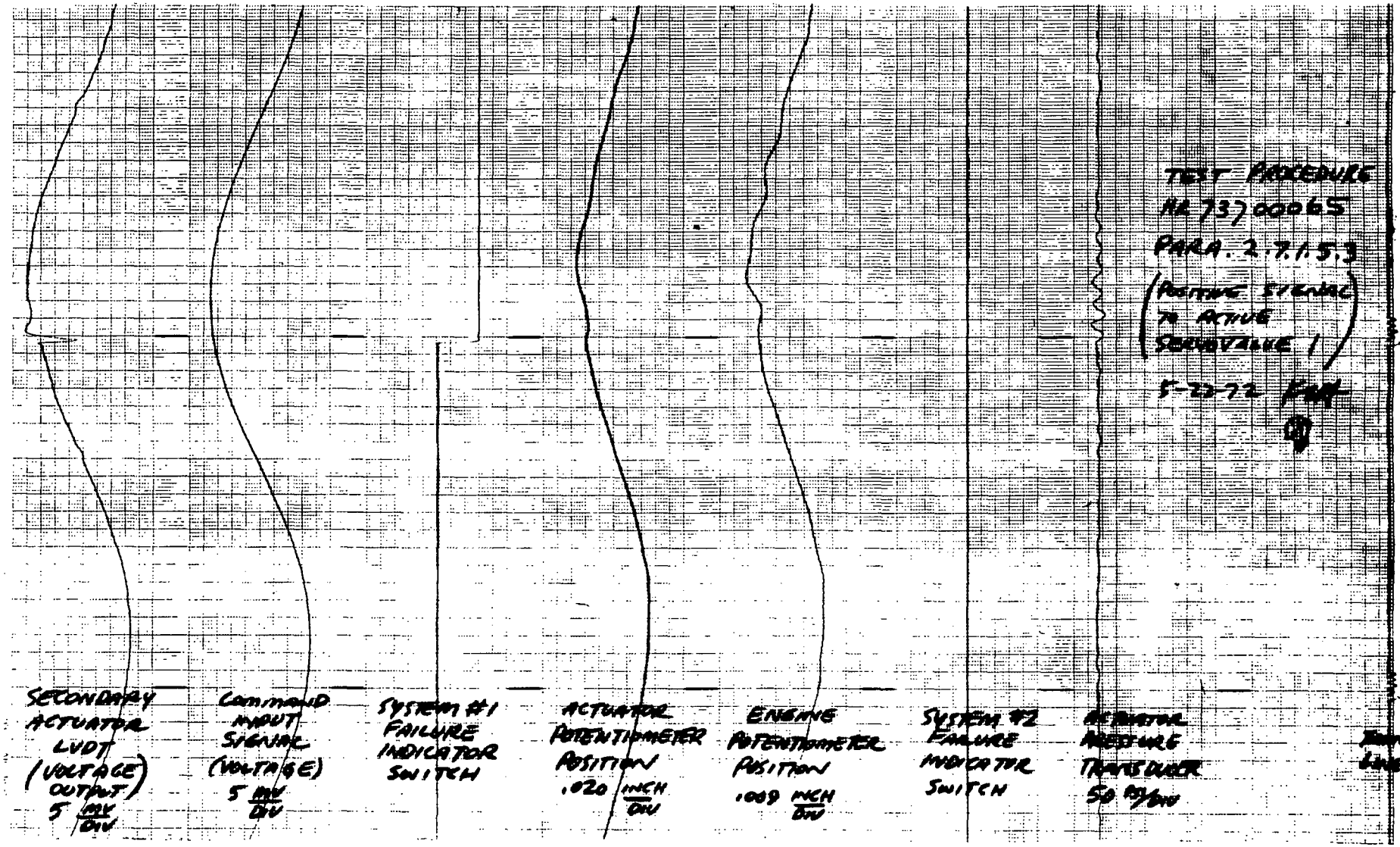


Figure 25. Hardover (+ Extend) Command Signal to Active Servovalve 1

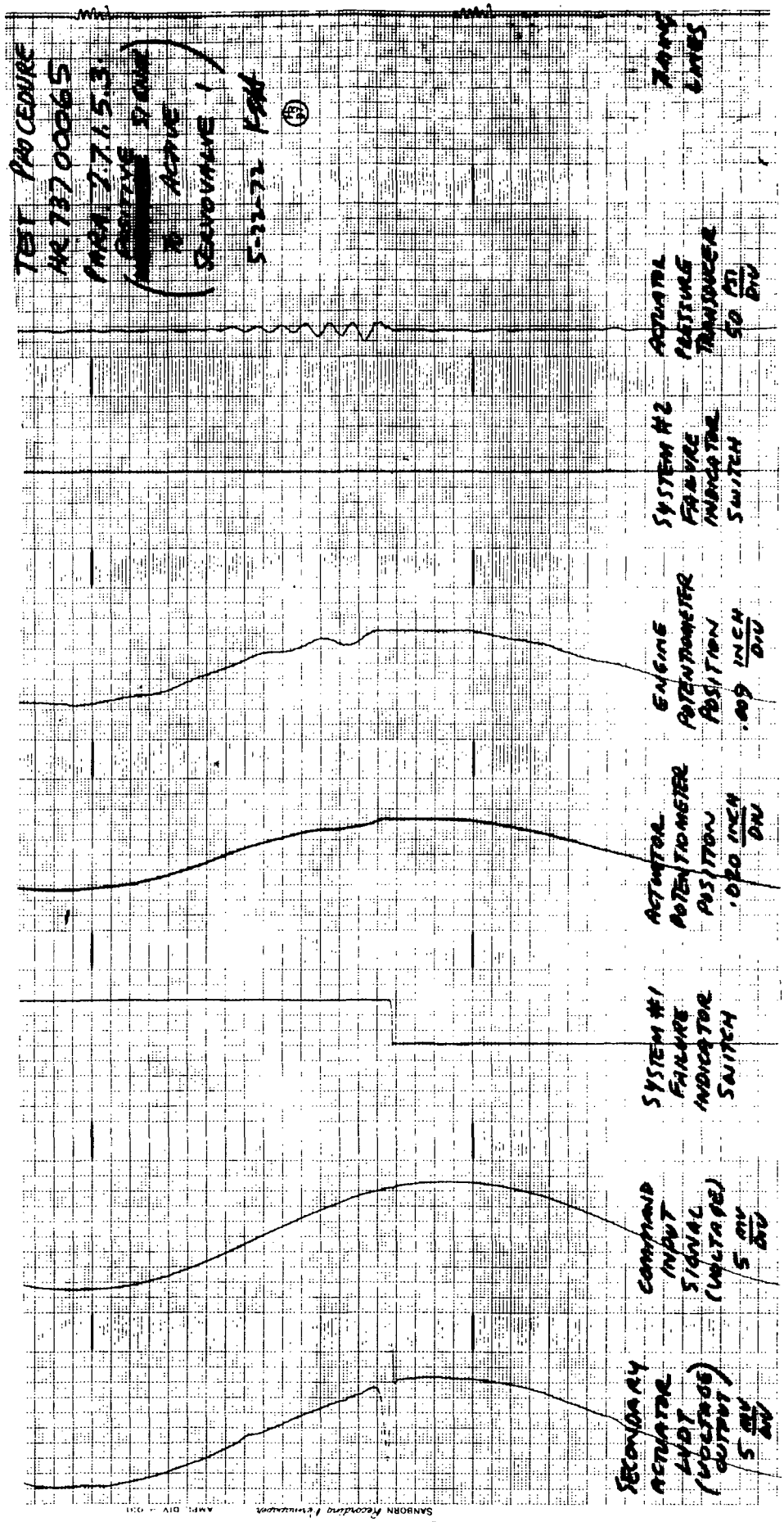


Figure 26. Hardover (+ Retract) Command Signal to Active Servovalve 1

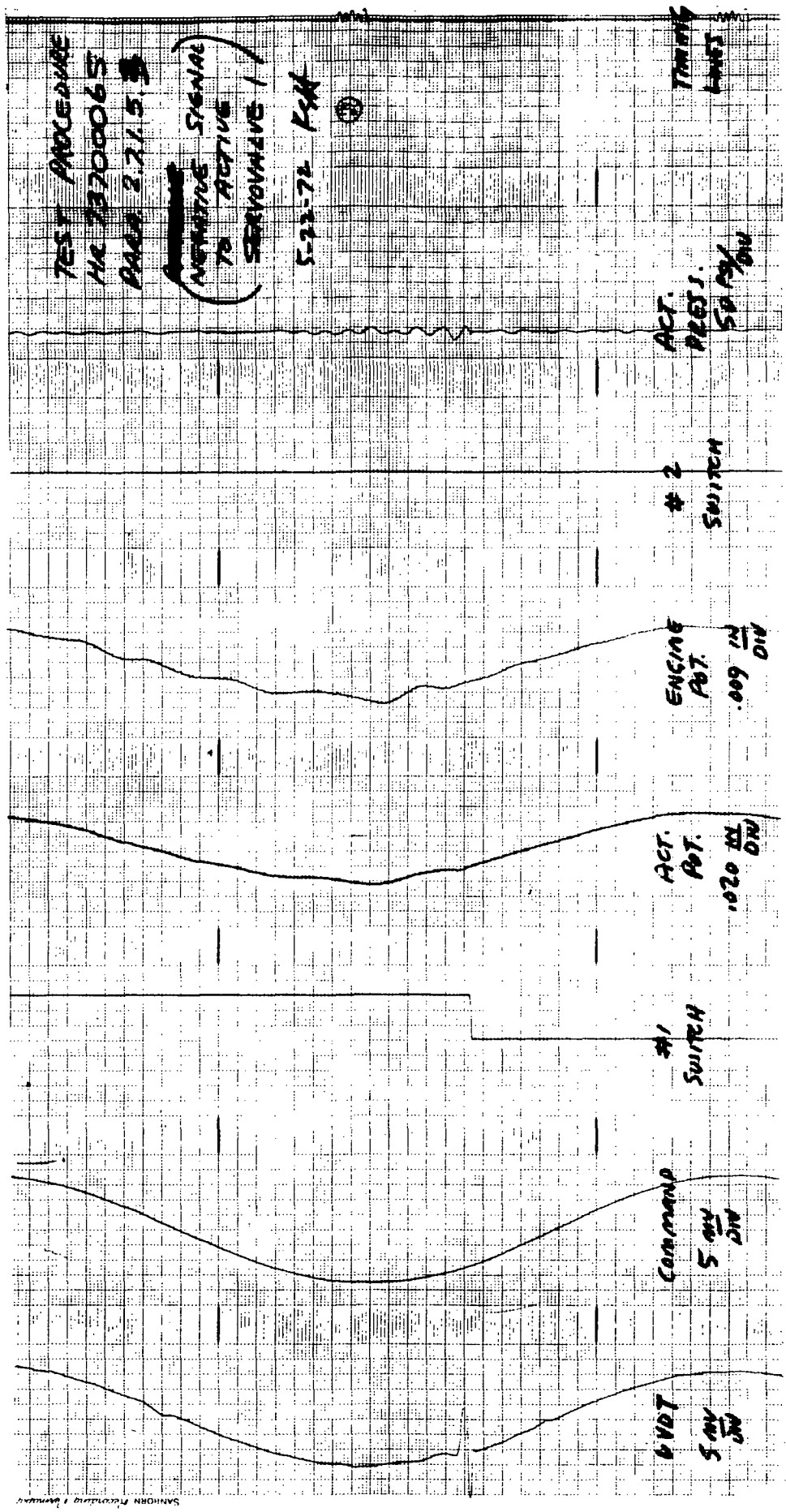


Figure 27. Hardover (- Extend) Command Signal to Active Servovalve 1

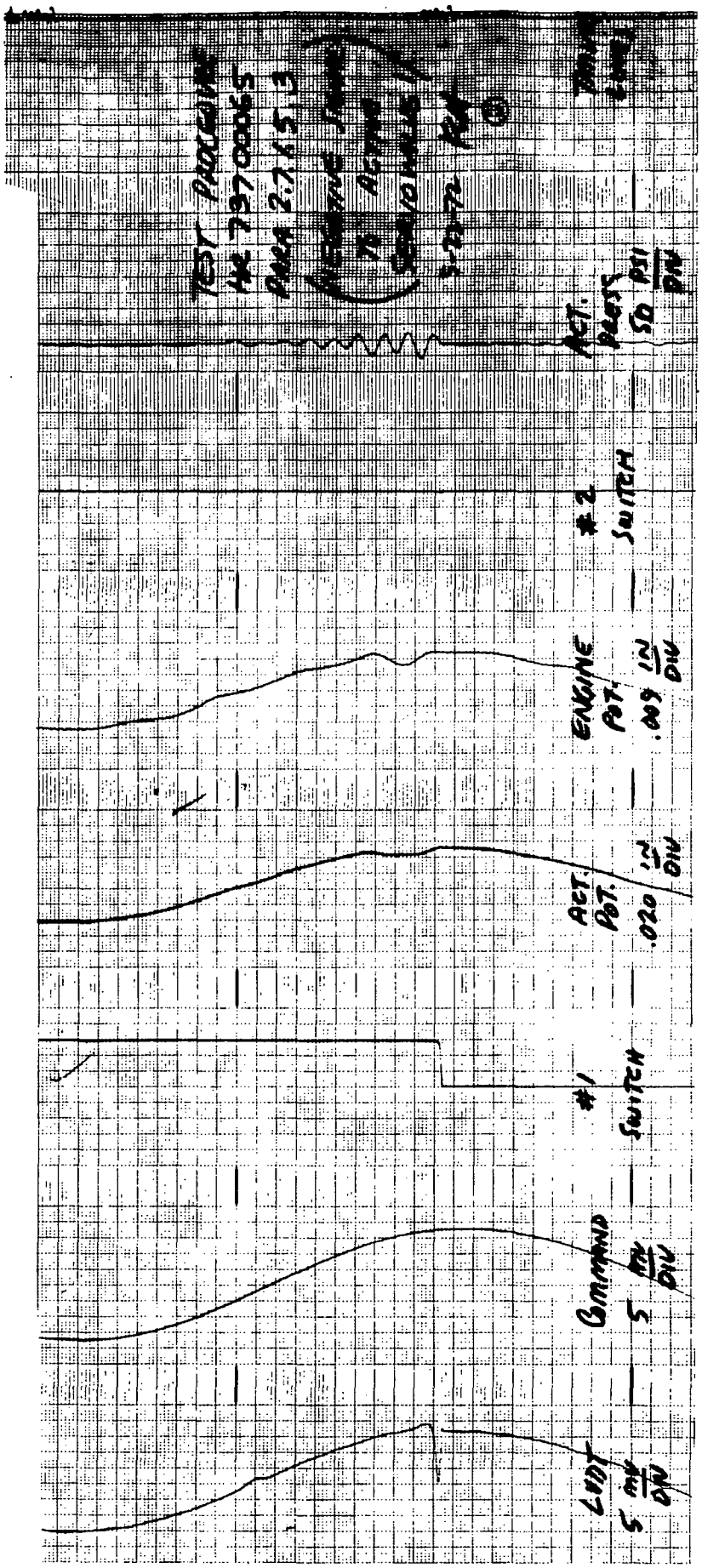


Figure 28. Hardover (- Retract) Command Signal to Active Servovalve 1

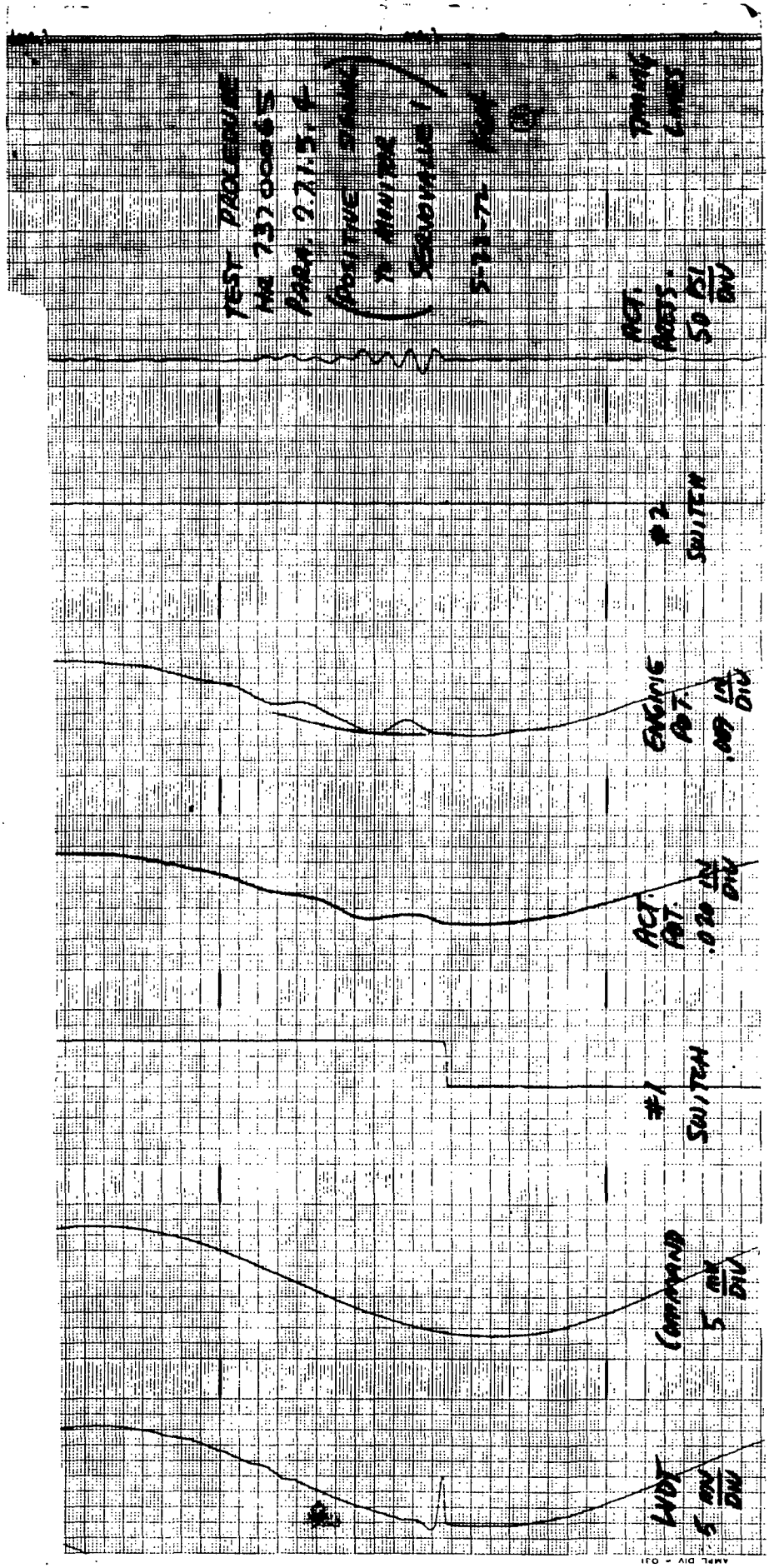


Figure 29. Hardover (+ Extend) Signal
To Monitor Servovalve 1

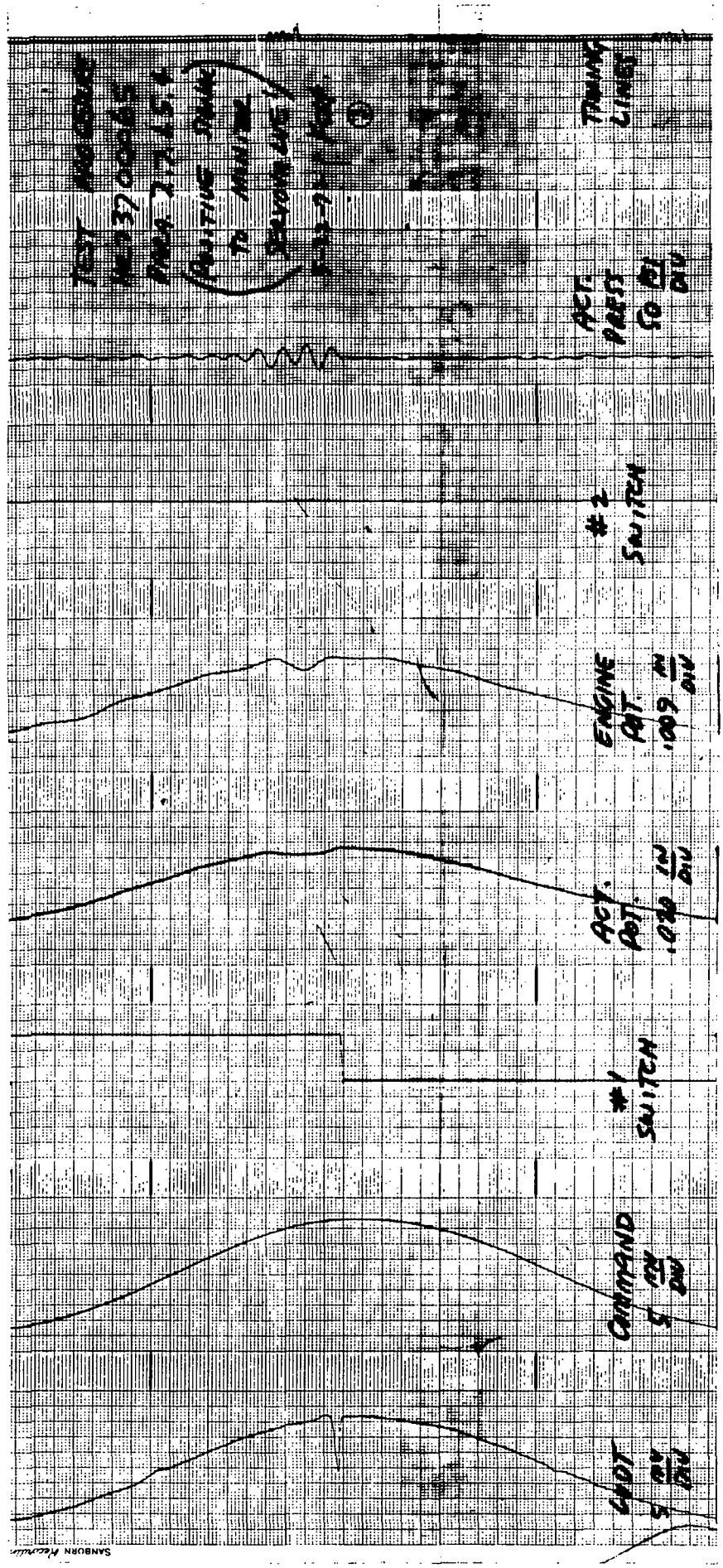


Figure 30. Hardover (+ Retract) Signal to Monitor Servovalve 1

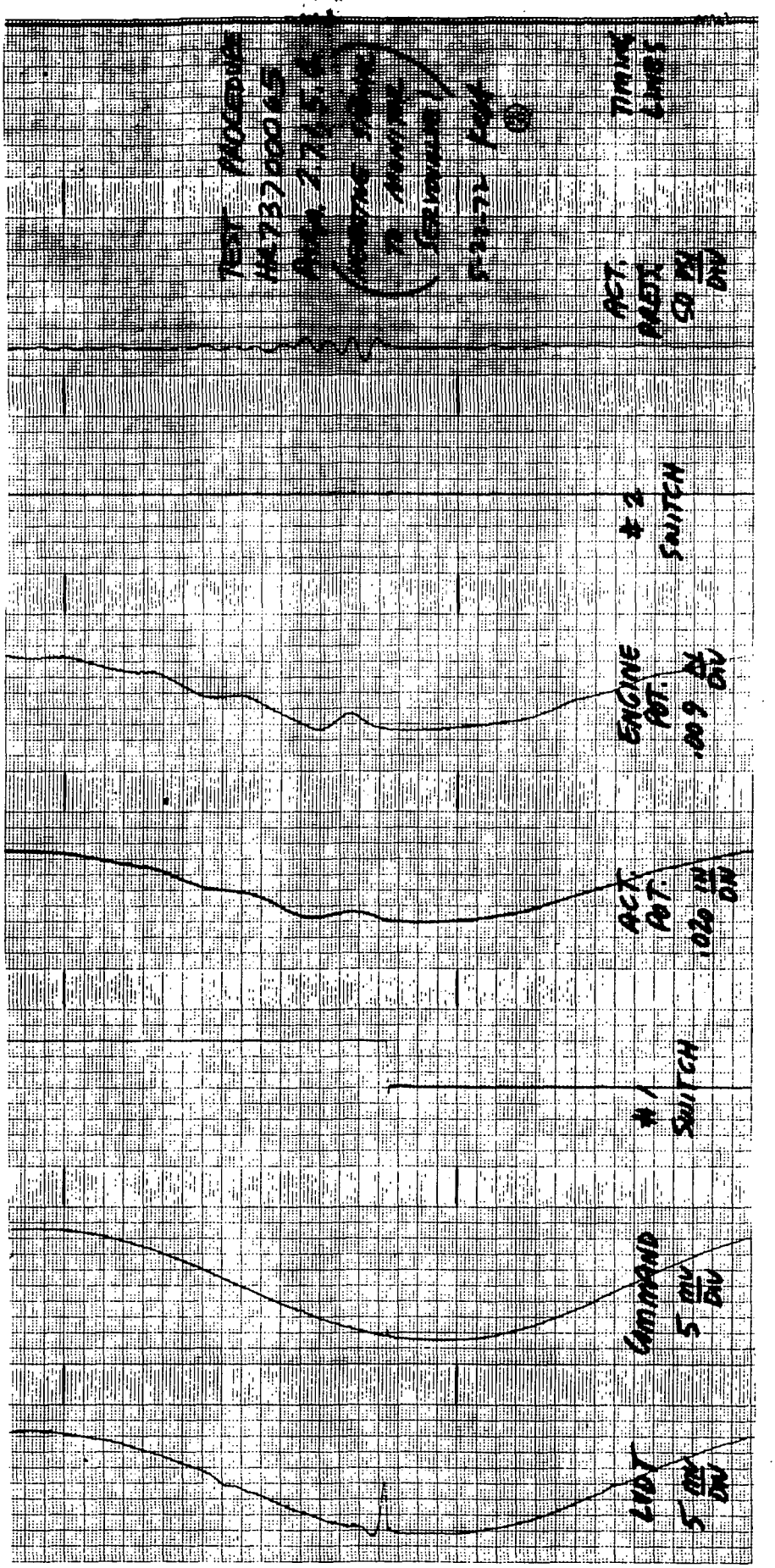


Figure 31. Hardover (- Extend) Signal to Monitor Servovalve 1

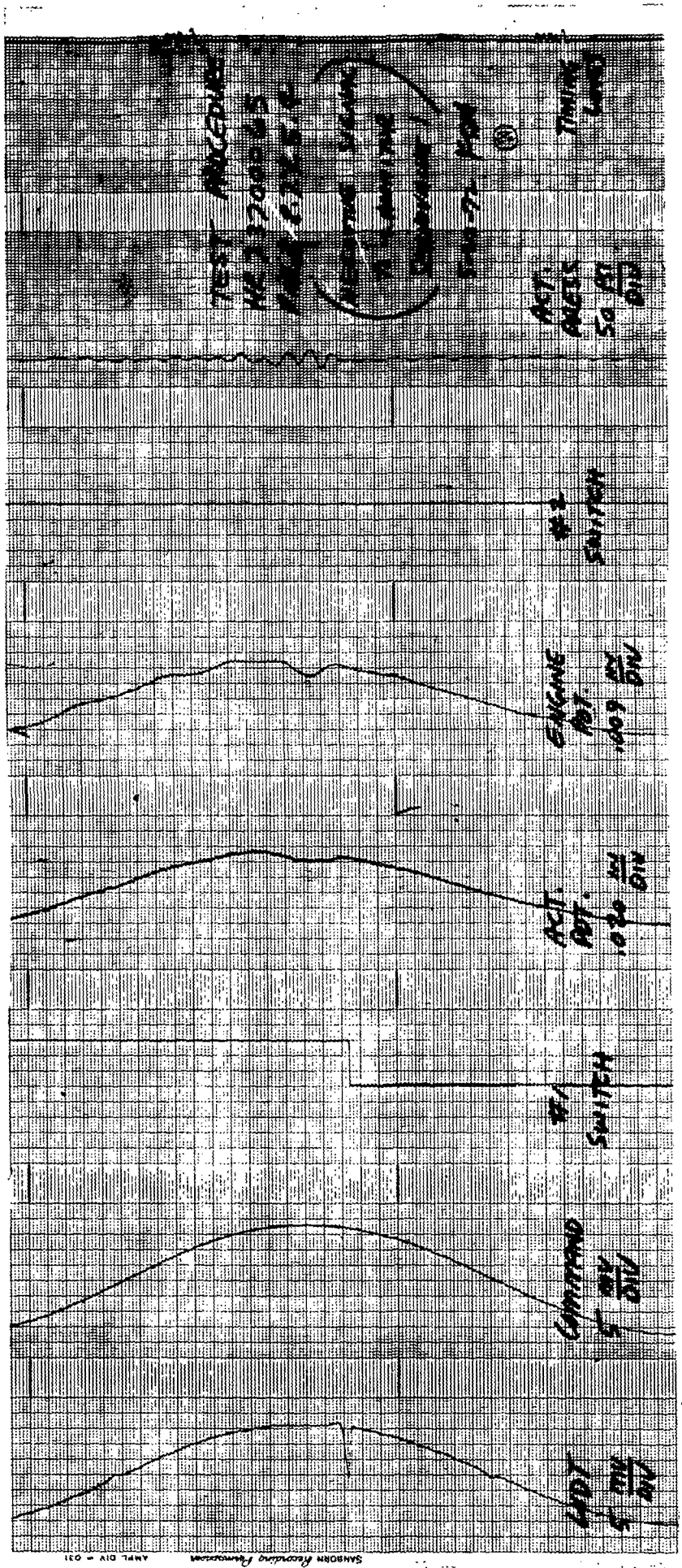


Figure 32. Hardover (- Retract) Signal to Monitor Servovalve 1

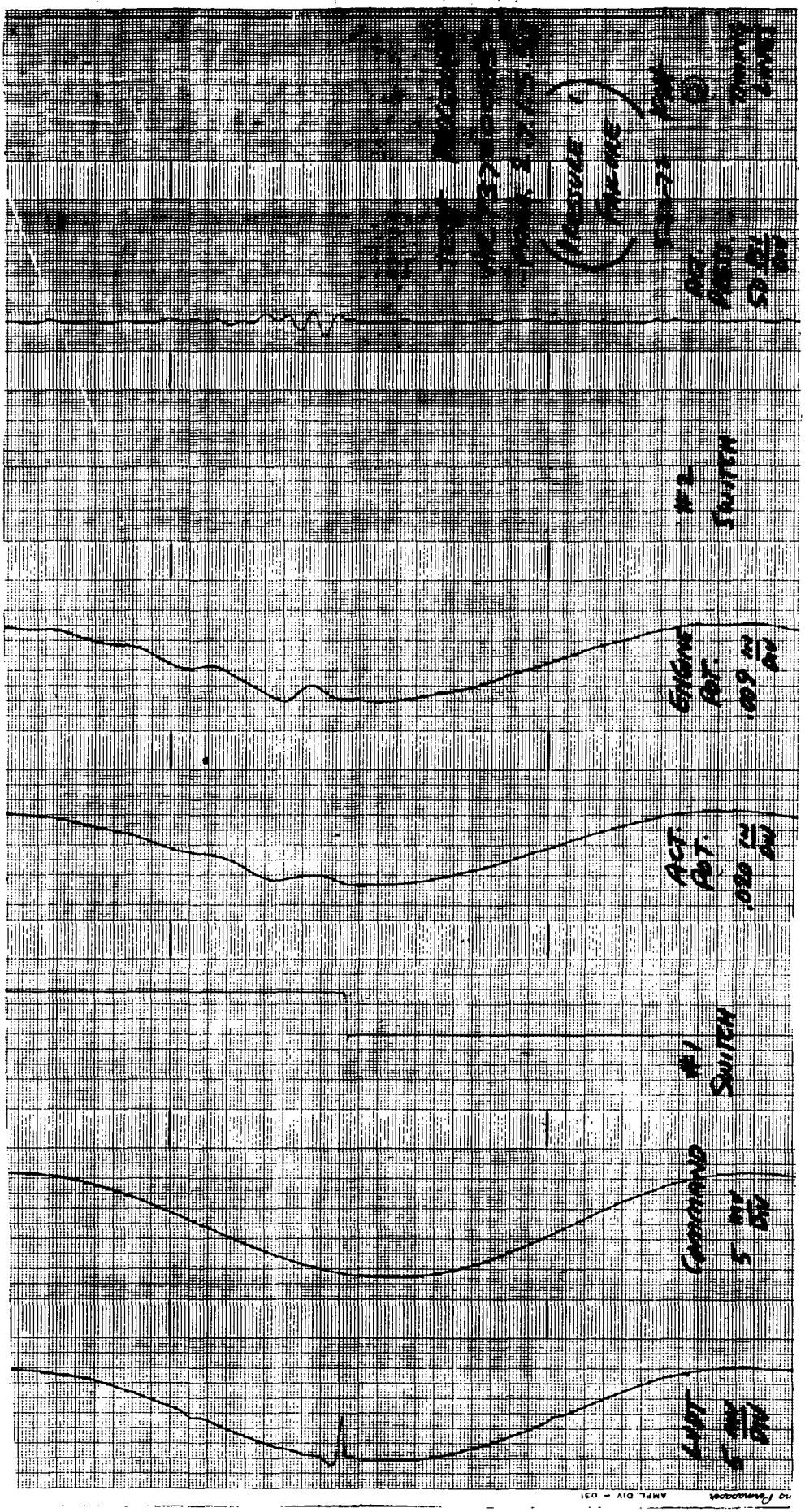


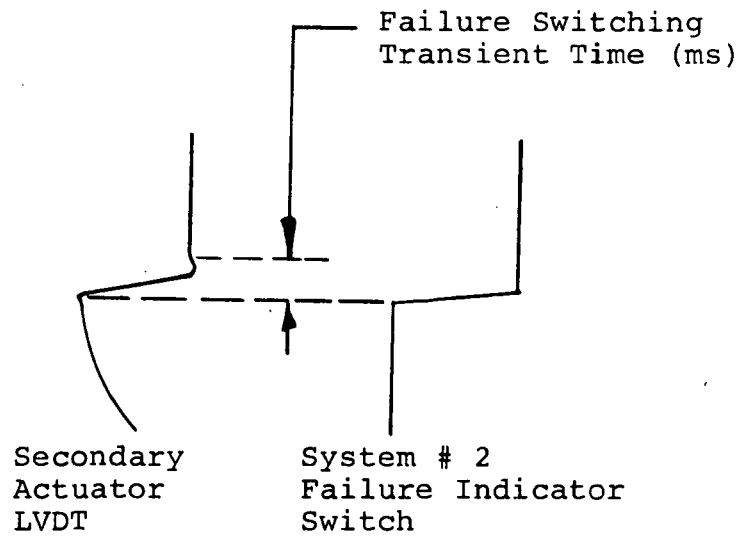
Figure 33. Pressure 1 Failure
(System 1 Active)

6.4.2 Hydraulic Logic System 2 (Fail-Operate Mode)

With system 1 failed and standby system 2 in control of the unit utilizing system pressure P2, failure switching transient data was plotted under specific test conditions as indicated in Figures 34 through 43.

Failure switching transient time was then determined for each test condition and tabulated as shown in Table 4. To eliminate any reference or correlation to system loop gain valves, the failure switching transient time measurement method was selected as follows:

Time is measured (on the secondary actuator LVDT plot) from the time system # 2 failure indicator switch disengages to the point at which the LVDT reaches mechanical null position. For example:



HYDRAULIC RESEARCH and MANUFACTURING COMPANY
25200 WEST RYE CANYON ROAD • VALENCIA, CALIFORNIA 91355
Textron COMPANY

Test Procedure HR 73700065 Paragraph No.	Test Description	Failure Switching Transient Time * (milliseconds)	Figure No.
2.7.2.5.3	Hardover Command Signal to Active Servovalve 2 (+) extend	30.0	34
	(+) retract	90.0	35
	(-) extend	115.0	36
	(-) retract	20.0	37
2.7.2.5.4	Hardover Command Signal to Monitor Servovalve 2 (+) extend	60.0	38
	(+) retract	50.0	39
	(-) extend	50.0	40
	(-) retract	50.0	41
2.7.2.5.5	Pressure 1 failure	00.0 (no effect)	42
2.7.2.5.6	Pressure 2 failure	30.0	43

*Time is measured (on the secondary actuator LVDT plot) from the time system # 2 failure indicator switch disengages to the point at which the LVDT reaches mechanical null position.

TABLE 4. Failure Switching Transients - Hydraulic Logic System 2

It can be seen that times shown in Table 4 are considerably higher than those in Table 3. Reason is laid to the fact that the secondary actuator centering springs must center the actuator to mechanical null after failure occurs. Failure switching transient time is therefore a function of command amplitude, centering springrate and preload, actuator oil passage sizing, position of actuator at the time of failure and the type of hardover failure whether positive or negative (extend or retract).

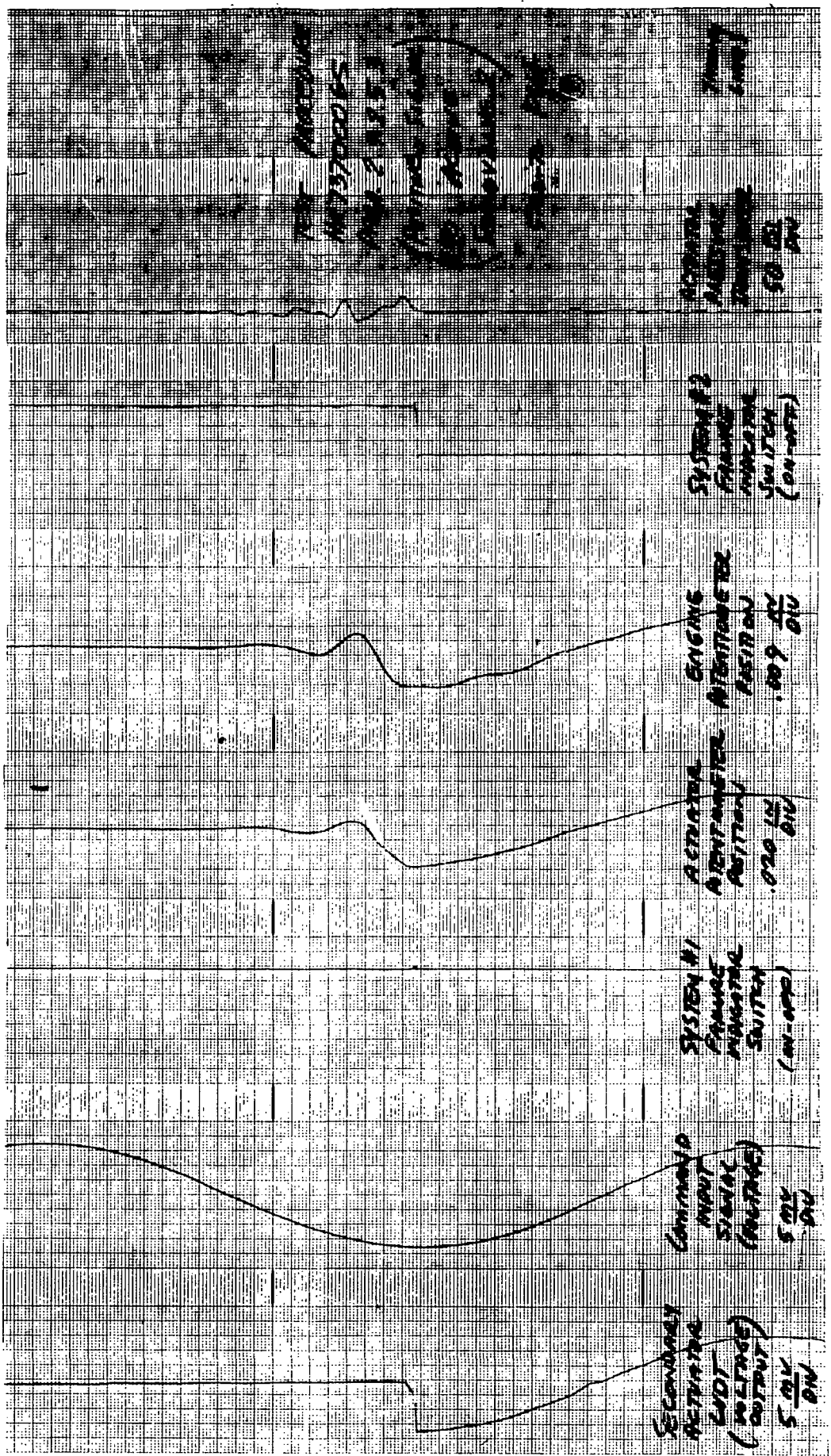


Figure 34. Hardover (+ Extend) Command Signal to Active Servovalve 2

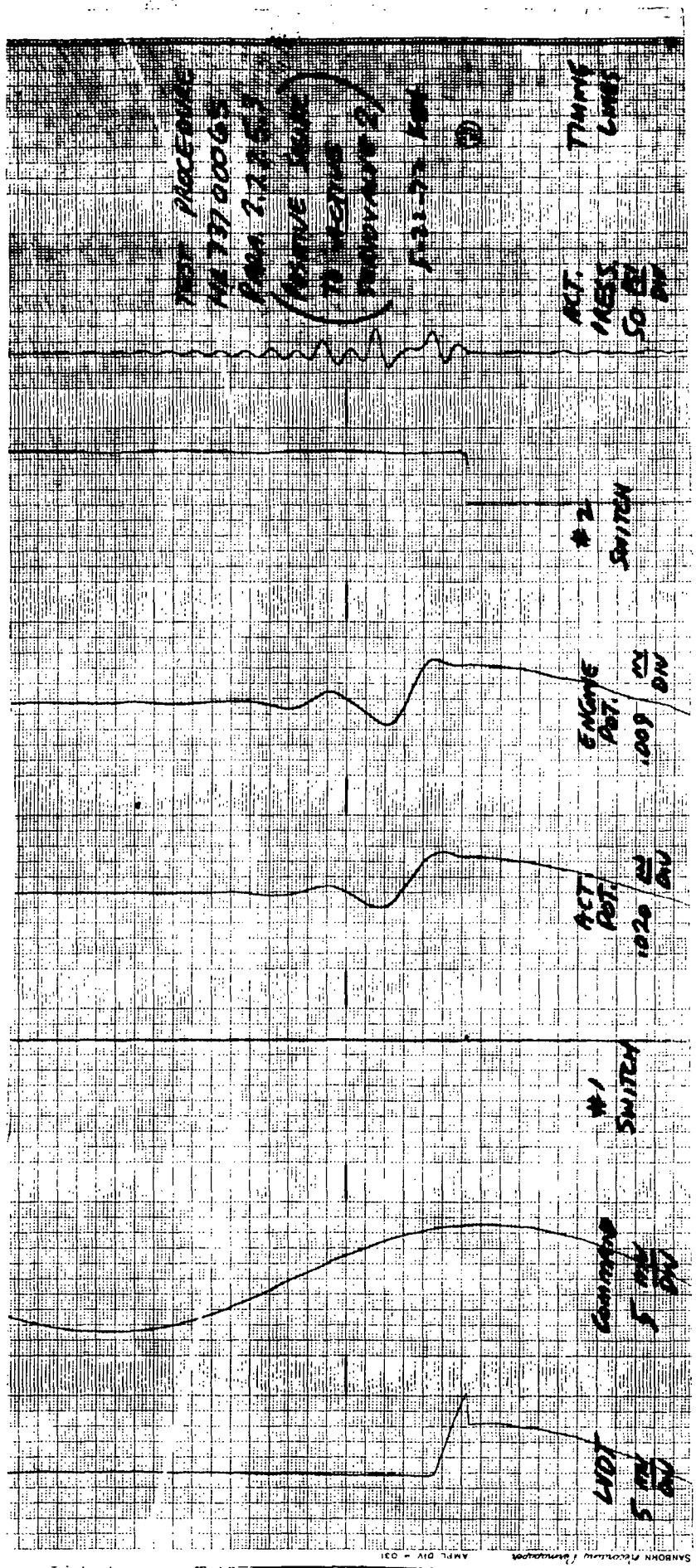


Figure 35. Hardover (+ Retract) Command Signal to Active Servovalve 2

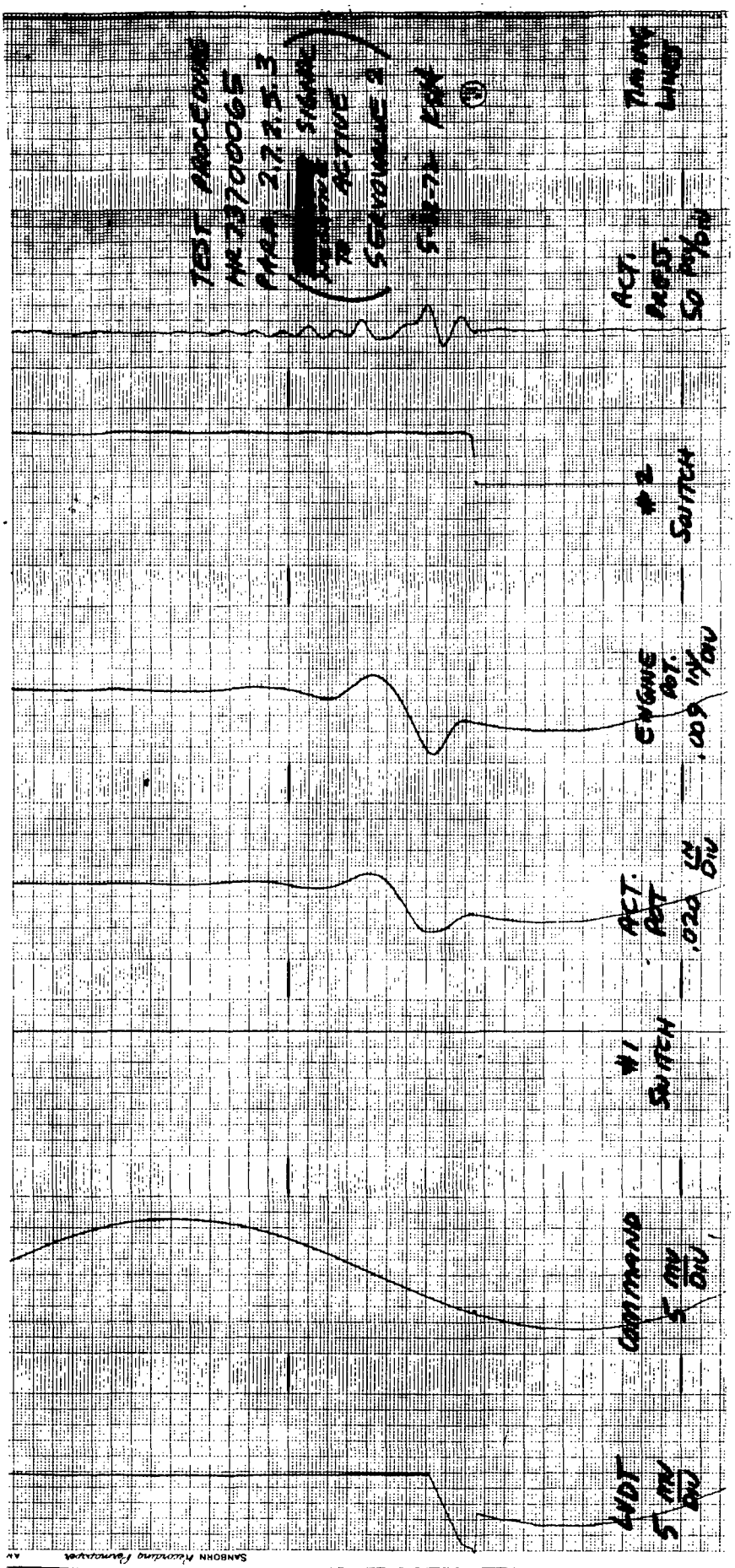


Figure 36. Hardover (- Extend) Command Signal to Active Servovalve 2

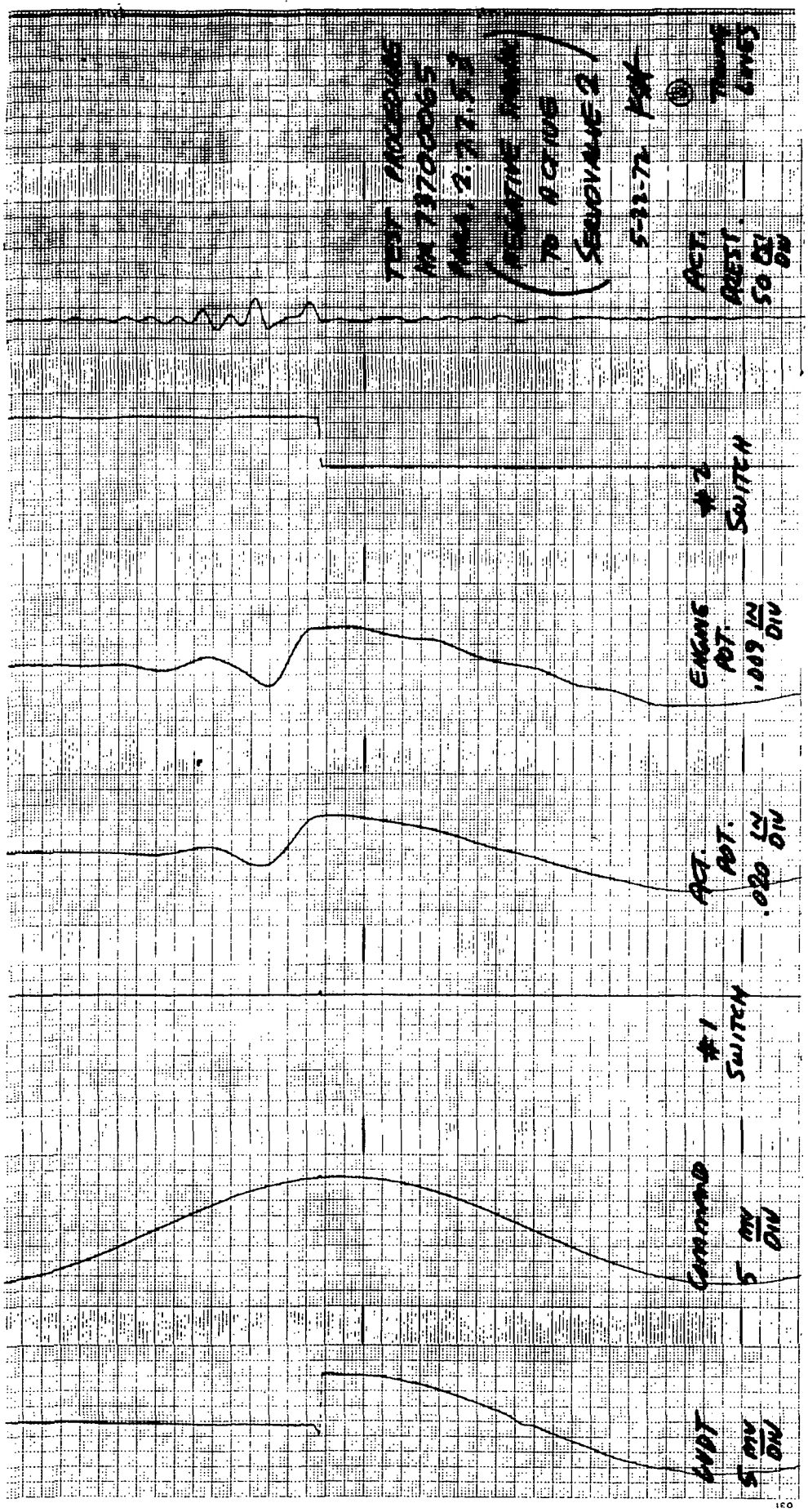


Figure 37. Hardover (- Retract) Command Signal to Active Servovalve 2

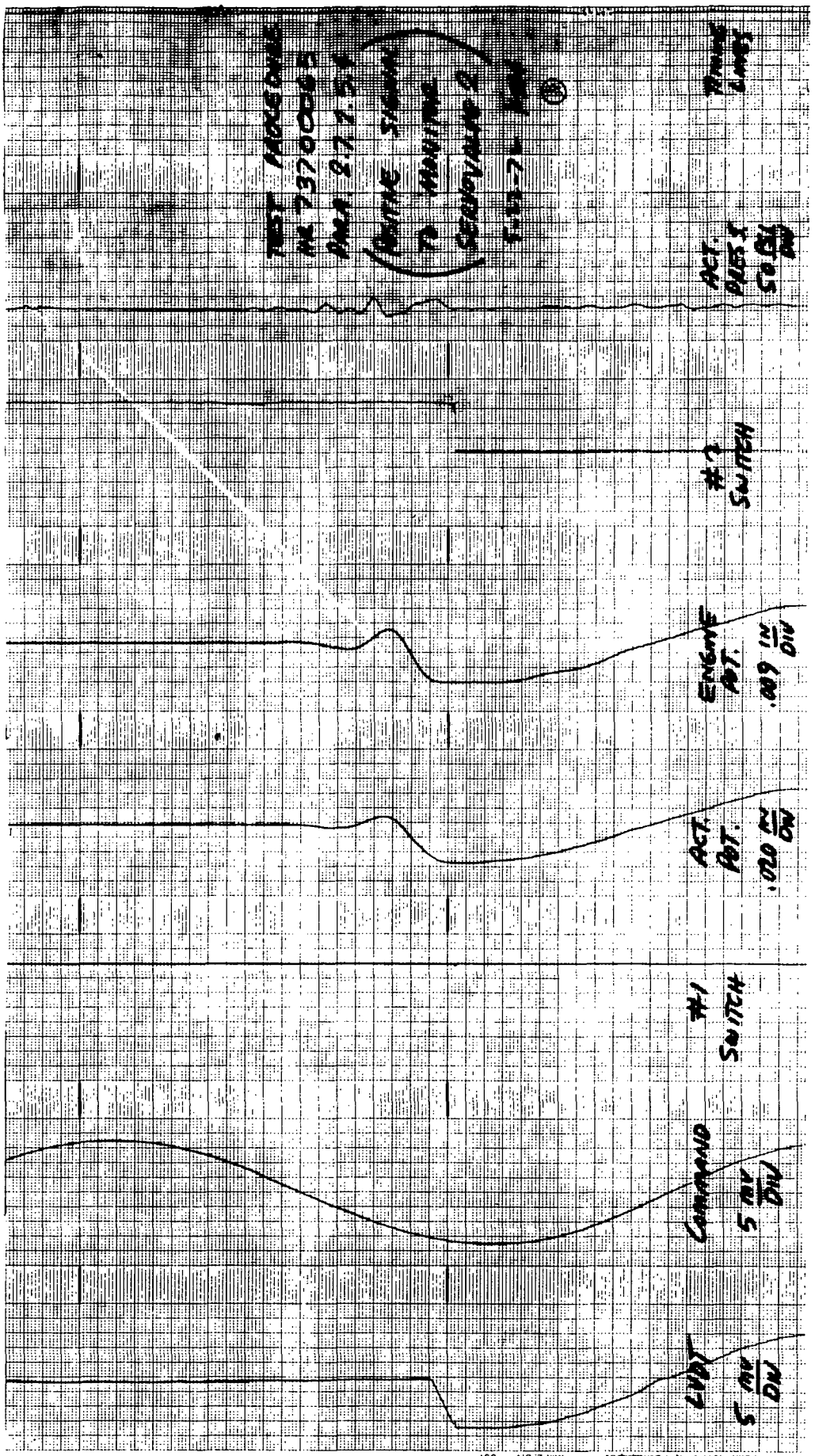


Figure 38. Hardover (+ Extend) Command Signal to Monitor Servovalve 2

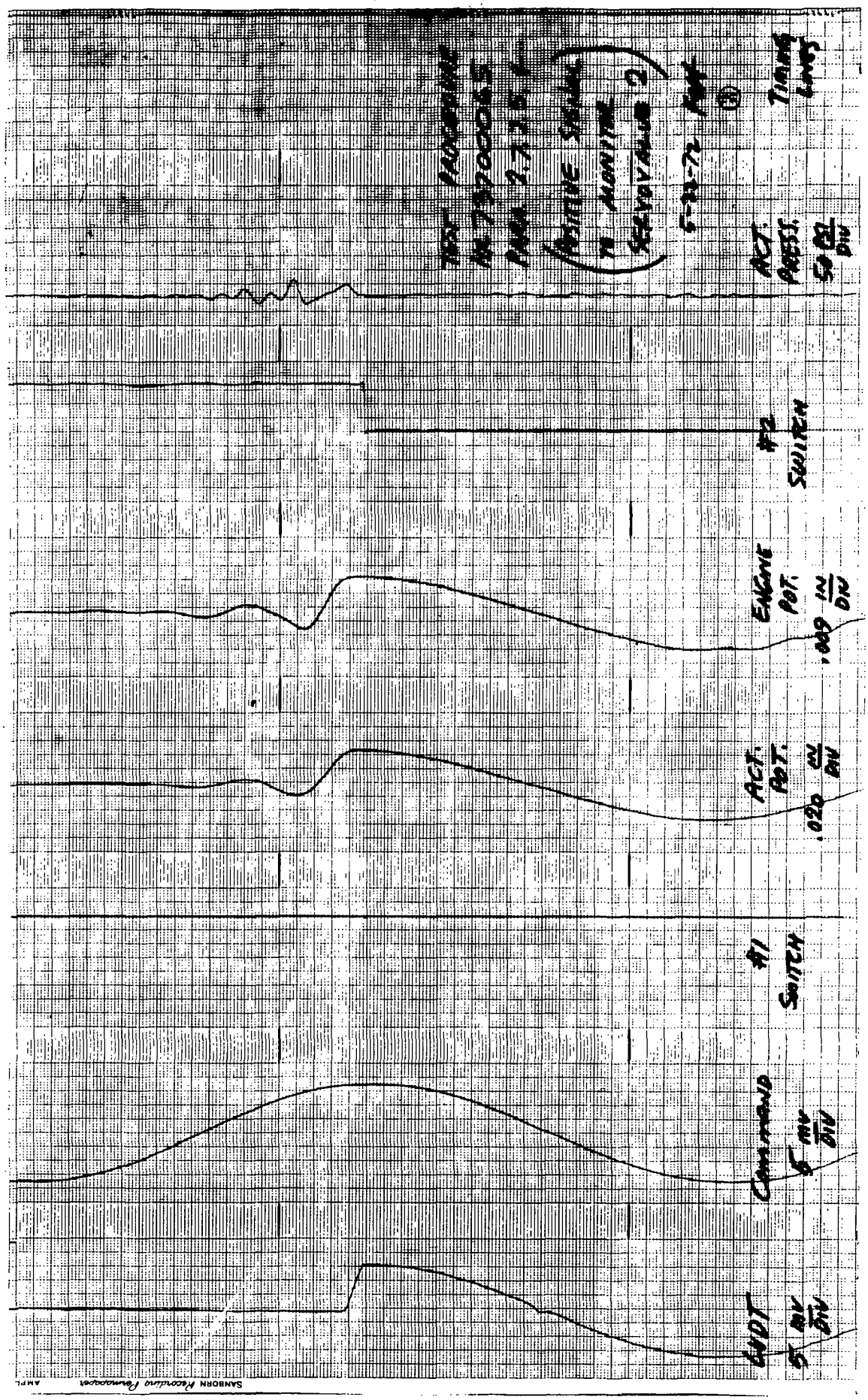


Figure 39. Hardover (+ Retract) Command Signal to Monitor Servovalve 2

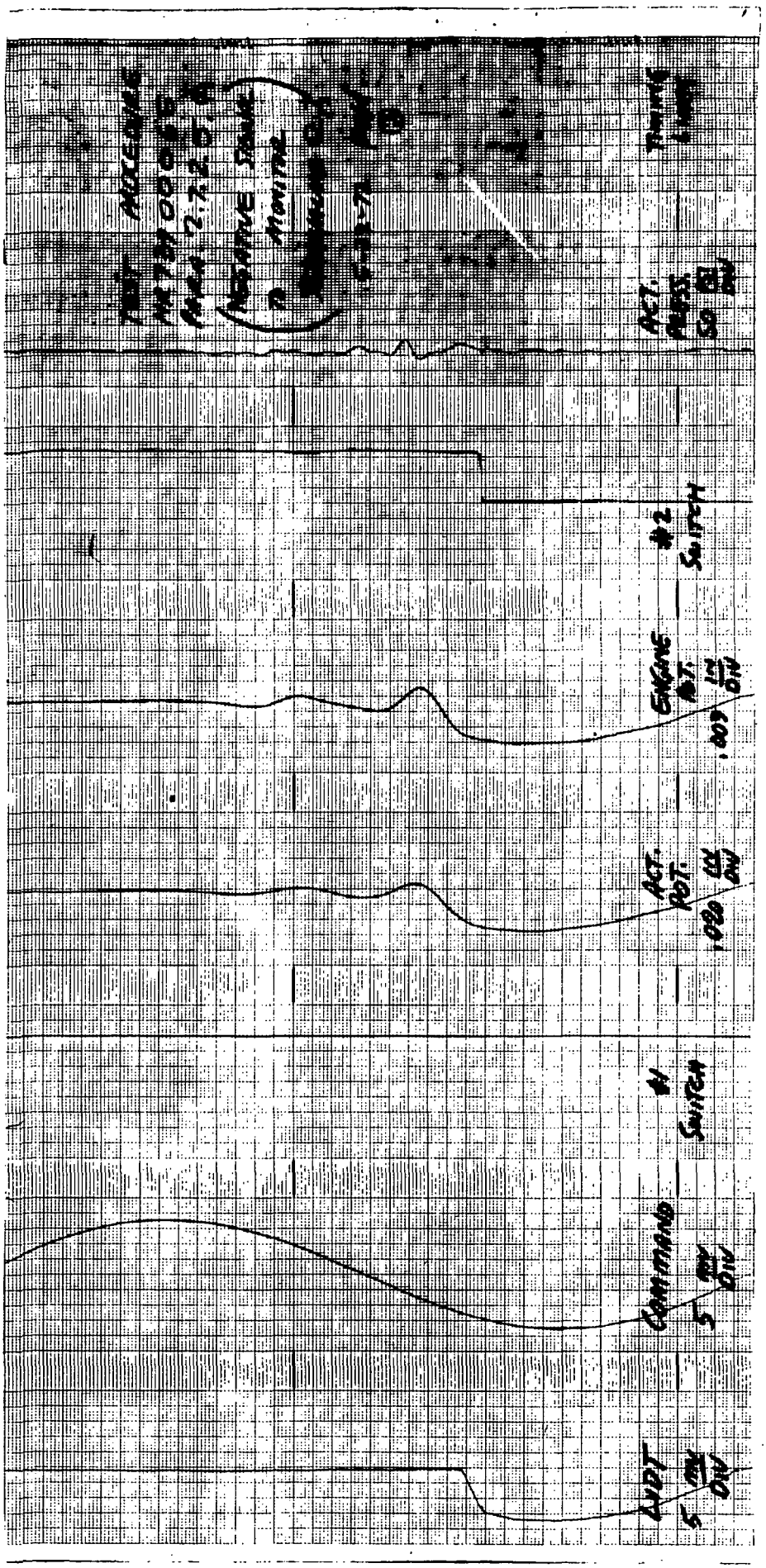


Figure 40. Hardover (- Extend) Command Signal to Monitor Servovalve 2

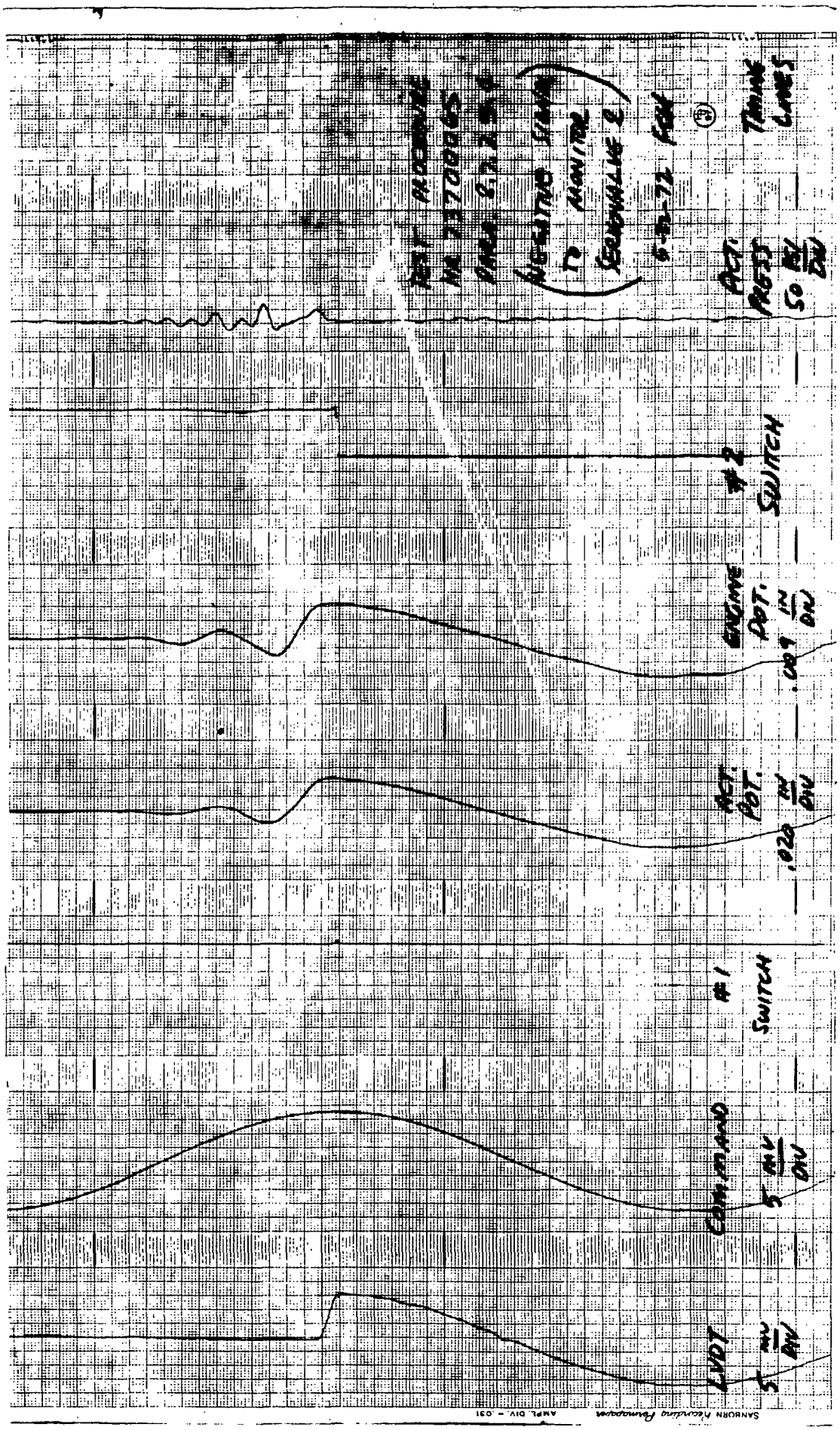


Figure 41. Hardover (- Retract) Command Signal to Monitor Servovalve 2

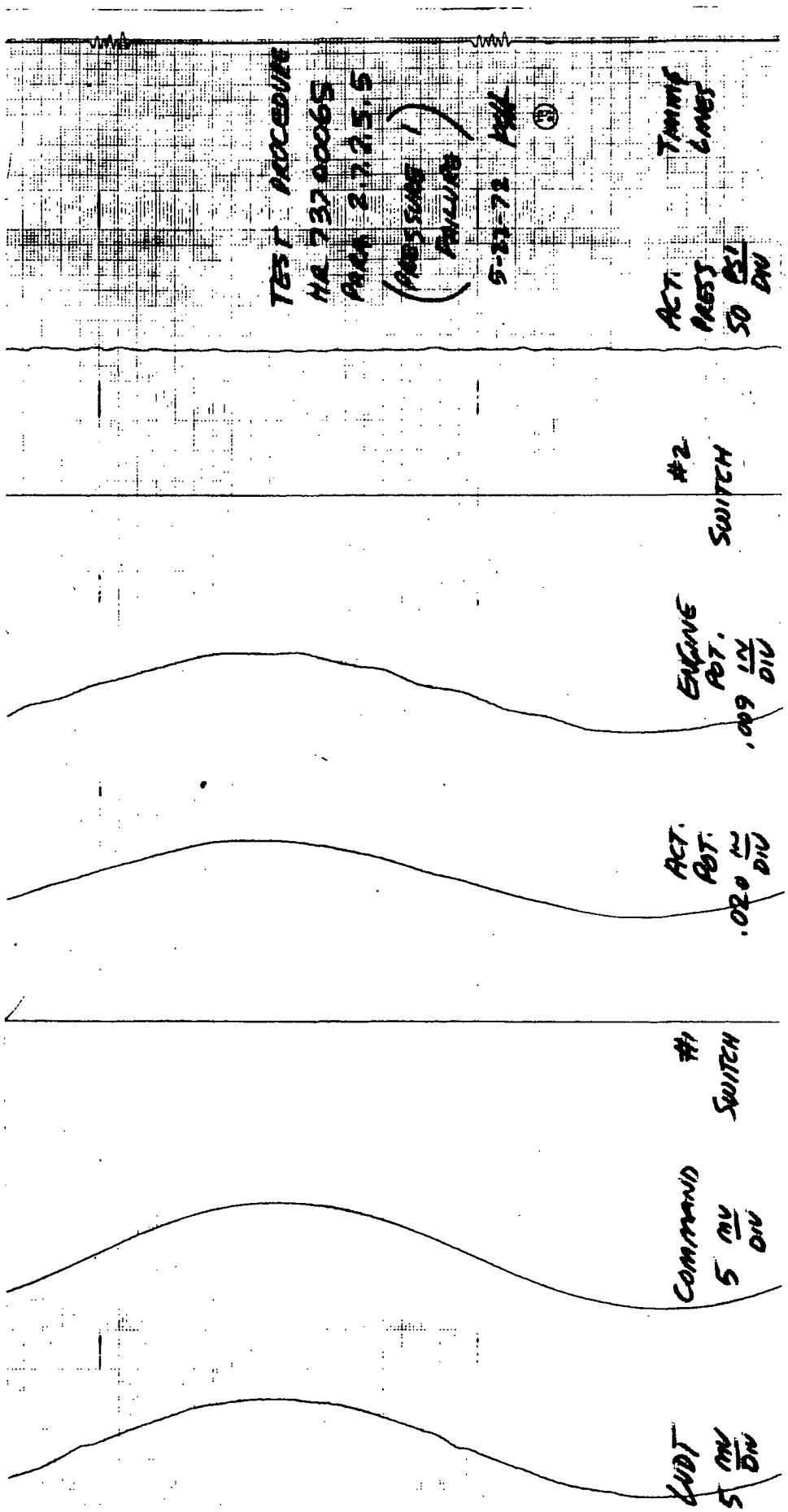


Figure 42. Pressure 1 Failure
(System 2, Active)

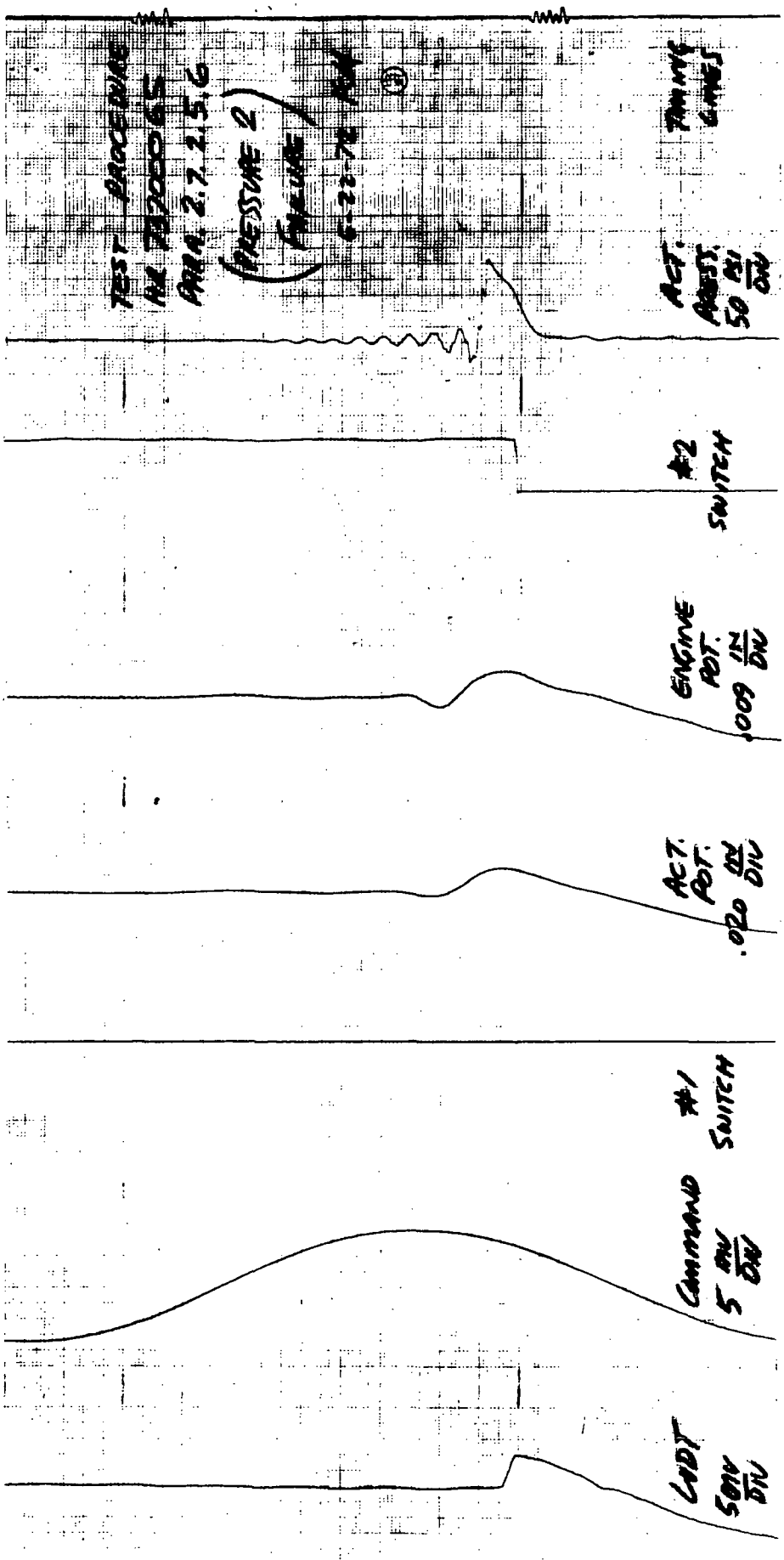


Figure 43. Pressure 2 Failure (System 2 Active)

7. TEST DATA COMPARISON

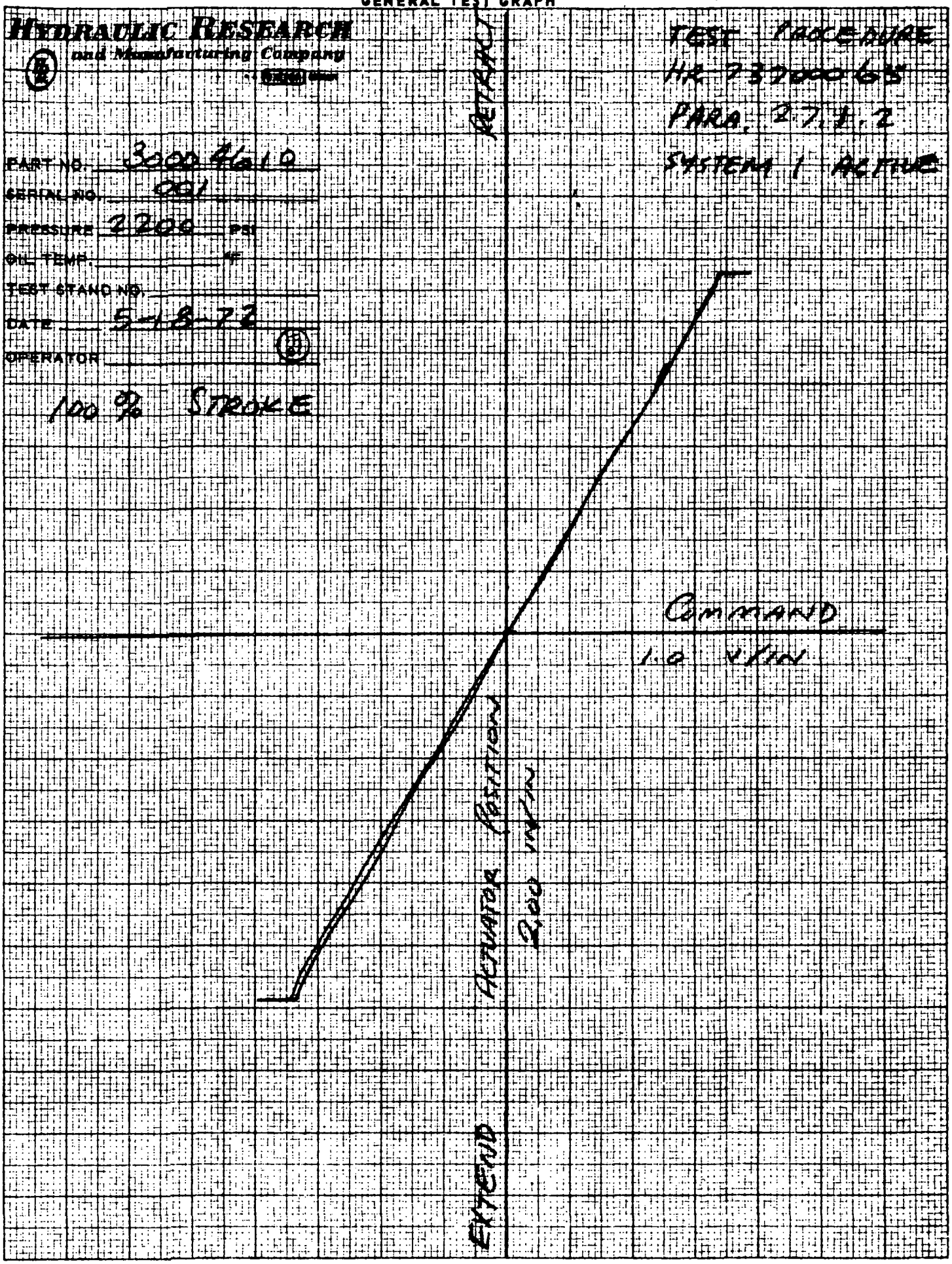
A comparison is presented in the following paragraphs of various test data characteristics between the 30004610 TVC Servoactuator (modified 301100 S-1C servoactuator) and the 301100 S-1C servoactuator.

A receiving acceptance test was conducted on the 301100 S-1C Servoactuator at the time of receipt from NASA and prior to any modification. Data from this test is used in the following comparison. Four areas of comparison are presented: (1) Linearity and Hysteresis (2) Total unit frequency response (3) Sine wave response and (4) Step response.

7.1 Linearity and Hysteresis

Linearity and hysteresis plots at 100% actuator piston stroke are shown in Figures 44 and 45 for the 30004610 and 301100 units respectively. Reference is made to Paragraph 5.1.1 for comparative linearity and hysteresis valves between the 301100 (non-modified) and 30004610 (system 1) units.

	Linearity	Hysteresis
301100	2.05%	1.23%
30004610 (System 1)	2.33%	4.07%



EL 008

Figure 44. 30004610 Linearity and Hysteresis

Reproduced from best available copy.

FLOW AND LEAKAGE PLOT

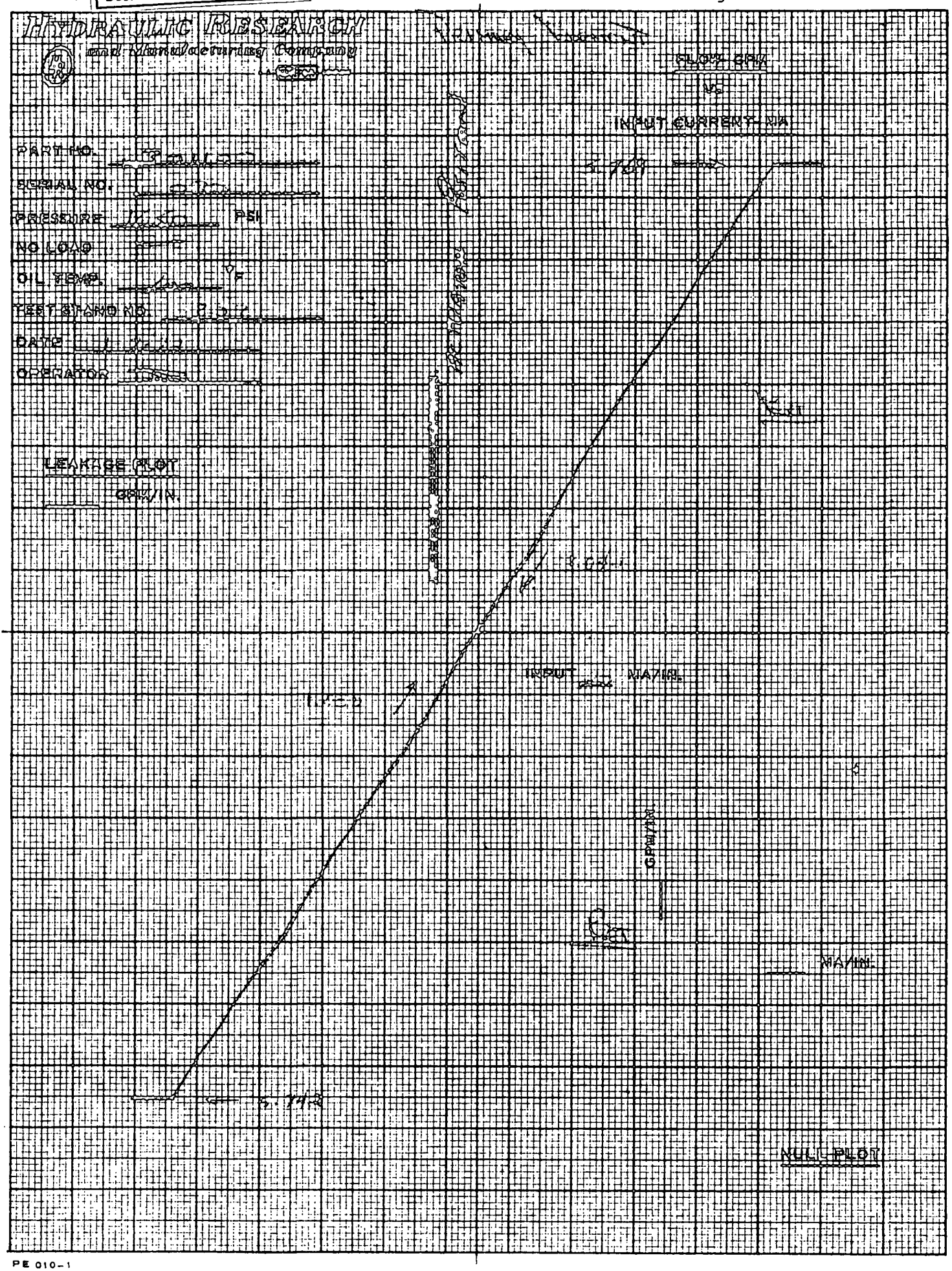


Figure 45. 301100 Linearity and Hysteresis

7.2 Total Unit Frequency Response

Frequency response plots for the total system 30004610 are shown in Figure 46 and for 301100 unit in Figures 47 and 48.

When comparing system response, the 30004610 unit is 4.5 db at -90° phase shift whereas the 301100 unit is -.4db at -135° phase shift. Differences are caused by changes in total loop gain (3-stage servovalve feedback spring springrate change - reference paragraph 9.).

When comparing the two phase angle plots, it can be seen that the two are relatively equivalent. For example:

Phase Shift (degrees)	Frequency (cps)	
	30004610 unit	301100 unit
-30	1.7	1.3
-60	3.0	2.3
-90	4.0	4.0

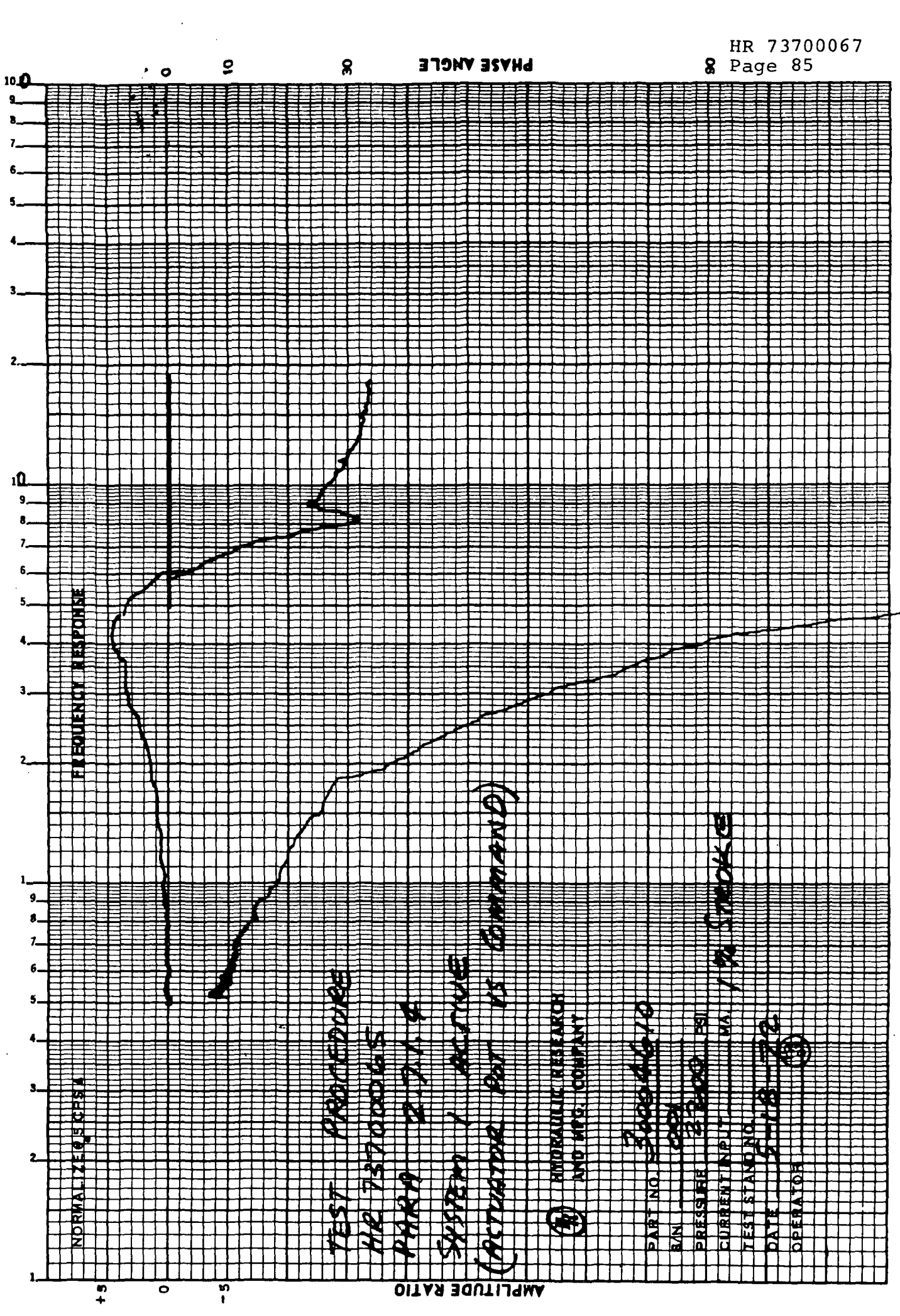


Figure 46. 30004610 (System 1) Frequency Response

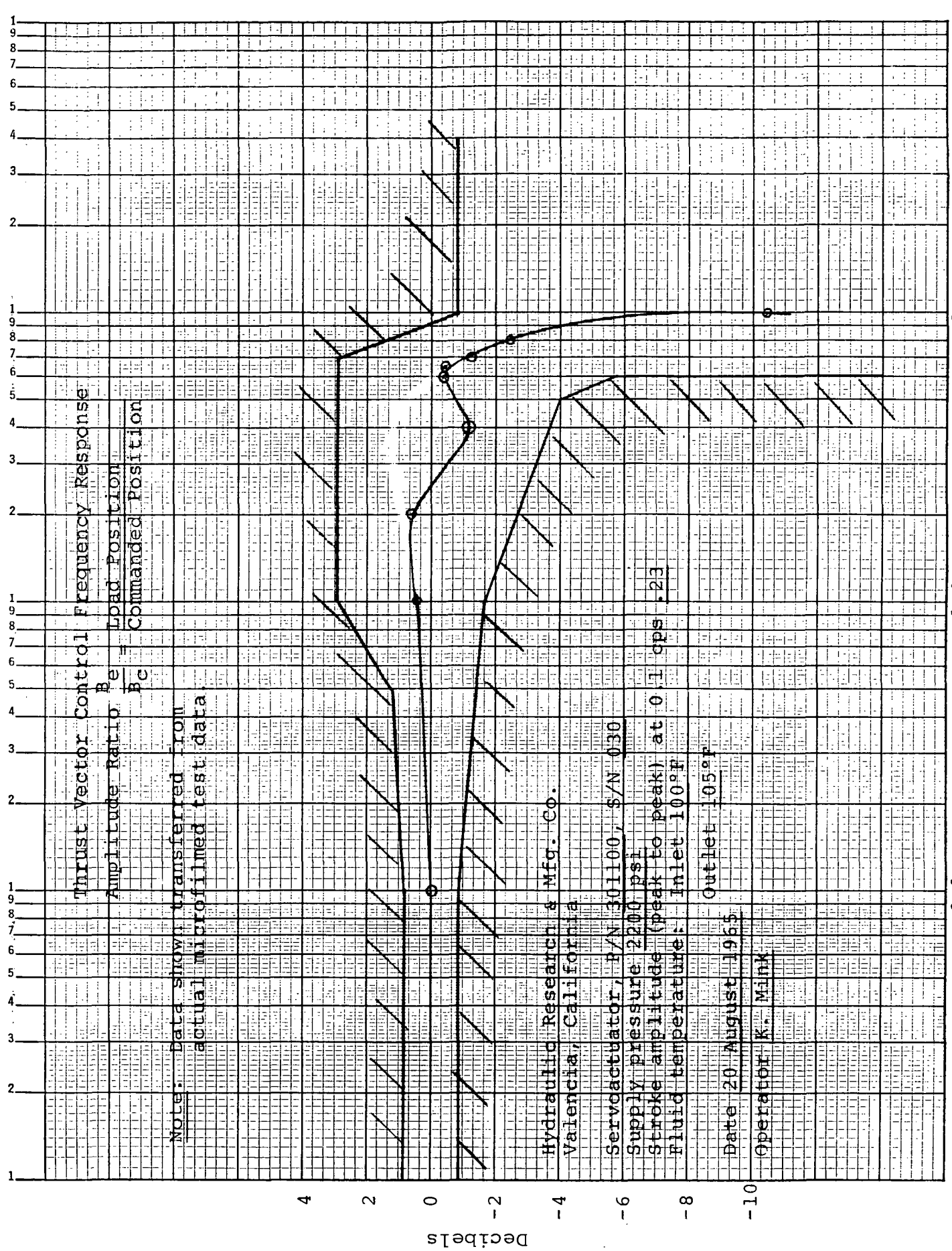


Figure 47. 301100 Frequency Response - Amplitude Ratio

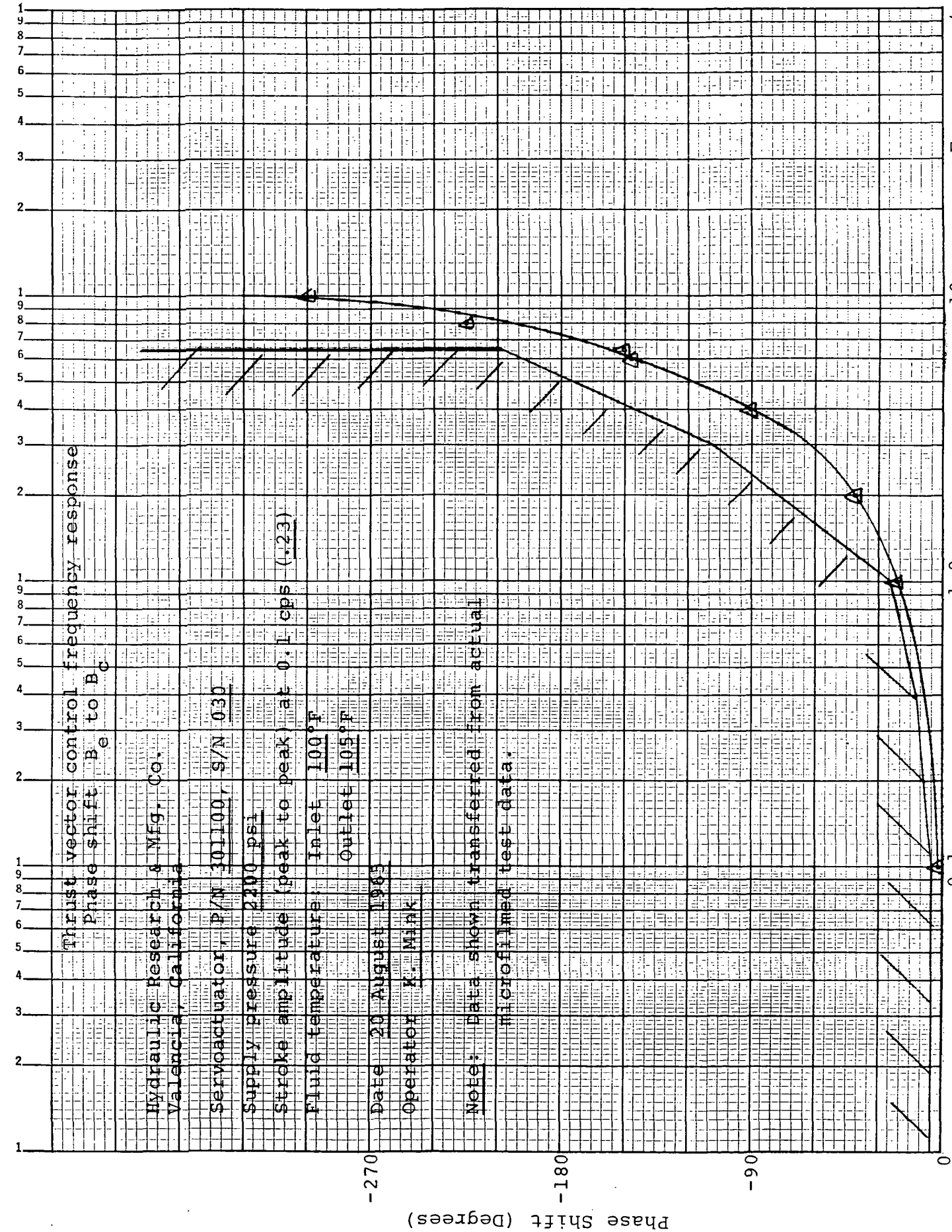


Figure 48. 301100 Frequency Response - Phase Angle

7.3 Sine Wave Response

Figures 49 and 50 show sine wave response plots for the 30004610 and 301100 units respectively. Calibration on each plot has been made equivalent along with actuator and engine potentiometer amplitudes.

As can be seen, sine wave response of the 30004610 unit versus the 301100 unit shows slightly higher chatter throughout the stroke cycle. The response wave form appears to be smoother and more nearly a sine wave in the 30004610 unit. Reference is made to paragraph 8 (system design problem areas) for an in depth discussion of the chatter problem with causes and suggestions for solution.

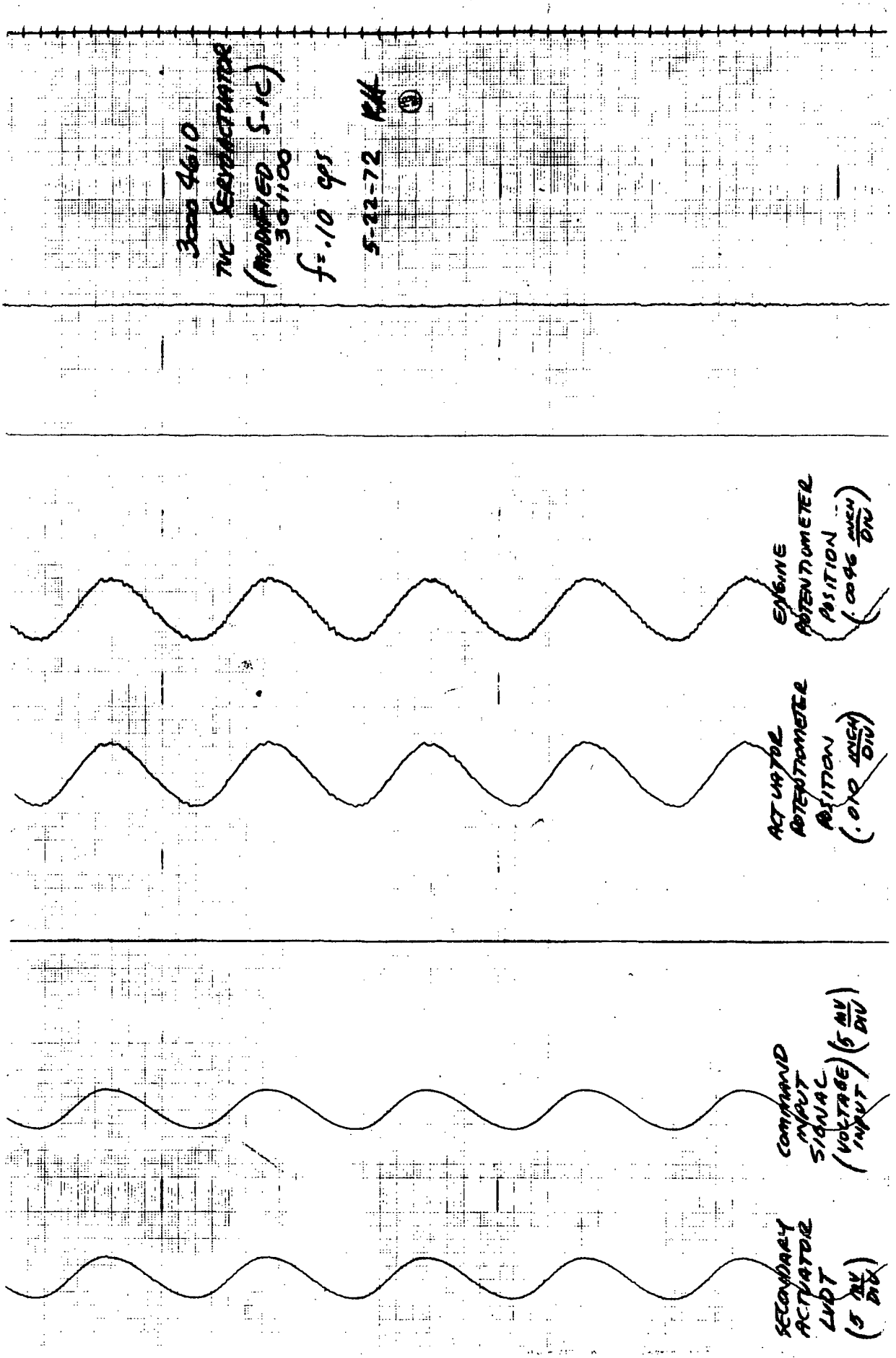


Figure 49. 30004610 Unit Sine Wave Response



Figure 50. 301100 Unit Sine Wave Response

7.4 Step Response

Step response plots for the 30004610 and 301100 units are shown in Figures 51 and 52 respectively. Calibration on each plot has been made equivalent along with actuator and engine potentiometer amplitudes.

As shown, the 30004610 actuator and engine experienced slightly higher overshoots with the engine following the actuator position very closely. The 30004610 engine position appears to have damped considerably sooner than the 301100 engine.

Lower step response rates in the 30004610 actuator and engine position can be attributed to differences in system linkage and feedback designs.

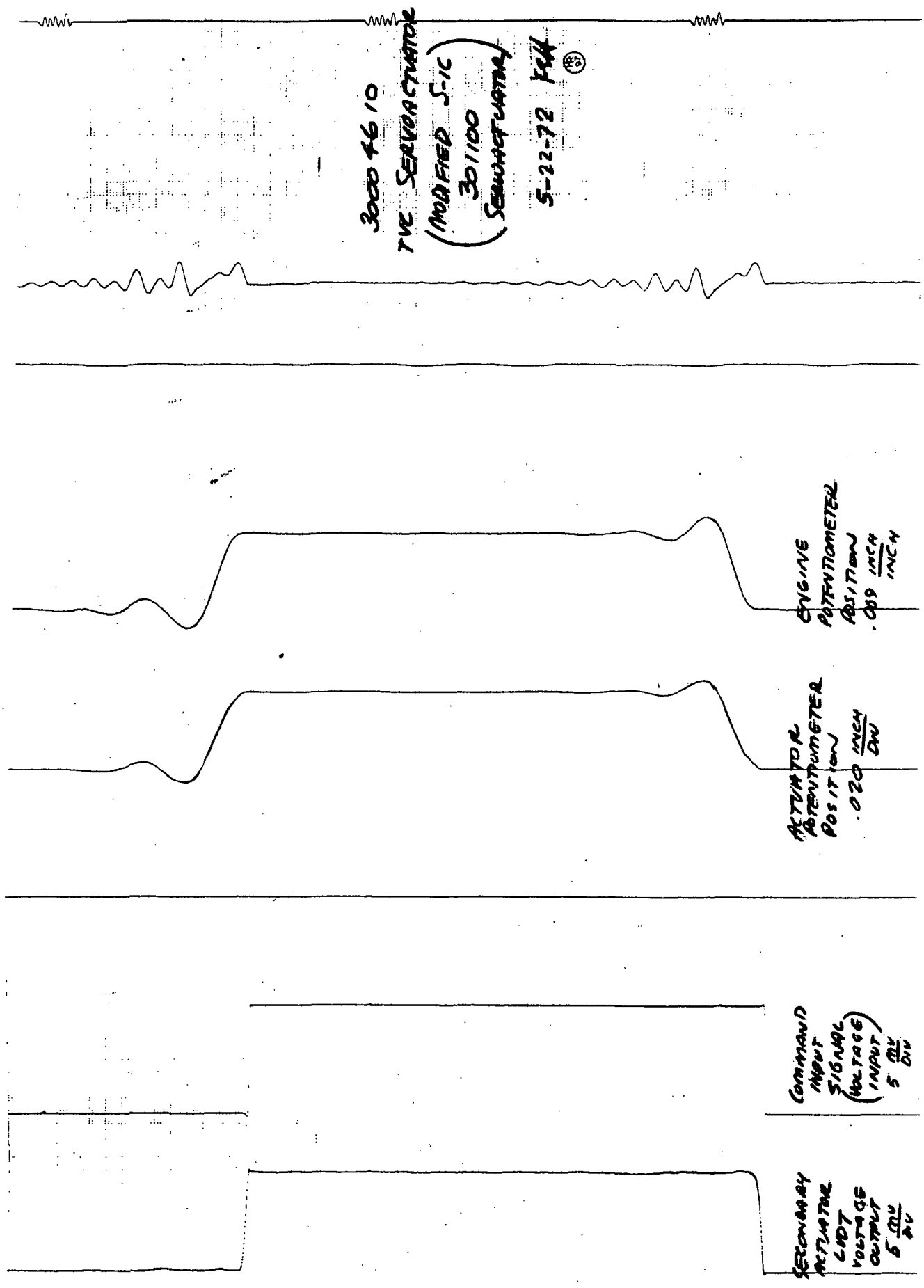


Figure 51. 30004610 Unit Step Response

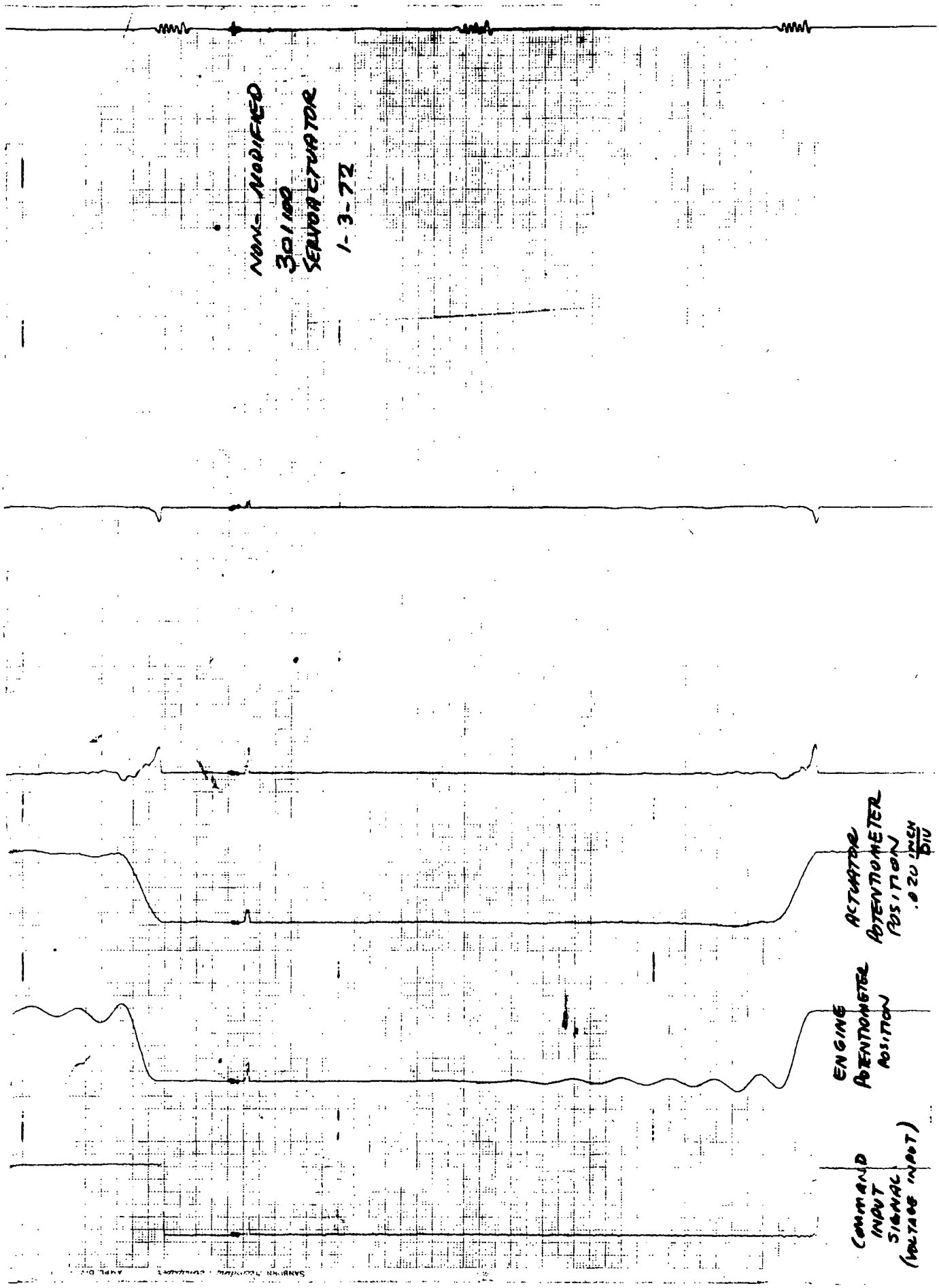


Figure 52. 301100 Unit Step Response

8. TEST EQUIPMENT DESCRIPTION

The test equipment utilized for all development testing and data recording is as follows:

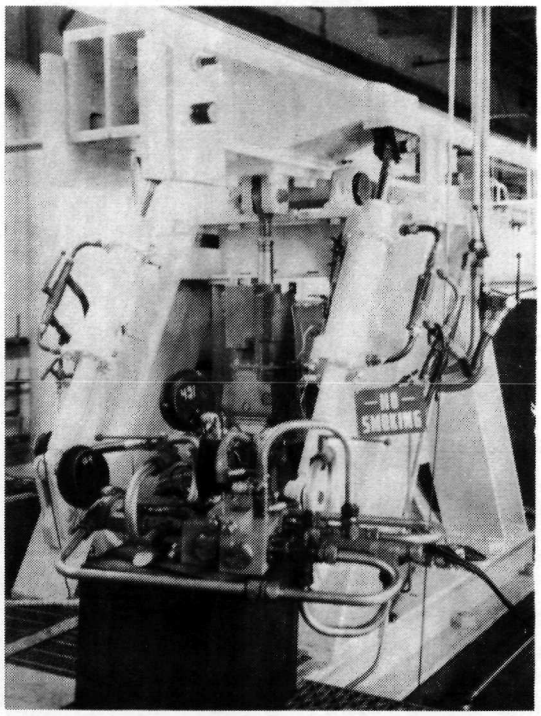
(1) S-1C dynamic load simulator (see photograph in Figure 53).

(2) Electronic test equipment includes the following (see photograph in Figure 53):

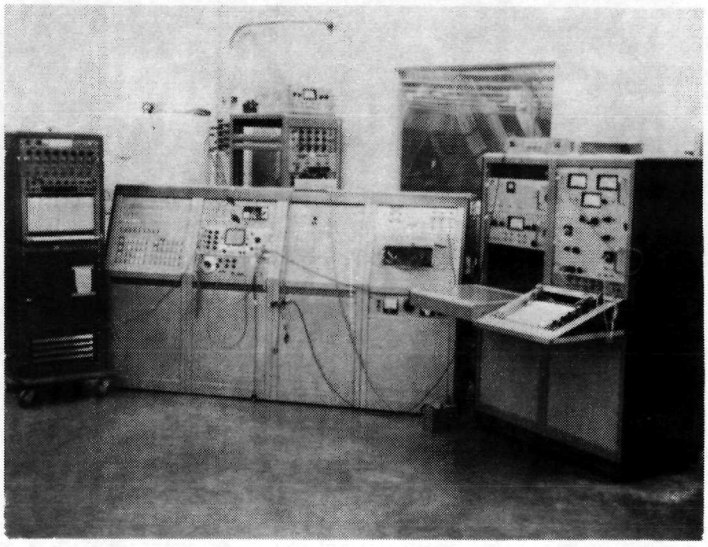
- (a) Sanborn Model 950 Recorder (8 channel)
- (b) Standard Controls Model 300 Pressure Transducer (single ended).
- (c) Industrial Instruments Corp. Model 101G Frequency Response Analyzer.
- (d) Redundant Servoactuator Electronic Test Console includes the following:
  - 1) Four (4) servoamplifiers
  - 2) One (1) demodulator
  - 3) Tektronix Model RM564 Storage Oscilloscope
  - 4) Hewlett-Packard Model 3300A function generator
  - 5) System monitor/operating panel (failure and switching buttons)
  - 6) Calibration panel

(3) S-1C pumping system includes the following (see photograph in Figure 54):

(a) Nine (9) Denison Engineering Company - Model 700 - 184400 newton/meter^2 (5000 psi) and 1264 cm^3/sec (20 gpm) piston type hydraulic pumps.

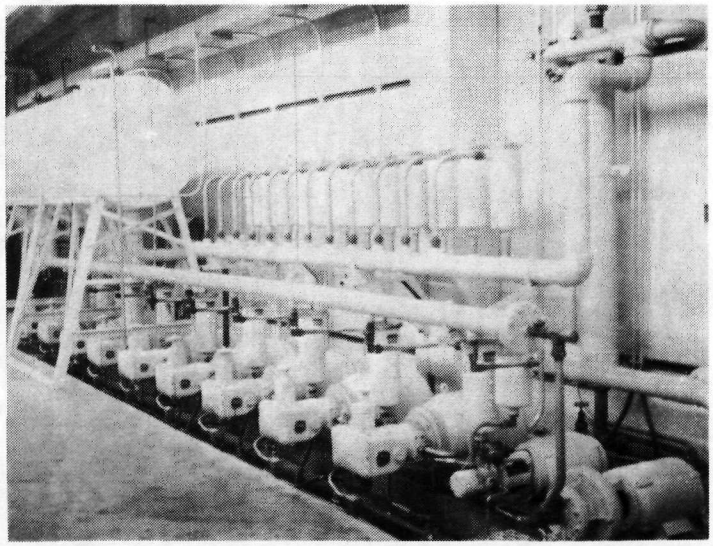


S-1C
Dynamic Load
Simulator



Electronic
Test Equipment

Figure 53. Photographs of Test Equipment



S-1C
Pumping System

Figure 54. Photograph of Test Equipment

9. SYSTEM DESIGN PROBLEM AREAS

Two major problem areas exist within the 30004610 unit design which are both a result of the type of mechanical feedback design selected for the S-1C modification. The problem areas are: (1) Actuator mechanical null shift and (2) Engine position chatter. Problem area description and suggested solution are as follows:

(1) Actuator Mechanical Null Shift:

Throughout the complete development testing program, actuator mechanical null shifting from the mid-stroke lock position was experienced. Shifting occurred at the 3-stage servovalve feedback spring input point. Shifting is caused by either or both of two reasons: (a) Feedback spring position moving under dynamic impulsing caused by low torqued tie down screws and/or (b) Components, including feedback spring retainer, moving with increase in oil and ambient temperature.

If, upon further testing, the problem persists actuator mechanical null position may be readjusted by performing the following procedure:

Referring to Figure 55, with the unit pressurized and temperature stabilized, remove the small

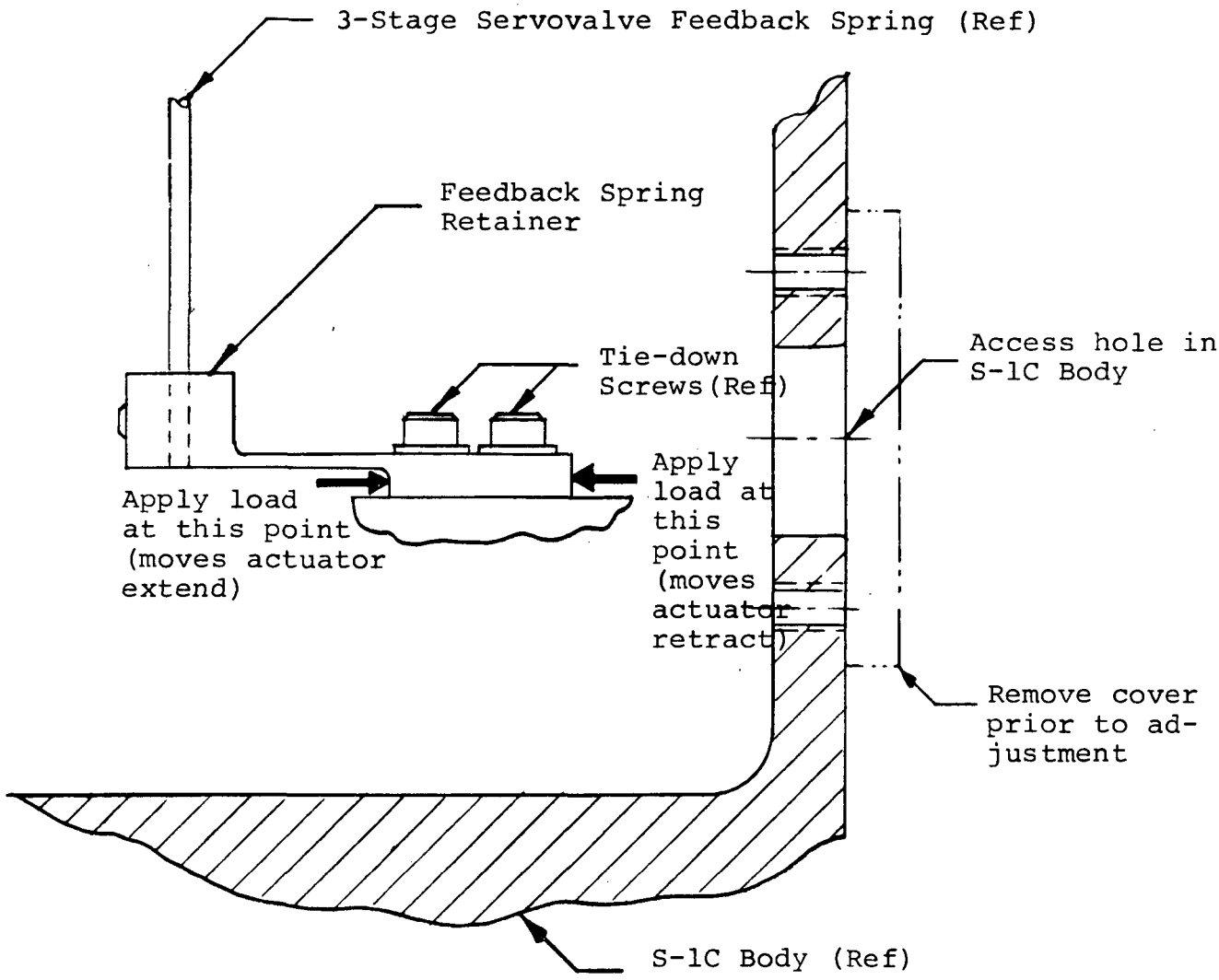


Figure 55. Actuator Null Adjustment

cover which opens the access hole in the S-1C body to the torque motor cavity. From the access hole, tap the feedback spring retainer in the appropriate direction to readjust the feedback spring and subsequently the actuator piston in the desired direction.

(2) Engine Position Chatter:

As can be seen from the comparative test results (sine wave) in Paragraph 6. between the 30004610 and 301100 units, the 30004610 unit actuator and engine potentiometer positions experienced slightly increased amounts of chatter throughout the stroke cycle.

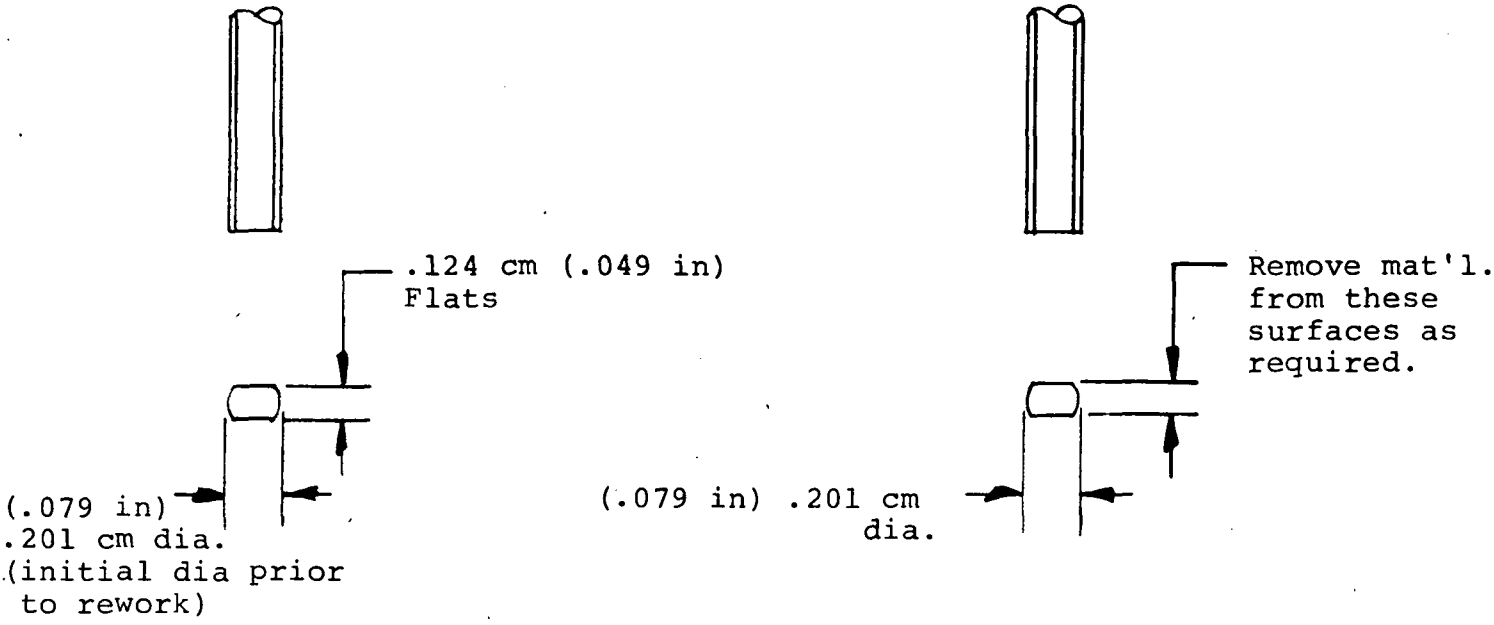
Upon modifying the 301100 S-1C unit, the position loop gain (K) was significantly increased. Reducing the 3-stage servovalve feedback spring springrate reduced the magnitude of chatter in the actuator and engine position. Reducing the springrate effectively reduces the position loop gain (K).

It was decided that at the present springrate the actuator and engine chatter was very minimal, particularly when the actual chatter magnitude was observed. Adequate test results have been produced using the present springrate and therefore no further adjusting was made.

If, upon further testing, the chatter is felt to be excessive further springrate adjustment is possible by two methods described as follows and shown in Figure 56:

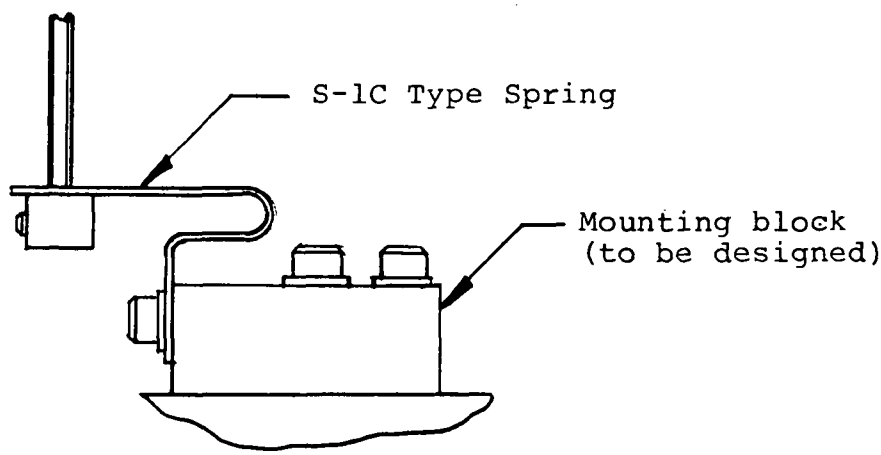
(a) Remove material from the sides of the existing feedback spring per Figure 56., method # 1. Reduction of the existing spring springrate will result.

(b) Add a S-1C type spring in series with the existing/or trimmed feedback spring per Figure 56., method # 2. Reduction of the total springrate will result.



Present Feedback Spring Configuration

Feedback Spring Adjustment Method # 1



Feedback Spring Adjustment Method # 2

Figure 56. 3-Stage Servovalve Feedback Spring Springrate Adjustment

10. CONTINUATION OF DEVELOPMENT TESTING

The 30004610 TVC Servoactuator with the 33000660-3 Redundant Servoactuator (minilogic) combine to form a total system which is very much a state-of-the-art system in the field of redundant servosystems. Development testing thus far conducted on the system has provided baseline performance data for the system as designed and tested under specific operating conditions only. It is recommended the system be subjected to more extensive testing and evaluation under a variety of operating conditions. It is also recommended that the 30004610 unit be tested utilizing the 34000220 Servoactuator and Electronic Model as a hydraulic logic module (reference Paragraph 3.). The following is a list of recommended additional testing:

(1) System Design Improvement (if required):

(a) Feedback springrate development (reference Paragraph 9.).

(2) Pressure System Supply Selector Valve Assembly Testing Program (Separate Unit):

(a) Switching Pressures (P1 and P2)

(b) Pressure drop at flowrate (P1, P2 and P3)

(c) Failure Switching Transients

1.) Single hardover failure to P1 and P2
2.) Single slowover failure to P1 and P2
3.) Multiple hardover failure to P1 and P2
4.) Multiple slowover failure to P1 and P2

(3) Total System Testing Program - 33000660-3 and 34000220 Units Separately (Hydraulic Logic Modules) with Engine Inertia Load Only:

(a) Failure Switching Transients: Variable system loop gain, frequency and amplitude.

1.) Single positive and negative hardover failures to servovalves.

2.) Single command input signal failures.
3.) Single LVDT signal failures.
4.) Single pressure failures.
5.) Multiple positive and negative hardover failures to servovalves.
6.) Multiple command input signal failures.
7.) Multiple LVDT signal failures.
8.) Multiple pressure failures.

(4) Total System Testing Program - 33000660-3 and 34000220 Units (Hydraulic Logic Modules) with Engine Inertia and Static 72000 lb (External) Loads Only:

(a) Failure Switching Transients: Variable System loop gain, frequency and amplitude.
1) through 8) same as (3) above.

APPENDIX A

HR 73700065

Test Procedure

For

Hydraulic Research and Manufacturing Company

Part Number 30004610

Servoactuator, Thrust Vector Control

Operate/Fail-Operate/Fail-Center

HYDRAULIC RESEARCH
and MANUFACTURING COMPANY
25200 WEST RYE CANYON ROAD • VALENCIA, CALIF. 91355
(805) 259-4030 TWX 910-336-1438
CODE IDENT 81873

REPORT NO. HR 73700065
HR&M JOB NO. TP 30004610
CONTRACT
NO. PAGES 27
DATE 5-19-72
REV. A

TEST PROCEDURE

FOR

HYDRAULIC RESEARCH AND MANUFACTURING COMPANY

PART NUMBER 30004610

SERVOACTUATOR, THRUST VECTOR CONTROL

OPERATE/FAIL-OPERATE/FAIL-CENTER

PREPARED BY Kenneth E. Hart DATE 6-11-72
CHECKED BY _____ DATE _____
APPROVED BY _____ DATE _____
APPROVED BY _____ DATE _____
APPROVED BY _____ DATE _____

EG 055 (REV. 4-69)

FORWARD

This procedure lists test requirements for Thrust Vector Servoactuator, Part Number 3004610. The servoactuator meets the requirements of the National Aeronautics and Space Administration (George C. Marshall Space Flight Center) Contract Number 8-27928.

The test requirements herein are designed to properly test the 30004610 TVC Servoactuator utilizing the control loop hydraulic logic module conforming to the 3000660-3 Redundant Servoactuator (Minilogic) which is an active-standby type unit (operate/fail-operate/fail-trail). The 33000660-3 unit which conforms to the National Aeronautics and Space Administration (George C. Marshall Space Flight Center) Contract Number 8-27847, shall be assembled onto the 30004610 TVC Servoactuator per drawing 30004610, Sheet 2. All testing shall be accomplished with the unit assembled in this manner and shall be tested at a supply pressure of 2200 $\pm$50 PSIG.

Refer to 30004610 and 33000660 for unit hydraulic and electrical schematics.

CONTENTS

Paragraph		Page
1.	Test Conditions	6
2.	Functional Tests	7
2.1	Component Acceptance Test	7
2.1.1	3-Stage Servovalve Adjustment	7
2.2	Unit Assembly and Physical Inspection	8
2.3	Preliminary Total System Operation	8
2.3.1	Control Loop Hydraulic Logic System 1 Operation (Preliminary)	9
2.3.2	Control Loop Hydraulic Logic System 2 Operation (Preliminary)	9
2.4	Potentiometer Resistance	9
2.4.1	Fixed Resistance	9
2.5	Mechanical Null and Centering Mechanism	10
2.6	Secondary Actuator LVDT Adjustment	11
2.7	Complete System Operation	11
2.7.1	Control Loop Hydraulic Logic System 1 Active - System 2 Standby (on)	11
2.7.1.1	Servovalve Phasing (Polarity)	12
2.7.1.2	Linearity and Hysteresis	13
2.7.1.3	Threshold	14
2.7.1.4	Frequency Response	14
2.7.1.5	Hydraulic Failure Logic	15
2.7.1.5.1	Active Servovalve Failure Switching Current	15
2.7.1.5.2	Monitor Servovalve Failure Switching Current	15

CONTENTS (Continued)

Paragraph		Page
2.7.1.5.3	Hardover Active Servovalve Failure Switching Transient	15
2.7.1.5.4	Hardover Monitor Servovalve Failure Switching Transient	16
2.7.1.5.5	Pressure 1 Switching Transient - P2 and P3 Standby	16
2.7.2	Control Loop Hydraulic Logic System 2 Active - System 1 Failed	18
2.7.2.1	Servovalve Phasing (Polarity)	18
2.7.2.2	Linearity and Hysteresis	19
2.7.2.3	Threshold	19
2.7.2.4	Frequency Response	20
2.7.2.5	Hydraulic Failure Logic	20
2.7.2.5.1	Active Servovalve Failure Switching Current	20
2.7.2.5.2	Monitor Servovalve Failure Switching Current	21
2.7.2.5.3	Hardover Active Servovalve Failure Switching Transient	21
2.7.2.5.4	Hardover Monitor Servovalve Failure Switching Transient	22
2.7.2.5.5	Pressure 1 Switching Transient - P2 and P3 Standby (on)	22
2.7.2.5.6	Pressure 2 Switching Transient - P1 Failed and P3 Standby (on)	23

FIGURES

		Page
Figure 1.	30004610 Hydraulic Setup ----------	24
Figure 2.	30004610 Electrical Setup ----------	25
Figure 3.	30004610 Dynamic Testing Setup ----------	26
Figure 4.	30004610 Total System Block Diagram -------	27

1. TEST CONDITIONS

The following test conditions shall apply unless otherwise specified.

1.1 Test Fluid

MIL-H-5606 hydraulic fluid shall be used.

1.2 Fluid Filtration

Filtration of 15 micron absolute shall be provided in each supply pressure.

1.3 Temperature

Ambient (room): $+85 \pm 15°F.$
Fluid: $+100 \pm 20°F$

1.4 Pressure

Supply (P1, P2 and P3): 2200 ± 50 PSIG
Return (R1, R2 and R3): 50 ± 50 PSIG

1.5 Electrical

Servovalve:	16 ma (rated)
Solenoid Valve:	28 VDC
Failure Indicator Switch:	28 VDC

1.6 Measuring Equipment

Each instrument or measuring device to be calibrated with calibration records kept and maintained.

1.7 Sequence of Testing

Testing sequence shall comply to Paragraph 2.

2. FUNCTIONAL TESTS

The following functional test procedure for testing of the 30004610 Thrust Vector Control Servoactuator includes, for each test, the test requirement and required results. Reference is made to the following:

a. Figure 1. 30004610 Hydraulic Test Setup
b. Figure 2. 30004610 Electrical Test Setup
c. Figure 3. 30004610 Dynamic Test Setup
d. Figure 4. 30004610 Total System Block Diagram

Unless otherwise specified: Control loop hydraulic logic System 1 is to be used for all system checking and adjustments and all components of Systems 1 and 2 are to be energized. System pressure 1 is to be used for all checking and adjustments.

2.1 Component Acceptance Test

2.1.1 3-Stage Servovalve Adjustment

Prior to complete 30004610 unit assembly, it is necessary to preassemble the second stage servovalve and feedback assembly (Ref: 240570 drawing) using the armature assembly 30004053 (Ref: 30004610 drawing). Assemble the 30004053 armature assembly and adjust its position on the 240570 second stage

2.1.1 (Continued)

servovalve and feedback assembly (using an appropriate assembly test fixture) such that each nozzle spacing is equivalent. Test per assembly test and instruction procedure for 30002150 subassembly 240570.

After nozzle adjustment and testing is completed, assemble the 240570 onto the 30004610 unit and pressurize to 2200 ± 50 PSIG. Adjust the position of the 240570 such that the third stage spool is centered and no actuator piston movement is detected.

2.2 Unit Assembly and Physical Inspection

Requirement: Assemble the unit, utilizing the control loop hydraulic logic module complying to 33000660-3(30004610 Sheet 2), and carefully and thoroughly examine for compliance to drawing 30004610.

Results: Assembly Date 2Q72 (HR 97)

Packing Cure Date 2Q71 (JJ)

2.3 Preliminary Total System Operation

2.3.1 Control Loop Hydraulic Logic System 1 Operation (Prelim.)

To check for proper total system operation and prior to any adjustments, set up the unit per hydraulic test setup Figure 1. Pressurize Systems 1, 2 and 3 and energize logic System 1 and 2 solenoid valves and servovalves. Electrically set up the system per the system block diagram Figure 4. Slowly cycle command input 1 and note the actuator movement. Actuator shall extend and retract upon command input.

Results: Actuator Movement EXTENDS & RETRACTS

2.3.2 Control Loop Hydraulic Logic System 2 Operation (Prelim.)

With System 2 pressurized and system 1 depressurized and with the solenoid valves and servovalves energized, slowly cycle command input 2. The actuator shall extend and retract upon command input.

Results: Actuator Movement EXTENDS & RETRACTS

2.4 Potentiometer Resistance

2.4.1 Fixed Resistance

Check the potentiometer resistance between pins A and C and between E and G. The resistance shall be 7000 ± 700 ohms

Results: A and C 7500 ohms
E and G 7200 ohms

2.5 Mechanical Null and Centering Mechanism

With the control loop hydraulic logic module removed from the unit, remove the actuator mid-position lock and block the logic P1, R1, P2 and R2 hydraulic lines. Referring to drawing 30004610 hydraulic schematic (Sheet 3), pressurize the unit and allow the internal linkage to null the unit through the unit internal feedback system. Adjust as necessary the 3 stage servovalve feedback spring pickup and the secondary actuator sleeve position (per drawings 30004610 and 30004045) to provide for actuator mechanical null equivalent to that when in the mid-position lock position. Shimming and adjustment instructions:

a) Servovalve feedback spring: internal linkage pickup (tiedown) point may be varied as required by shimming or repositioning.

b) Secondary actuators: Shimming of only one secondary actuator is required to null the unit since each actuator is independently spring centered.

With the dial indicators, measure displacement of the piston from the mid-stroke locked position. Mechanical input can be applied through an access plug on the secondary actuators opposite the centering springs. Apply a mechanical input to the secondary actuators to move the piston extend and retract. Re-check mechanical null return for proper operation of the automatic piston centering mechanism.

2.5 (Continued)

The piston shall always return to within 1.0 percent (± 0.057 inch) of mid-stroke locked position. This test shall be performed at the rated system pressure of 2200 ± 50 PSIG and dial indicators shall be setup per Figure 2.

Results: Centering .050 AT OIL & AMBIENT OPER. TEMP

2.6 Secondary Actuator LVDT Adjustment

With mechanical null adjustment completed, null adjust the logic LVDT probe at the mechanical null position (prior to attachment of the control loop hydraulic logic module). Null voltage shall be 15 millivolts max.

Null Voltage 6.0 mv

2.7 Complete System Operation

The complete system, 30004610 unit with the control loop hydraulic logic module assembled as described, shall be tested under the following logic system conditions:

a) Logic System 1 Active - System 2 Standby (on)

b) Logic System 2 Active - System 1 Failed

2.7.1 Control Loop Hydraulic System 1 Active - System 2 Standby (on)

Unless otherwise specified during all testing, logic system 1 active - system 2 standby, systems

1 and 2 to be pressurized to 2200 ±50 PSIG and all electrical components to be energized. Logic system, through command input 1, is to be closed loop with a servoamplifier gain of 54.0 ma/v and LVDT demodulator gain of 3.40 v/in. Use actuator piston potentiometer element pins "A", "B", "C" and "D" only for tests. All test setups to be per Figure 3 (dynamic testing with an inertia load).

Test data for all failure switching transient tests shall be recorded on a Sanborn continuous recording device and shall include the following:

(1) Command Input Voltage

(2) LVDT Output Voltage

(3) Actuator Potentiometer Position

(4) Engine Potentiometer Position

(5) System 1 Failure Indicator Switch

(6) System 2 Failure Indicator Switch

(7) Actuator Pressure Transducer

Calibration for each plot shall be indicated.

2.7.1.1 Servovalve Phasing (Polarity)

Requirement: Apply approximately +5 ma to pin "A" of the System 1 active servovalve with the system open loop. The actuator shall move in the retract direction.

Results: Direction RETRACT (HR 3/7)

Apply approximately +5 ma to pin "B" of the System 1 active servovalve with the system open loop. The actuator shall move in the extend direction.

Results: Direction EXTEND (HR 3/7)

2.7.1.2 Linearity and Hysteresis

Requirement: Set up the unit per Figure 2 and such that the x-y recorder records actuator potentiometer position on the y-axis and command input 1 voltage on the x-axis. Set the System 1 active polarity such that the extend position of the actuator piston is recorded in the third quadrant of the plot. Plot actuator position versus command input 1 and use command input magnitudes equivalent to 1%, 5%, 20% and 100% of the maximum actuator piston stroke.

Results: Plots (3/7)

2.7.1.3 Threshold

Requirement: Determine the amount of threshold in both directions at the null position, within 10% of fully extended and within 10% of fully retracted. By slowly varying command input 1 voltage, approach the point where threshold is to be checked After holding the voltage constant and allowing the piston to stop, slowly adjust the voltage such that reverse motion occurs. The threshold is the percent of voltage for piston motion to occur to that for a full piston stroke from mechanical null (mid-stroke lock position).

Results:
Motion to occur 1.550 vdc
Full stroke 1.560 vdc EXTEND
Threshold .64 % HR 97

2.7.1.4 Frequency Response

Requirements: Run a frequency response test with the unit closed loop and set up per Figure 3 at frequency levels from 0.1 to 10 Hz. Use a frequency analyzer with command input 1 magnitude of 1% of maximum actuator stroke. Plot secondary actuator LVDT versus command and actuator potentiometer versus command. Identify and measure amplitude ratio and phase angle for each of the two plots.

Results: Plots HR 97

2.7.1.5 Hydraulic Failure Logic

2.7.1.5.1 Active Servovalve Failure Switching Current

Requirement: With stystem 1 set up open loop and the active and monitor 1 servovalves at null, slowly increase positive current to the active servovalve until the failure indicator switch opens. Repeat with in increasing negative current. Current shall be 5.5 ± 1.0 ma.

Results: (+) Current 4.80 ma
(-) Current 4.50 ma (HR 97)

2.7.1.5.2 Monitor Servovalve Failure Switching Current

Requirement: Repeat procedure per paragraph 2.7.1.5.1 for the monitor 1 servovalve.

Results: (+) Current 4.20 ma (HR 97) MARIFICATION ONLY
(-) Current 5.20 ma

2.7.1.5.3 Hardover Active Servovalve Failure Switching Transient

Requirement: Adjust all four servovalve servo-amp command input voltage signals such that, when operating on either system 1 or system 2 active servo-valve with zero command, the act-uator piston poetntiometer is equivalent within 1% of maximum

2.7.1.5.3 (Continued)

piston stroke from mechanical null (±.057 inch). While operating the unit at .5 Hz (sine wave), apply a positive and negative step input voltage signal to the servoamplifier 2 (active servovalve 1) respectively first in extend and then in retract portion of the stroke cycle (four separate plots). Record, on a Sanborn recording device, data as shown in para 2.7.1. Failure switching transient is defined as the time required from active servovalve 1 failure (indicated by pressure switch activation) to switch in of active servovalve 2 (indicated by resumption of commanded LVDT position).

Results: Switching Transient Plots (HR 97)

2.7.1.5.4 Hardover Monitor Servovalve Failure Switching Transient

Requirement: Repeat procedure in paragraph 2.7.1.5.3 while applying a step input voltage signal to the servoamp 1 (monitor servovalve 1).

Results: Switching Transient Plots (HR 97)

2.7.1.5.5 Pressure 1 Switching Transient - P2 and P3 Standby

Requirement: Adjust all four servovalve servoamp command input voltage signals such that, when operating on either system 1 or system 2 active servovalve with zero command, the actuator piston potentiometer position is equivalent within 1% of maximum piston stroke from mechanical null (± .057 inch). While operating the unit at .5 Hz (sine wave), rapidly reduce supply pressure 1 to zero (at the supply selector valve assembly). Record, on a Sanborn recording device, data as shown in para 2.7.1. Failure switching transient is defined as the time required from pressure 1 loss (indicated by the actuator pressure transducer) to switch in of pressure 2 (indicated by resumption of commanded LVDT position by active servovalve 2).

Results: Switching Transient Plots

2.7.2 Control Loop Hydraulic Logic System 2 Active - System 1 Failed

Unless otherwise specified during all testing, with logic system 2 active - system 1 failed, system 1 to be pressurized to 2200 ±50 PSIG and all system 2 electrical components to be energized. System 1 to be depressurized and/or de-energized. Logic system 2, through command input 2, is to be closed loop with a servo amplifier gain of 54.0 ma/v and LVDT ÷ demodulator gain of 3.40 v/in. Failure switching transient recorded data shall be as defined in para 2.7.1.

2.7.2.1 Servovalve Phasing (Polarity)

Requirement: Apply approximately +5 ma to pin "A" of the system 2 active servovalve with the system open loop. The actuator shall move in the retract direction.

Results: Direction RETRACT HR 97

Apply approximately +5 ma to pin "B" of the system 2 active servovalve with the system open loop. The actuator shall move in the extend direction.

Results: Direction EXTEND HR 97

2.7.2.2 Linearity and Hysteresis

Requirement: Setup the unit per Figure 2 and such that the x-y recorder records actuator potentiometer position on the y-axis and command input 2 voltage on the x-axis. Set the system 2 active polarity such that the extend position of the actuator piston is recorded in the third quadrant of the plot. Plot actuator position versus command input 2 and use command input magnitudes equivalent to 1%, 5%, 20% and 100% of the maximum actuator piston stroke.

Results: Plots (HR 97)

2.7.2.3 Threshold

Requirement: Determine the amount of threshold in both directions at the null position, within 10% of fully extended and within 10% of fully retracted. By slowly varying command input 2 voltage, approach the point where threshold is to be checked. After holding the voltage constant and allowing the piston to stop, slowly adjust the voltage such that reverse motion occurs. The threshold is the percent of voltage for piston motion to occur to that for a full piston stroke from

2.7.2.3 (Continued) mechanical null (mid-stroke lock position).

Results: Motion to occur 1.569 vdc
Full stroke 1.582 vdc EXTEND
Threshold .82 % HR 97

2.7.2.4 Frequency Response

Requirement: Run a frequency response test with the unit closed loop and set up per Figure 3 at frequency levels from 0.1 to 10 Hz. Use a frequency analyzer with command input 1 magnitude of 1% of maximum actuator stroke. Plot secondary actuator LVDT versus command and actuator potentiometer versus command. Identify and measure amplitude ratio and phase angle for each of the two plots.

Results: Plots HR 97

2.7.2.5 Hydraulic Failure Logic

2.7.2.5.1 Active Servovalve Failure Switching Current

Requirement: With system 2 set up open loop and the active and monitor 2 servovalves at null, slowly increase positive current to the active servovalve until the failure indicator switch opens. Repeat with an increasing negative current. Current shall be 5.5 ± 1.0 ma.

2.7.2.5.1 (Continued)

Results: (+) Current 4.80 ma
(-) Current 5.20 ma

2.7.2.5.2 Monitor Servovalve Failure Switching Current

Requirement: Repeat procedure per paragraph 2.7.2.5.1 for the monitor 2 servovalve.

Results: (+) Current 5.00 ma
(-) Current 5.80 ma

2.7.2.5.3 Hardover Active Servovalve Failure Switching Transient

Requirement: Adjust command input voltage signals to servo amp 3 (active servovalve 2) and servo amp 4 (monitor servovalve 2) such that, when operating on active servovalve 2 with zero command, the actuator piston potentiometer is equivalent to 1% of maximum piston stroke from mechanical null (±.057 inch). While operating the unit at .5 Hz (sine wave), apply a positive and negative step input voltage signal to the servo-amp 2 (active servovalve 2) respectively first in extend and then retract portion of the stroke cycle (four separate plots). Record, on a Sanborn recording device, data as shown in para 2.7.1. Failure switching transient is defined as the time required from active servovalve 2 failure (indicated by pressure switch

2.7.2.5.3 (Continued) activation) to switch in of stand-by pressure 3 and return of LVDT to mechanical null position.

Results: Switching Transient Plots (HR 97)

2.7.2.5.4 Hardover Monitor Servovalve Failure Switching Transient

Requirement: Repeat procedure in paragraph 2.7.2.5.3 while applying a step input voltage signal to the servoamp 4 (monitor servovalve 2).

Results: Switching Transient Plots (HR 97)

2.7.2.5.5 Pressure 1 Switching Transient - P2 and P3 Standby (on)

Requirement: With logic system 1 in the failed mode (by de-energizing all system 1 electrical components or applying a hardover command signal to active servovalve 1), pressurize all supply pressures 1, 2 and 3. Adjust command input voltage signals to servoamp 3 (active servovalve 2) and servoamp 4 (monitor servovalve 2) such that, when operating on active servovalve 2 with zero command, the actuator piston potentiometer is equivalent to 1% of maximum piston stroke from mechanical null (±.057 inch). While operating the unit at .1 Hz (sine wave), rapidly reduce pressure 1 to zero (at the supply selector

2.7.2.5.5 (Continued) valve assembly). Record, on a Sanborn recording device, data as defined in para 2.7.1. Failure switching transient is defined as the time required from pressure 1 loss (indicated by actuator pressure transducer) to switch in of pressure 2 (resumption of LVDT commanded position).

Results: Switching Transient Plot (HR 97)

2.7.2.5.6 Pressure 2 Switching Transient - P1 Failed and P3 Standby (on)

Requirement: With P1 failed repeat procedure per paragraph 2.7.2.5.5 while rapidly reducing supply pressure 2. Switching transient is defined as the time required from pressure 2 loss (indicated by the actuator pressure transducer) to switch in of standby pressure 3 and return of LVDT to mechanical null position.

Result: Switching Transient Plot (HR 97)

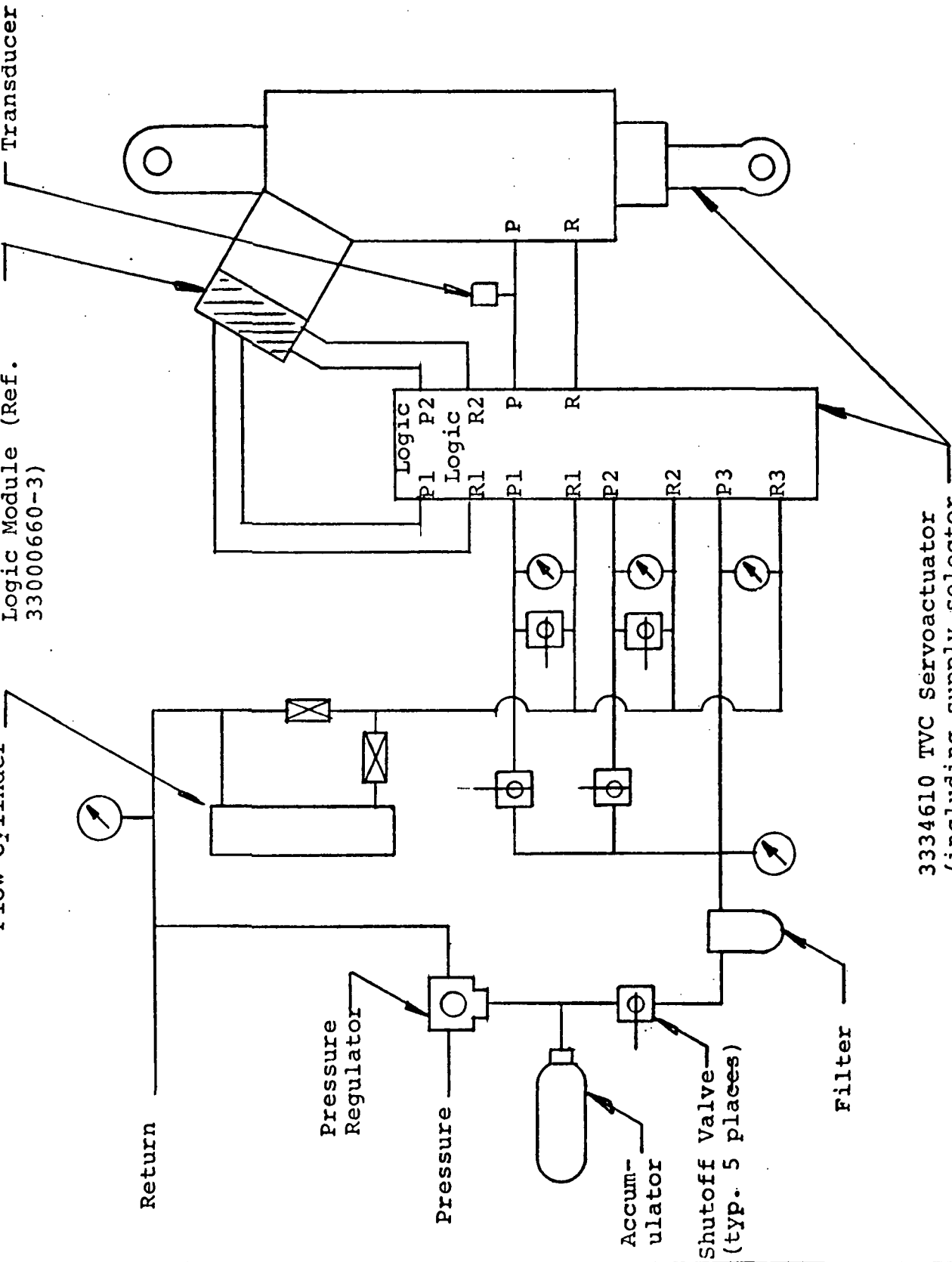


FIGURE 1 - 30004610 HYDRAULIC TEST SETUP

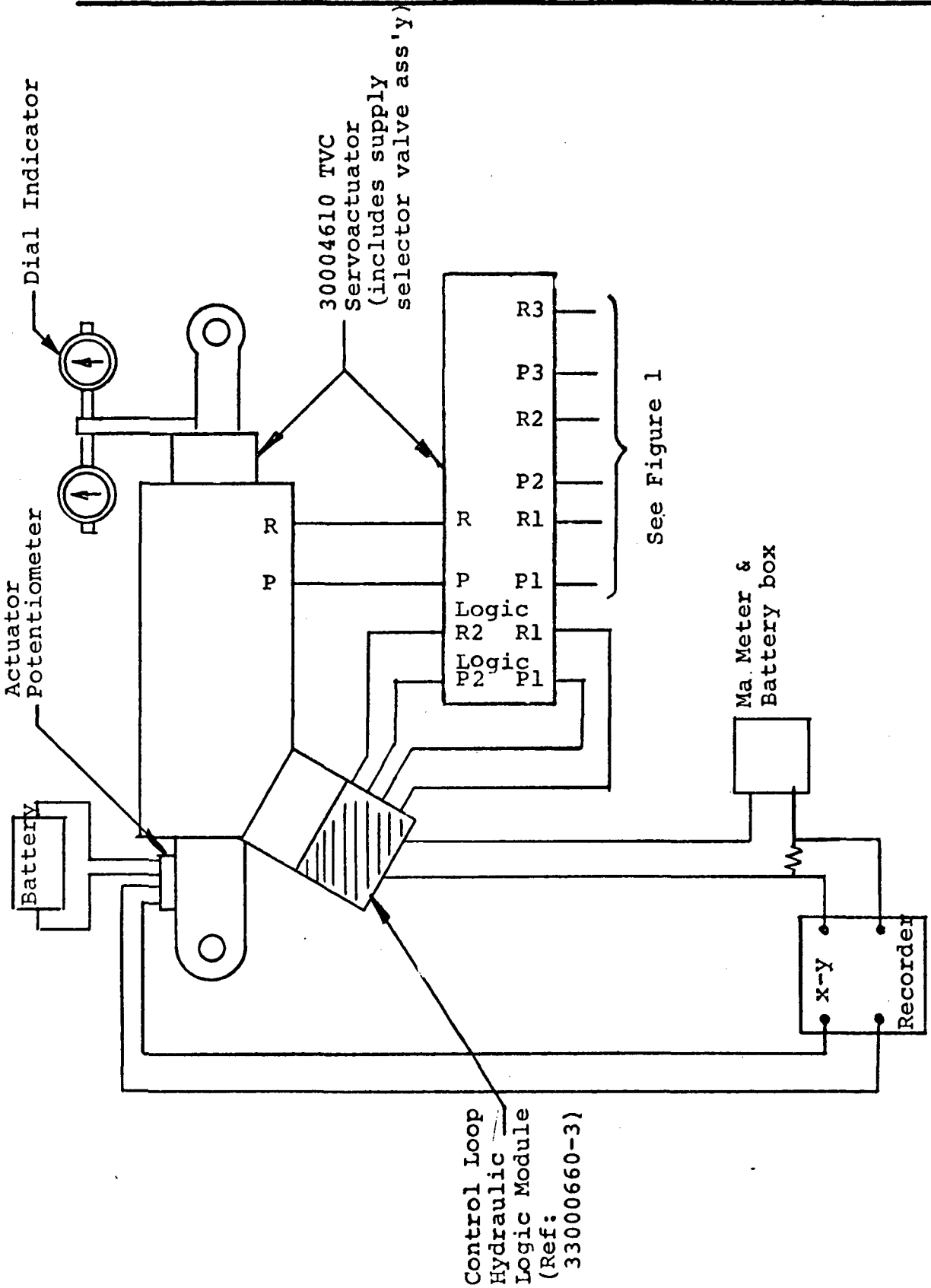


FIGURE 2 - 30004610 ELECTRICAL SETUP

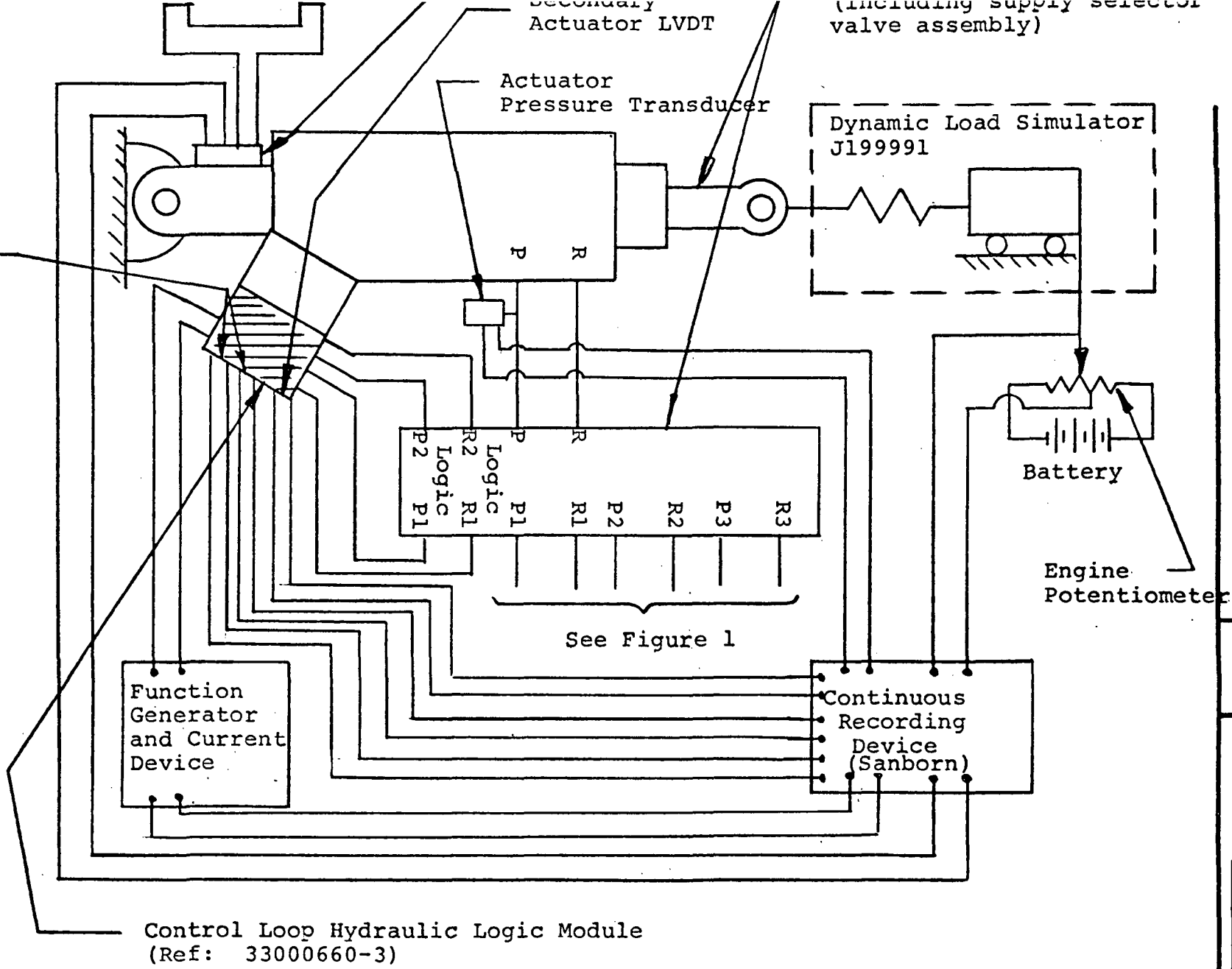
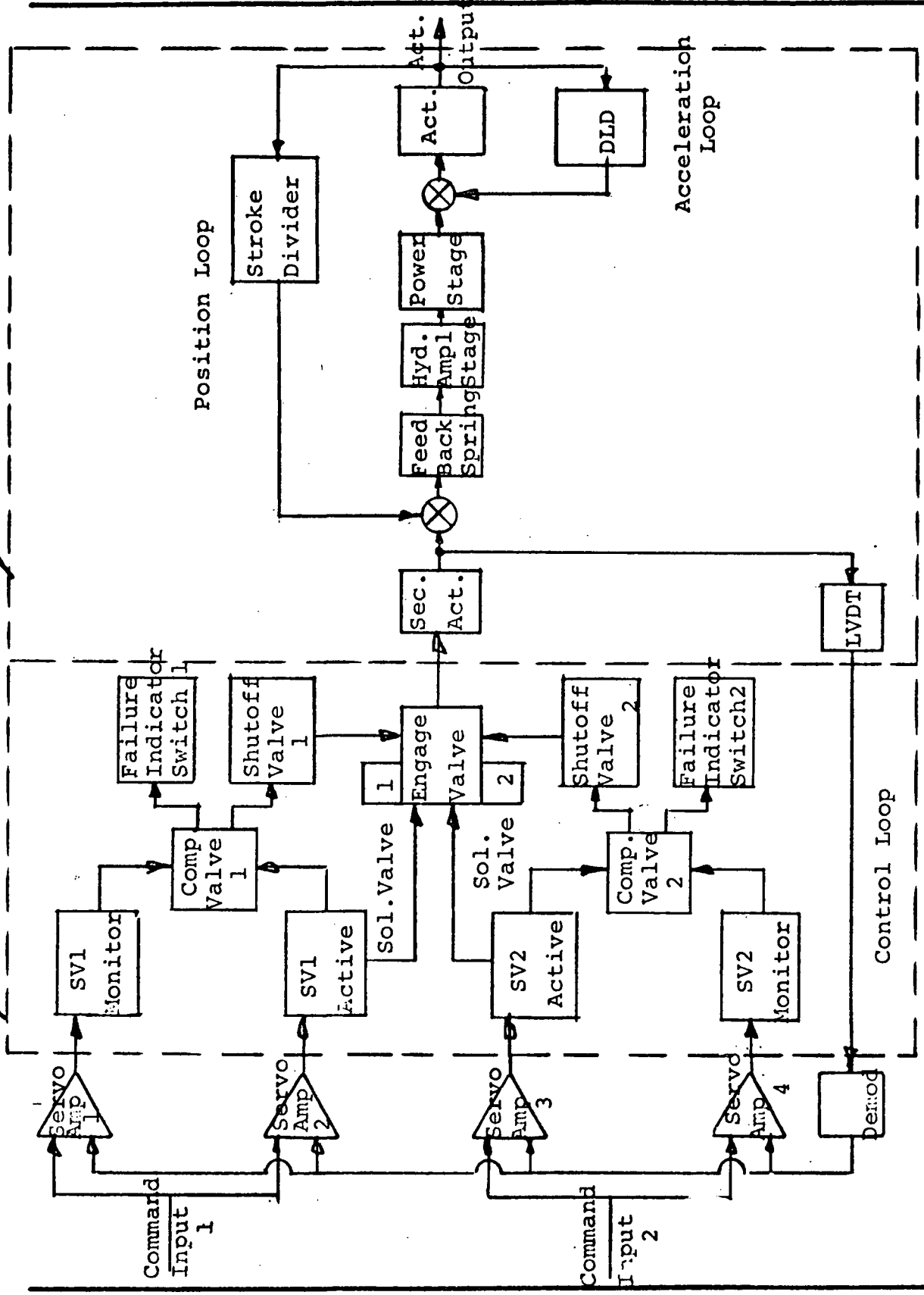


FIGURE 3 - 30004610 DYNAMIC TEST SETUP



NOTE: SV - Electrohydraulic Servovalve

FIGURE 4 - 30004610 TOTAL SYSTEM BLOCK DIAGRAM

GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company
A Division of

PART NO. 3000 4610
SERIAL NO. 001
PRESSURE 2200 PSI
OIL TEMP. ____ °F
TEST STAND NO. ____
DATE 5-10-72
OPERATOR [illegible]

1.90 OF STROKE

TEST PROCEDURE
HR 13700065
PARA. 2.7.1.2
SYSTEM 1 ACTIVE

RETRACT

EXTEND

COMMAND

10 VOLTS/IN

ACTUATOR POSITION .25"/IN

EL 009

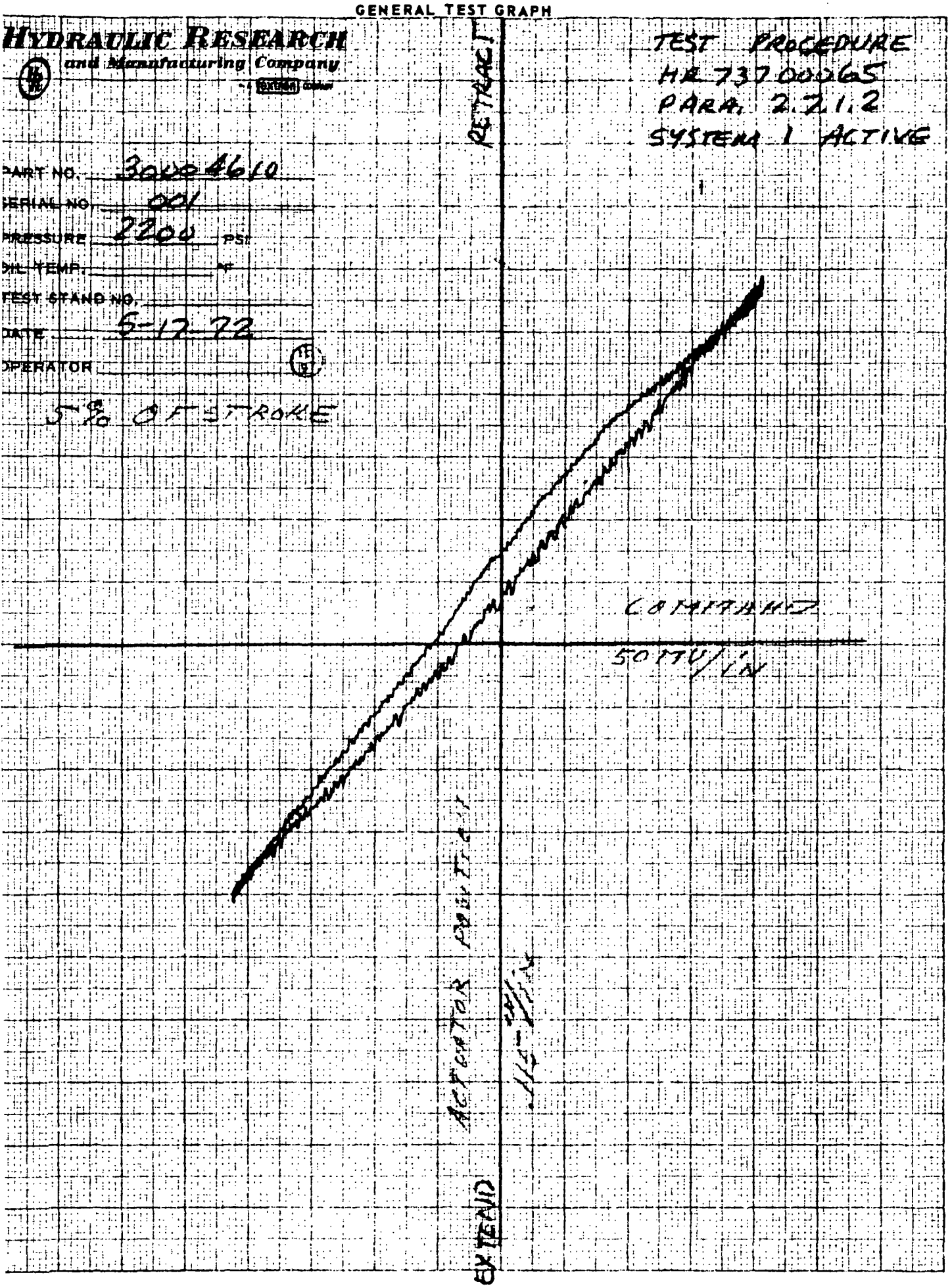
GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company

TEST PROCEDURE
HR 737 000 65
PARA. 2.7.1.2
SYSTEM 1 ACTIVE

PART NO. 30020 4610
SERIAL NO. 001
PRESSURE 2200 PSI
OIL TEMP. ____ °F
TEST STAND NO. ____
DATE 5-12-72
OPERATOR ____

5% OF STROKE



EL 009

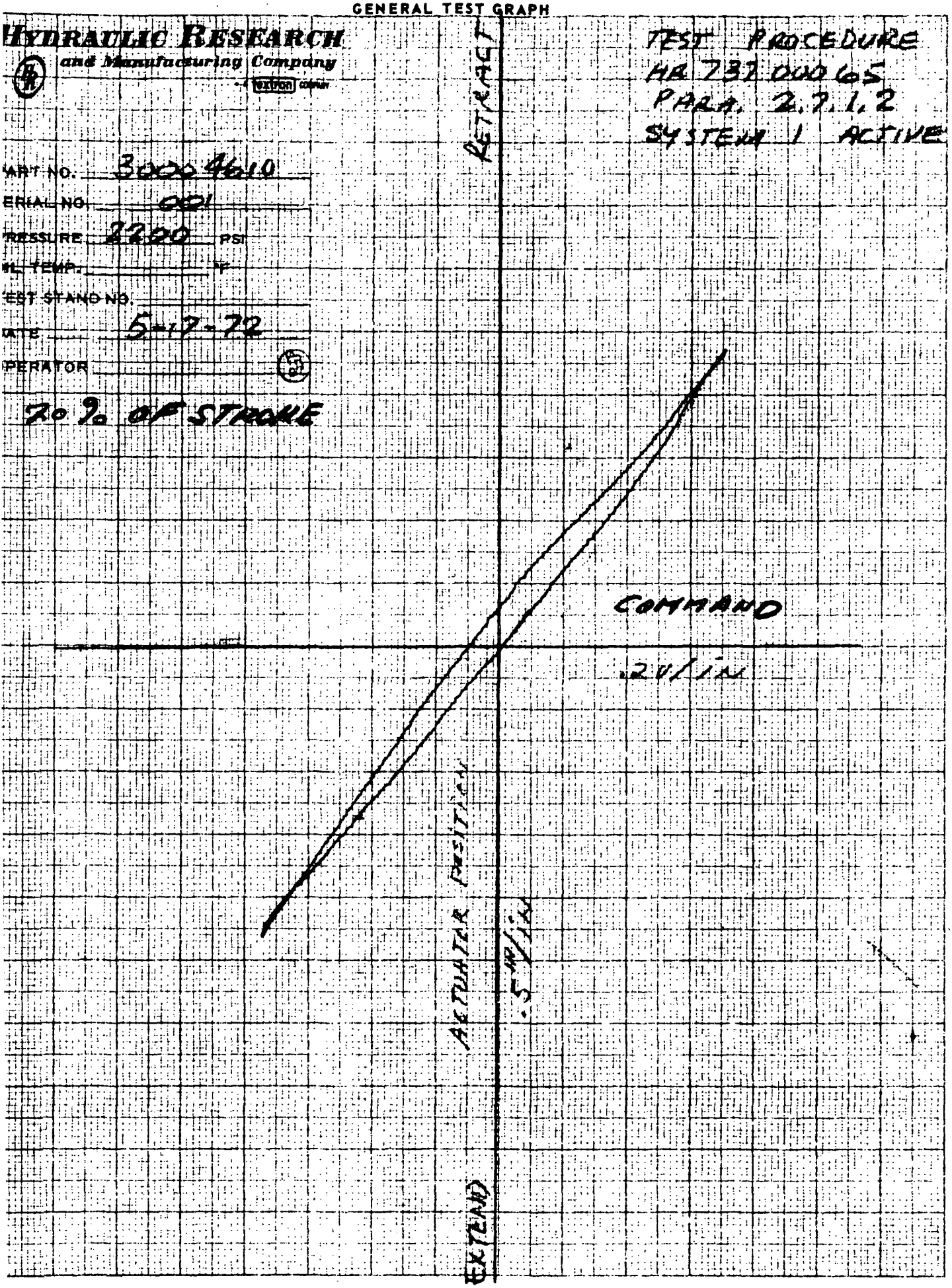
GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company
A Textron company

PART NO. 3022 4610
SERIAL NO. 001
PRESSURE 2220 PSI
OIL TEMP. ____ °F
TEST STAND NO. ____
DATE 5-17-72
OPERATOR ____

TEST PROCEDURE
HR 731 000 65
PARA. 2.7.1.2
SYSTEM 1 ACTIVE

20 % OF STROKE



L 009

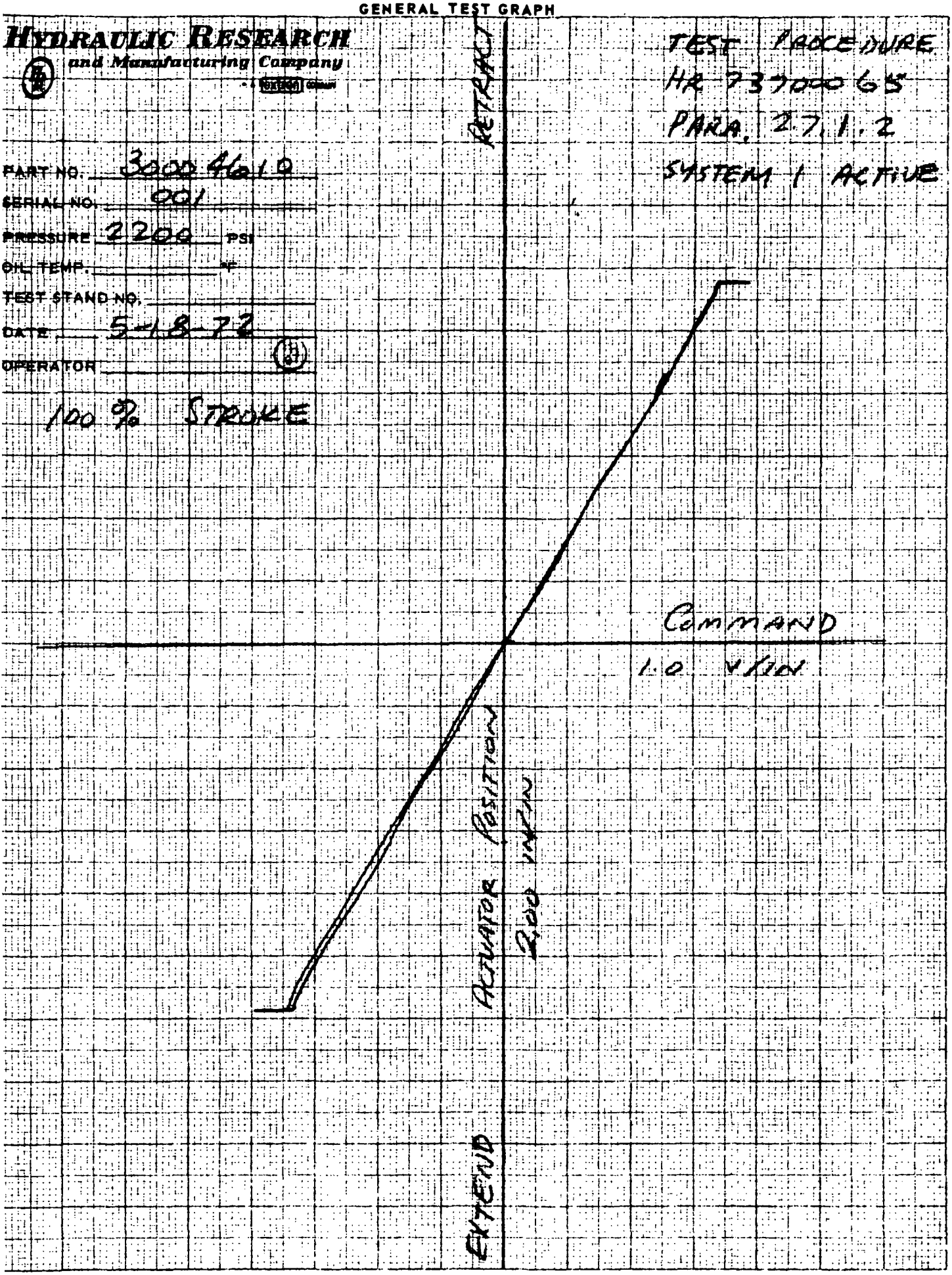
GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company

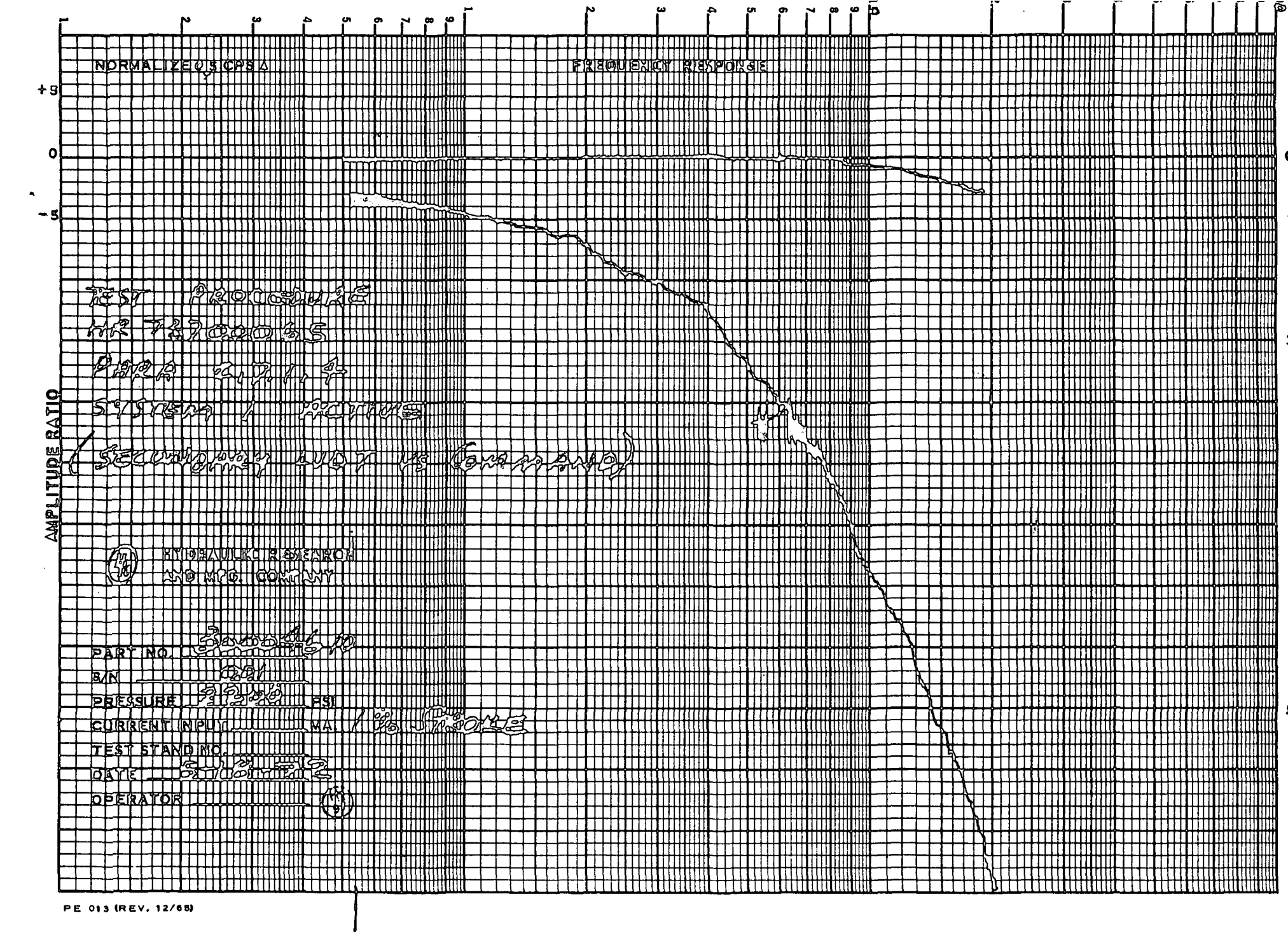
PART NO. 3000 4610
SERIAL NO. 001
PRESSURE 2200 PSI
OIL TEMP. ____ °F
TEST STAND NO. ____
DATE 5-18-72
OPERATOR ____

100 % STROKE

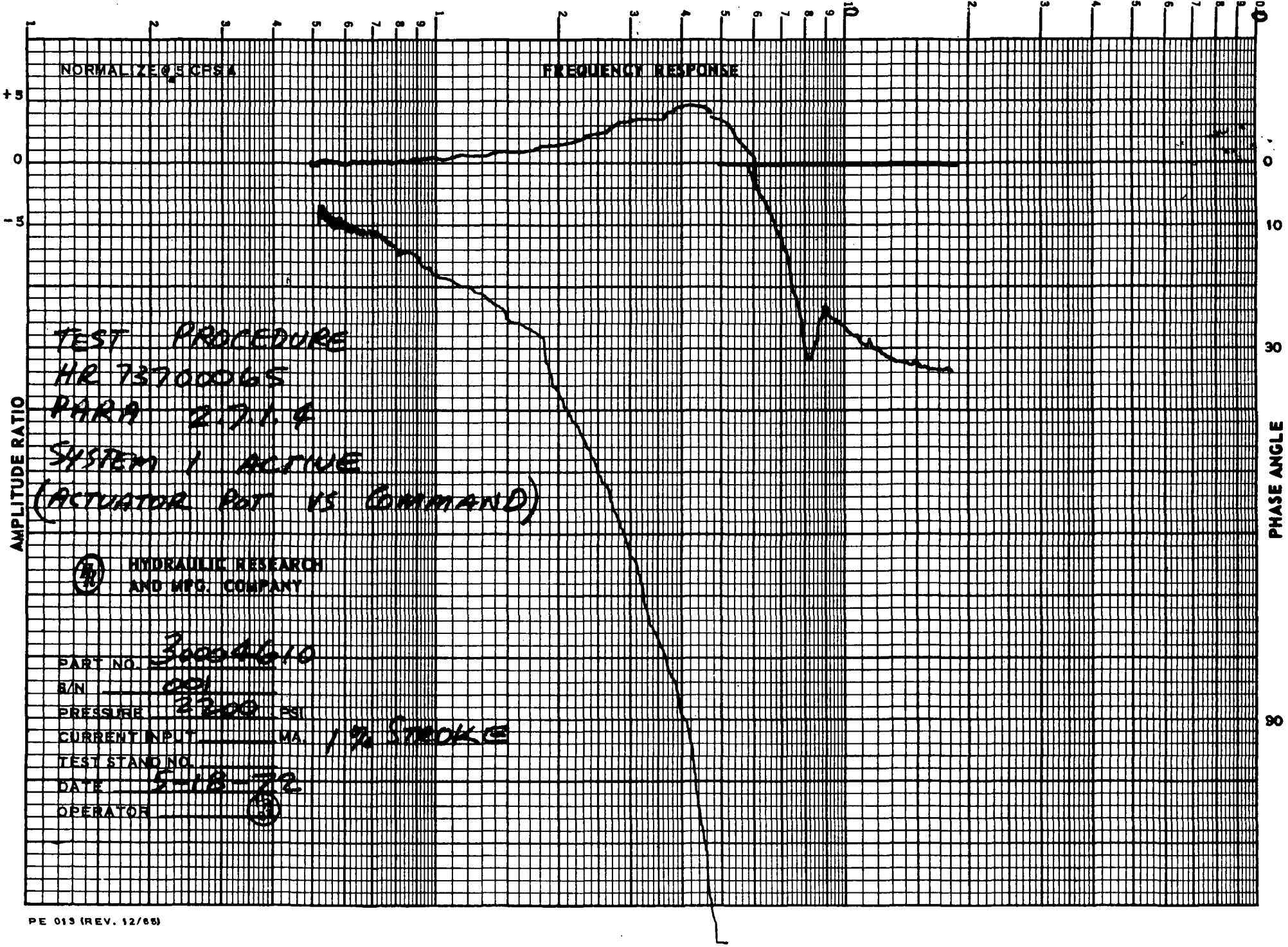
TEST PROCEDURE
HR 7370065
PARA. 27.1.2
SYSTEM 1 ACTIVE



EL 009



PE 013 (REV. 12/65)



PE 013 (REV. 12/65)

(REF)
.05 mv/div DIAL RANGE

(REF)
.05 mv/div DIAL RANGE

(REF)
.2 mv/div DIAL RANGE

(REF)
.2 mv/div DIAL RANGE

(REF)
.2 mv/div DIAL RANGE

NOTE: mv/div DIAL RANGE VALUES HYDRAULIC RESEARCH & MFG CALIBRATION USE ONLY.

CALIBRATION SHEET (ZERO POSITIONS)

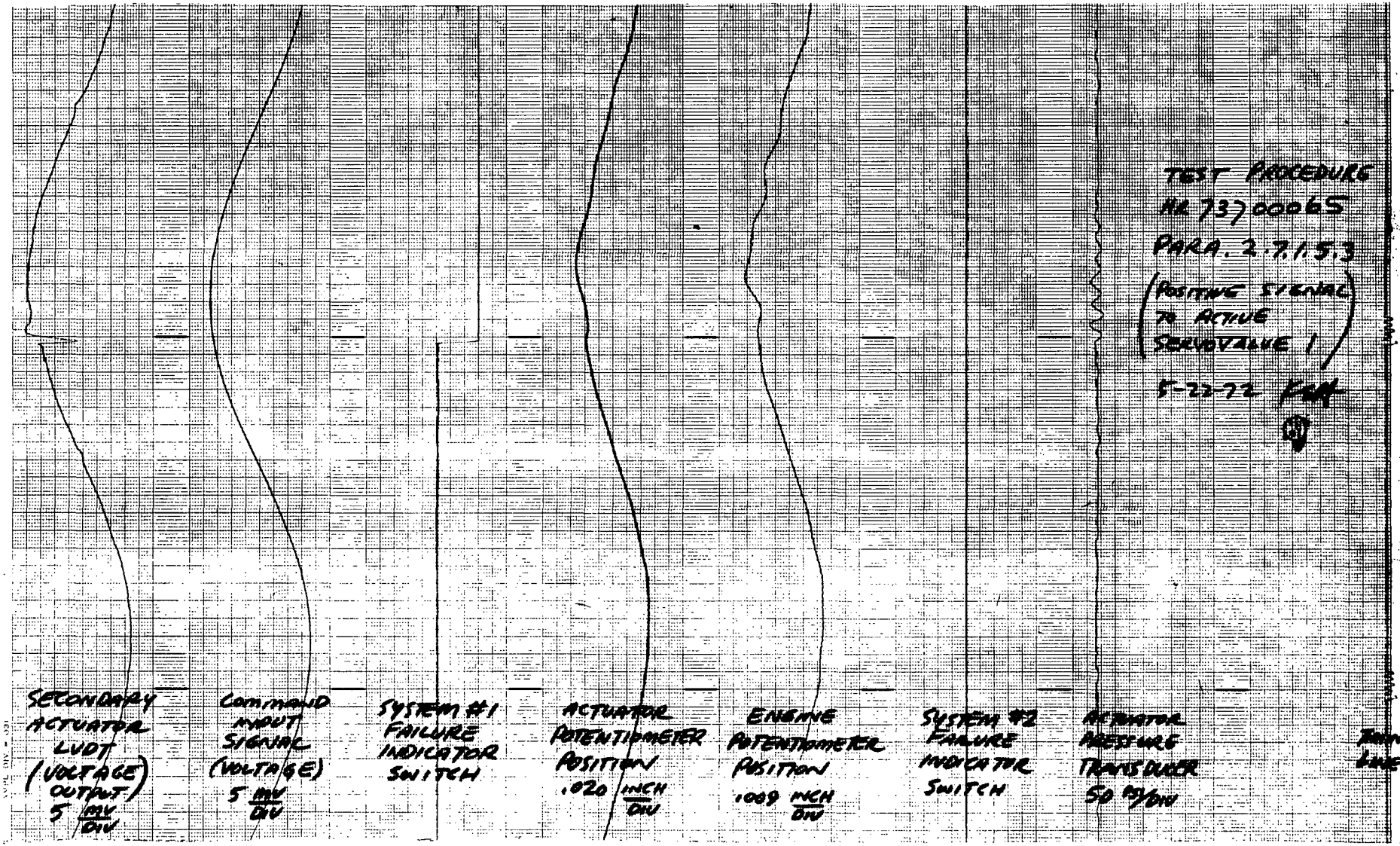
5-22-72
KSH

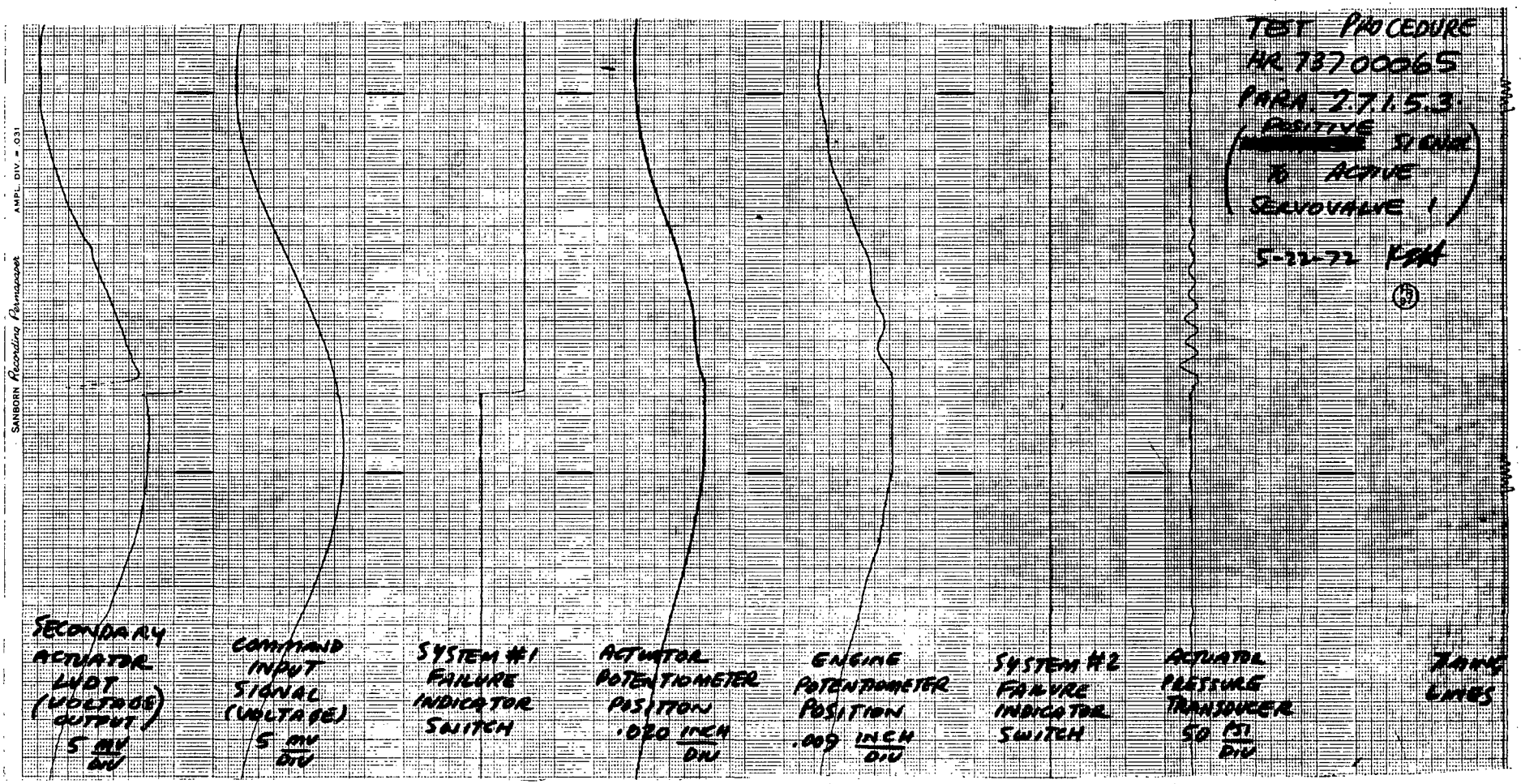
(37)

DIV →←

SECONDARY ACTUATOR LVDT (VOLTAGE) OUTPUT 5 mv/div.	COMMAND INPUT SIGNAL (VOLTAGE) INPUT 5 mv/div.	SYSTEM #1 FAILURE INDICATOR SWITCH (ON-OFF)	ACTUATOR POTENTIOMETER POSITION .020 inch/div.	ENGINE POTENTIOMETER POSITION .009 inch/div.	SYSTEM #2 FAILURE INDICATOR SWITCH (ON-OFF)	ACTUATOR PRESSURE TRANSDUCER 50 psi/div.	TIMING LINES (10 SEC INTERVALS)

AMHL DIV. - 031


TEST PROCEDURE
NR 737 00065
PARA. 2.7.1.5.3
(POSITIVE SIGNAL TO ACTIVE SERVOVALVE)
5-22-72
SECONDARY ACTUATOR LVDT (VOLTAGE) OUTPUT 5 MV/DIV
COMMAND INPUT SIGNAL (VOLTAGE) 5 MV/DIV
SYSTEM #1 FAILURE INDICATOR SWITCH
ACTUATOR POTENTIOMETER POSITION .020 INCH/DIV
ENGINE POTENTIOMETER POSITION .009 INCH/DIV
SYSTEM #2 FAILURE INDICATOR SWITCH
ACTUATOR PRESSURE TRANSDUCER 50 PSI/DIV
TIMING LINES


TEST PROCEDURE
AR 7370006S
PARA. 7.7.1.5.3.
(POSITIVE STEP TO ACTIVE SERVOVALVE)
5-22-72 FAH
(39)
SECONDARY ACTUATOR LVDT (VOLTAGE OUTPUT) 5 MV/DIV
COMMAND INPUT SIGNAL (VOLTAGE) 5 MV/DIV
SYSTEM #1 FAILURE INDICATOR SWITCH
ACTUATOR POTENTIOMETER POSITION .020 INCH/DIV
ENGINE POTENTIOMETER POSITION .005 INCH/DIV
SYSTEM #2 FAILURE INDICATOR SWITCH
ACTUATOR PRESSURE TRANSDUCER 50 PSI/DIV
TIME LINES

SANBORN Recording Permapac

TEST PROCEDURE
HR 23700065
PARA 2.7.1.5.3

[redacted] NEGATIVE SIGNAL TO ACTIVE SERVOVALVE 1 /

5-22-72 KH

LVDT
5 MV/DIV

COMMAND
5 MV/DIV

#1 SWITCH

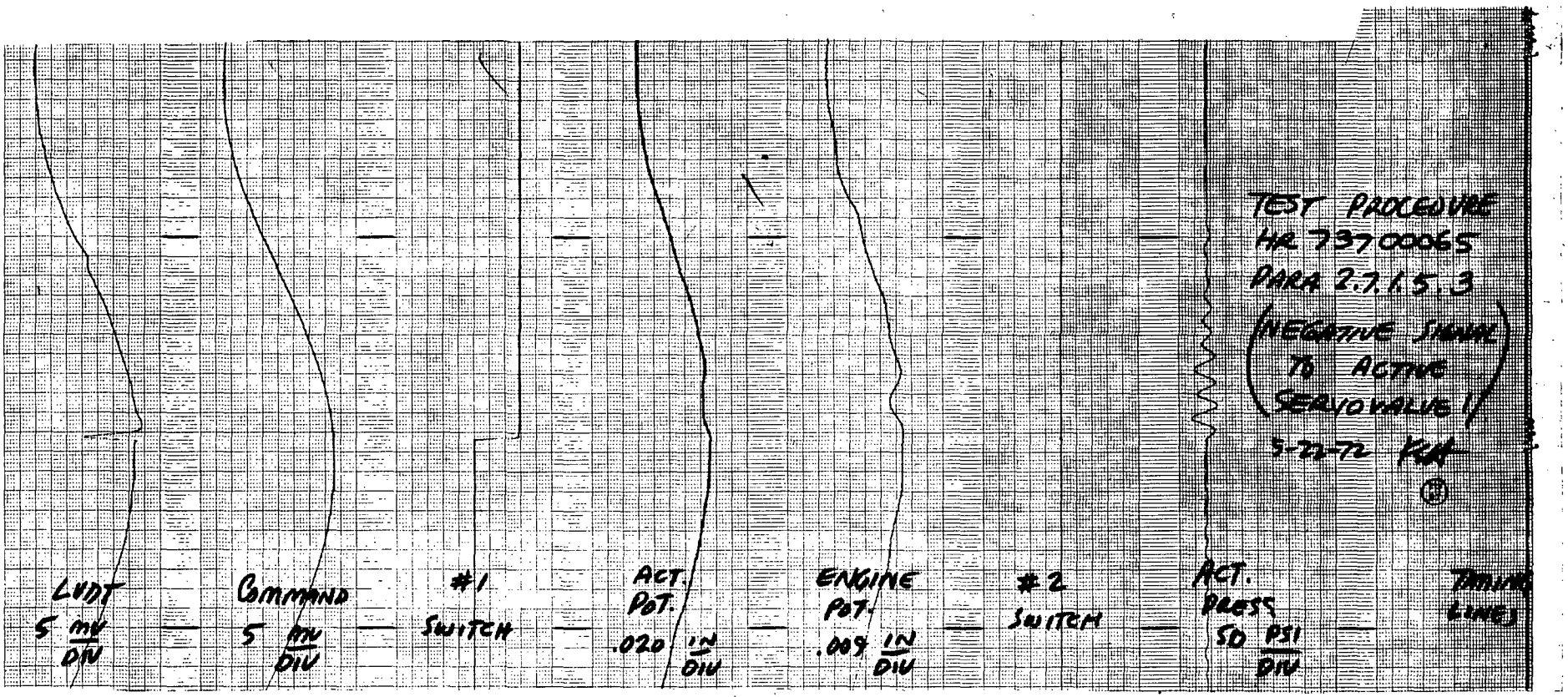
ACT. POT.
.1020 IN/DIV

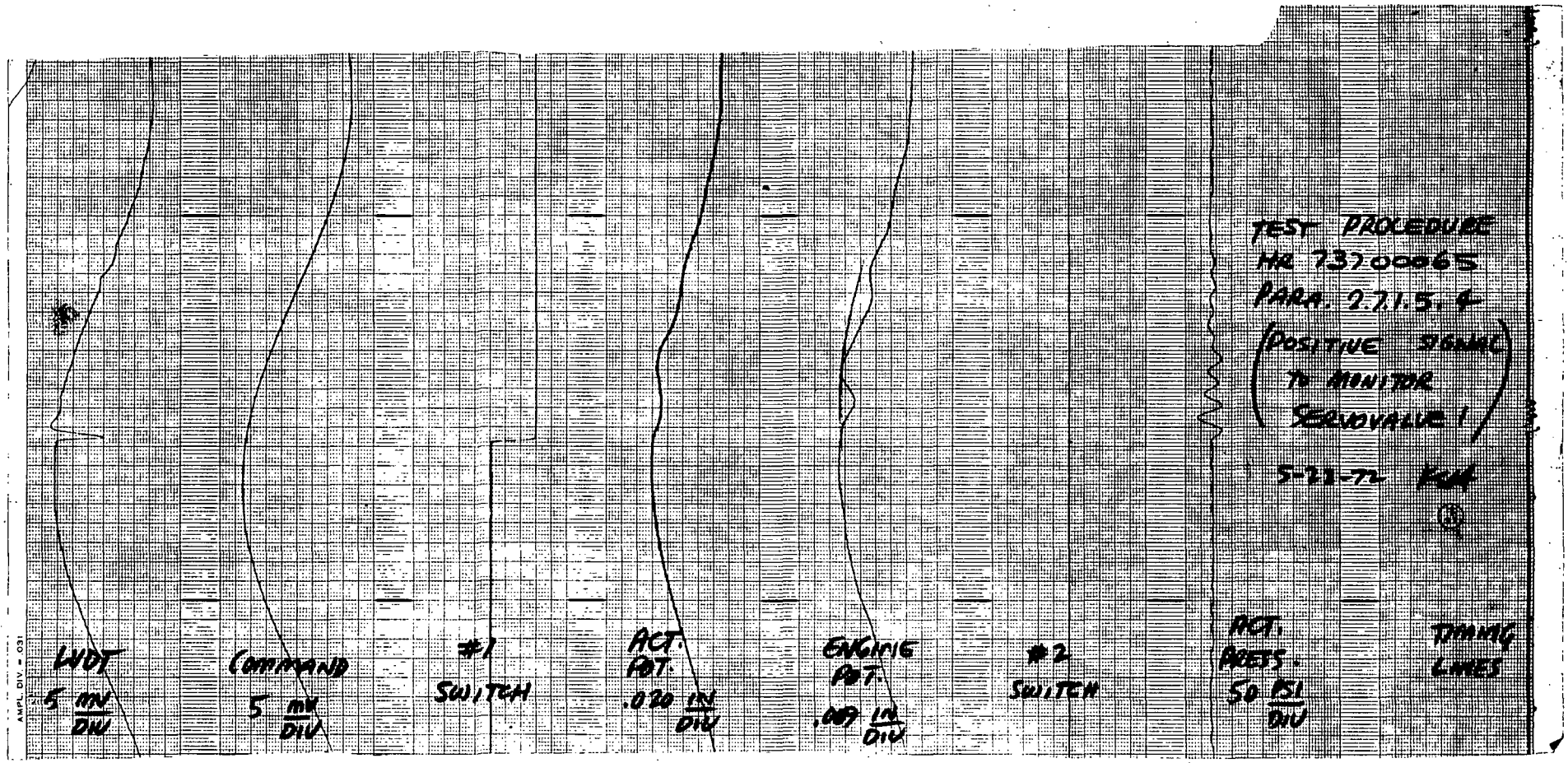
ENGINE POT.
.009 IN/DIV

#2 SWITCH

ACT. PRESS.
50 PSI/DIV

TIMING LINES


TEST PROCEDURE
HR 737 00065
PARA 2.7.1.5.3
(NEGATIVE SIGNAL
TO ACTIVE
SERVOVALVE I)
5-22-72 KLA
LVDT
5 MV/DIV
COMMAND
5 MV/DIV
#1
SWITCH
ACT.
POT.
.020 IN/DIV
ENGINE
POT.
.009 IN/DIV
#2
SWITCH
ACT.
PRESS
50 PSI/DIV
TIMING
LINES


TEST PROCEDURE
MR 73700065
PARA. 2.7.1.5.4
(POSITIVE SIGNAL
TO MONITOR
SERVOVALVE)
5-21-72
LVDT
5 MV/DIV
COMMAND
5 MV/DIV
#1
SWITCH
ACT.
POT.
.030 IN/DIV
ENGINE
POT.
.005 IN/DIV
#2
SWITCH
ACT.
PRESS.
50 PSI/DIV
TIMING
LINES
AMPL DIV - 031

SANBORN Recorder
TEST PROCEDURE
HR37000665
PARA. 2.7.2.5.4
(POSITIVE SIGNAL
TO MONITOR
SERVOVALVE)
5-22-74 KOK
SPOT
5 MV/DIV
COMMAND
5 MV/DIV
#1
SWITCH
ACT.
POT.
.020 IN/DIV
ENGINE
POT.
.009 IN/DIV
#2
SWITCH
ACT.
PRESS
50 PSI/DIV
TIMING
LINES

TEST PROCEDURE
HA-7370065
PARA. 2.2.1.5.4.
(USEFUL SIGNAL TO MONITOR SERVOVALVE)
5-23-72 FCH
③
LVDT
5 MV/DIV
COMMAND
5 MV/DIV
#1 SWITCH
ACT. POT.
.020 IN/DIV
ENGINE POT.
.009 IN/DIV
#2 SWITCH
ACT. PRESS.
50 PSI/DIV
TIMING LINES

SANBORN Recording Permanapen AMPL. DIV. - 031
LVDT
5 mv/div
COMMAND
5 mv/div
#1
SWITCH
ACT.
POT.
.020 mv/div
ENGINE
POT.
.009 mv/div
#2
SWITCH
ACT.
ACCEL
50 ft/div
TIMING
LINES
TEST PROCEDURE
HR 7370006S
PARA. 8.2.2.5.4
(NEGATIVE SIGNAL
TO ACTUATOR
SERVOVALVE)
5-20-72 YGM
(3)

LVDT
5 mv/div
Command
5 mv/div
#1 Switch
Act. Pot.
.020 in/div
Engine Pot.
.009 in/div
#2 Switch
Air Press
50 psi/div
Test Procedure
VAC 73700065
Para. 2.7.1.5.5.
(Pressure Failure)
5-22-73
Fail
Timing Lines

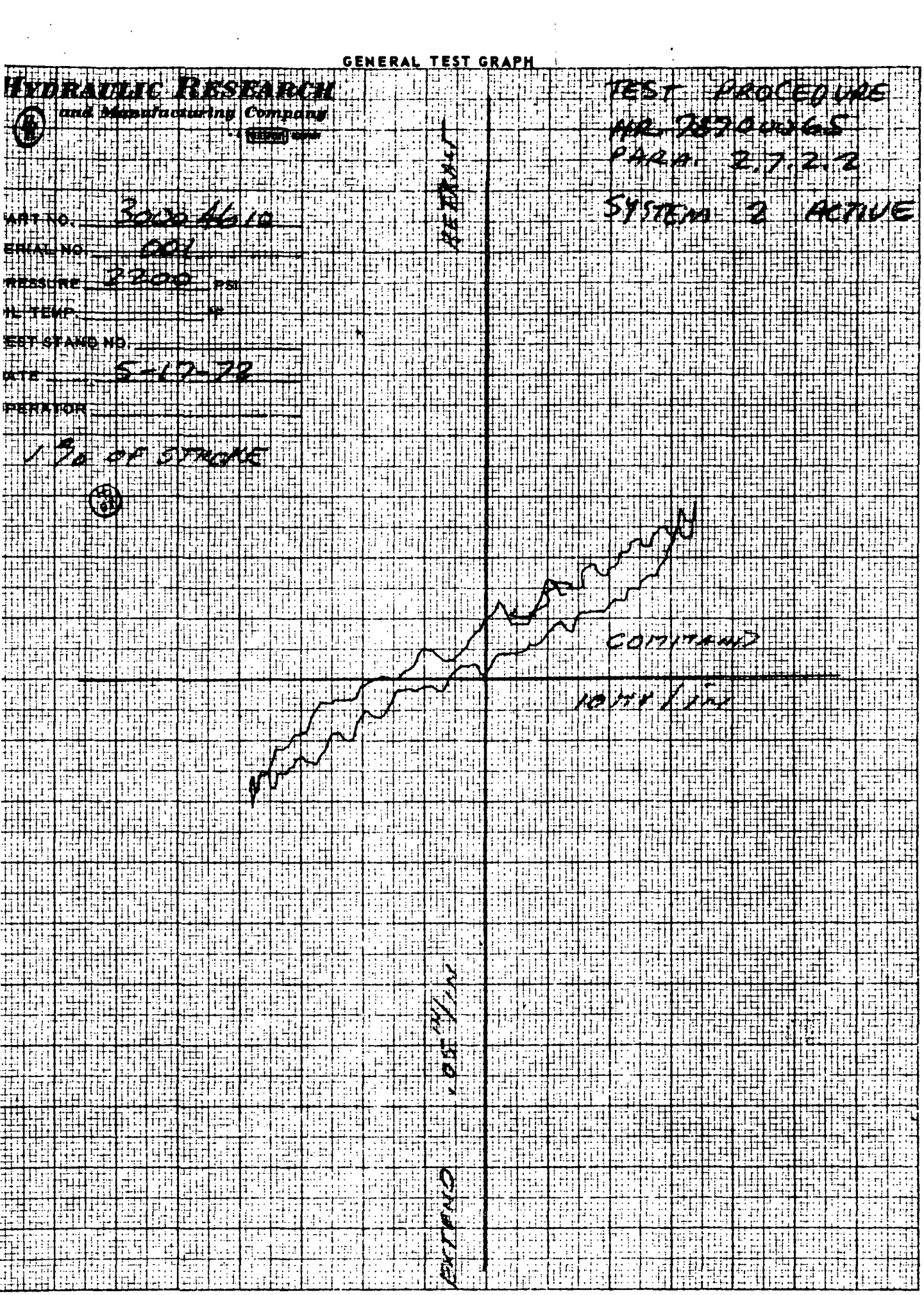
GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company

PART NO. 3020 4610
SERIAL NO. 004
PRESSURE 3200 PSI
OIL TEMP. °F
TEST STAND NO.
DATE 5-10-78
OPERATOR

1/2 OF STROKE

TEST PROCEDURE
MIL-2870 para 6.5
PARA. 2.7.2.2
SYSTEM 2 ACTIVE



EL 009

Reproduced from best available copy.

GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company

PART NO. 3000460-10
SERIAL NO. 001
PRESSURE 2200 PSI
OIL TEMP. ____ °F
TEST STAND NO. ____
DATE 5-17-72
OPERATOR ____

TEST PROCEDURE
HR 7370 00065
PARA 2.7.2.2
SYSTEM 2 ACTUATOR

EXTEND OUTPUT STROKE

RETRACT

COMMAND

FEEDBACK ACTUATOR POSITION

.115" / in.

EL 009

Reproduced from best available copy.

GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company

Test Procedure
HR 93200-65
Part 5.2.2
System 4 Hose

PART NO. 300066-10
SERIAL NO. 001
PRESSURE 2260 PSI
OIL TEMP. ____ °F
TEST STAND NO. ____
DATE 5-12-75
OPERATOR ____

2 @ 20 sec strokes

Compressed

Extended

Actuator Position - 5 Min

EL 009

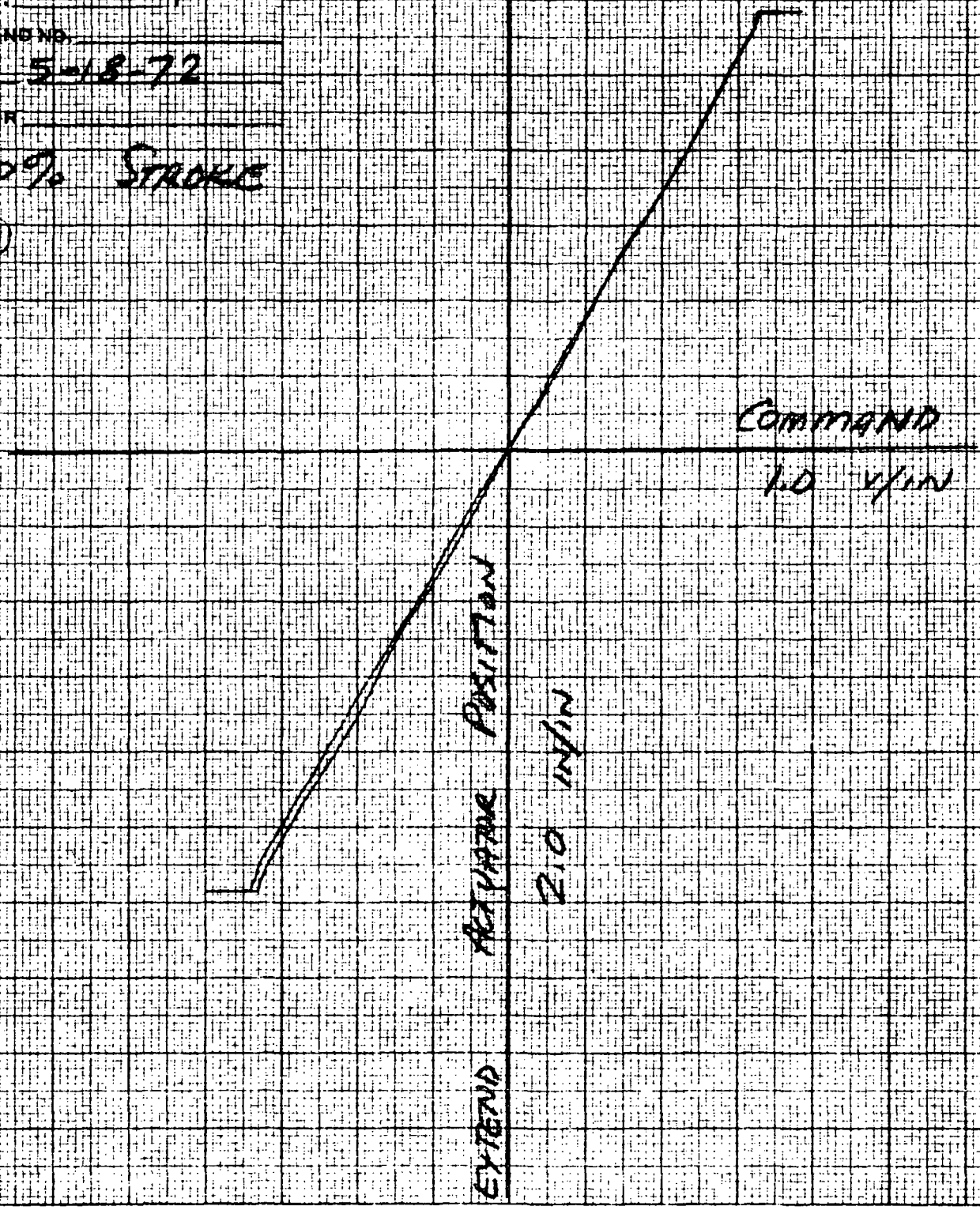
GENERAL TEST GRAPH

HYDRAULIC RESEARCH
and Manufacturing Company

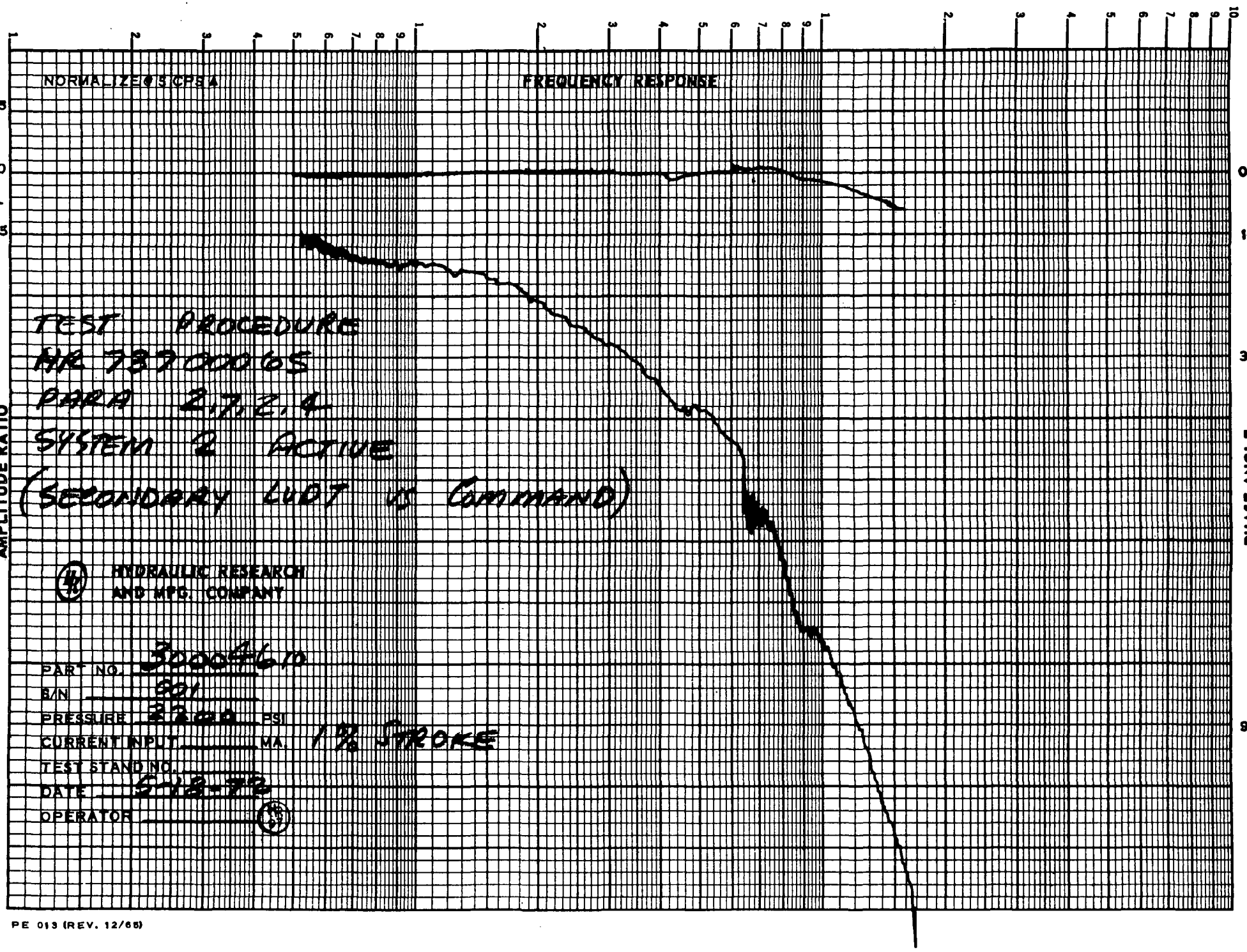
TEST PROCEDURE
HR 737-00065
PARA. 2.7.2.2
SYSTEM 2 ACTIVE

PART NO. 3000 Helo
SERIAL NO. 021
PRESSURE 2200 PSI
OIL TEMP. °F
TEST STAND NO.
DATE 5-18-72
OPERATOR

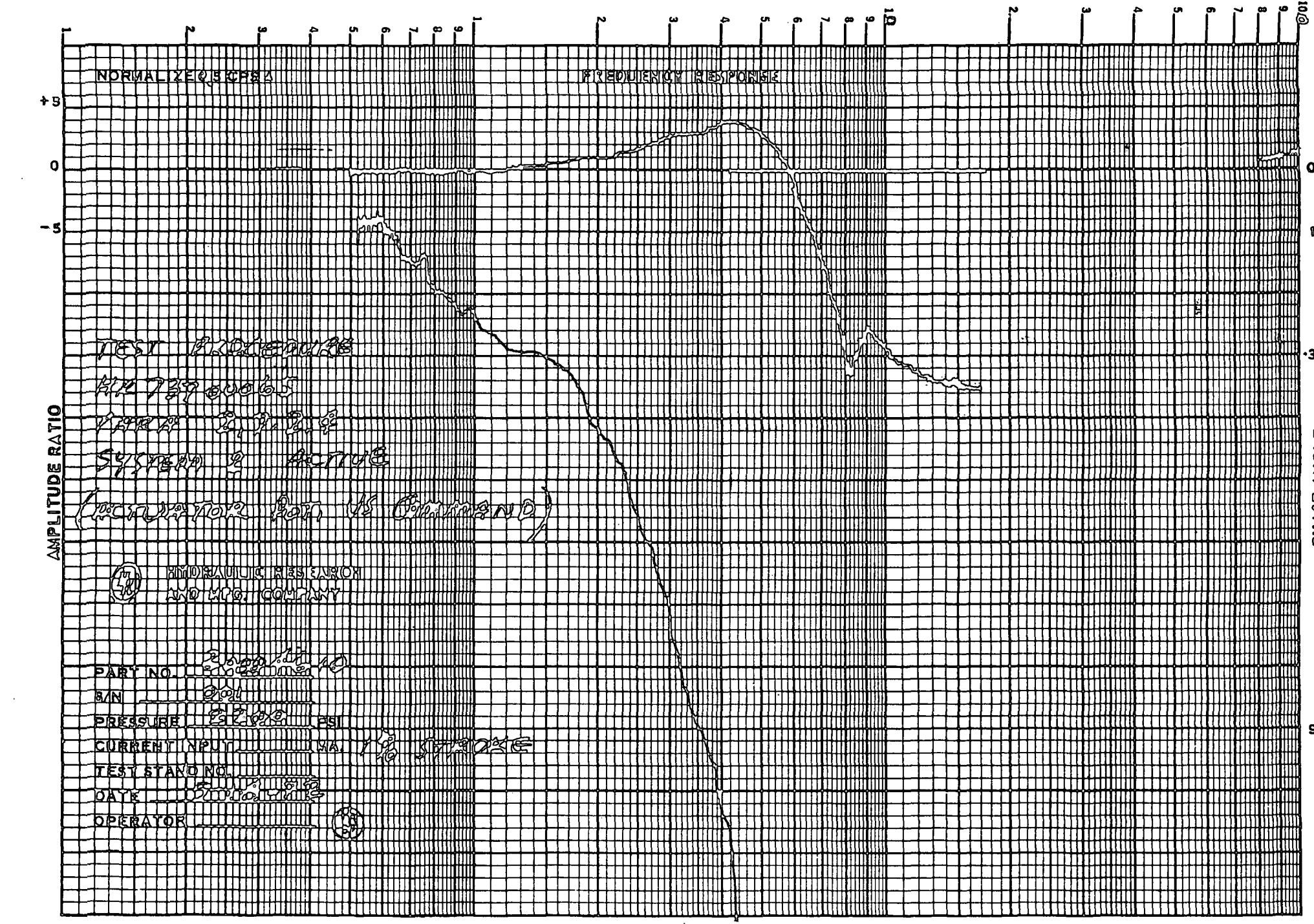
100% STROKE



EL 009



PE 013 (REV. 12/65)



PE 013 (REV. 12/85)

SANBORN Recording Permanent AMPL. DIV. - 031

TEST PROCEDURE
HR737000C65
PARA. 2.2.2.5.3
(Primary Failure
to Active
Servovalve 2)
5-23-72 Post
(5)

Secondary Actuator LVDT (Voltage Output) 5 mv/div

Command Input Signal (Voltage) 5 mv/div

System #1 Failure Indicator Switch (on-off)

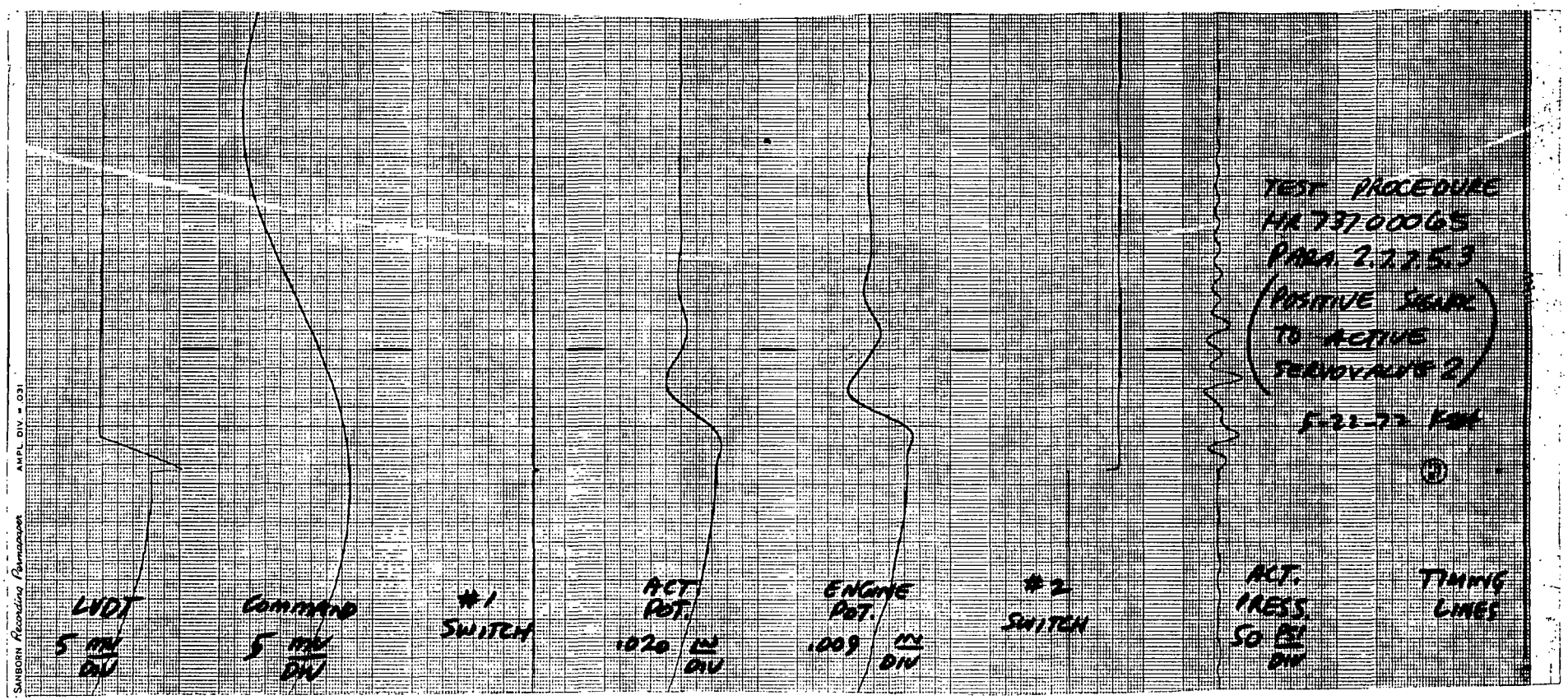
Actuator Potentiometer Position .020 in/div

Engine Potentiometer Position .009 in/div

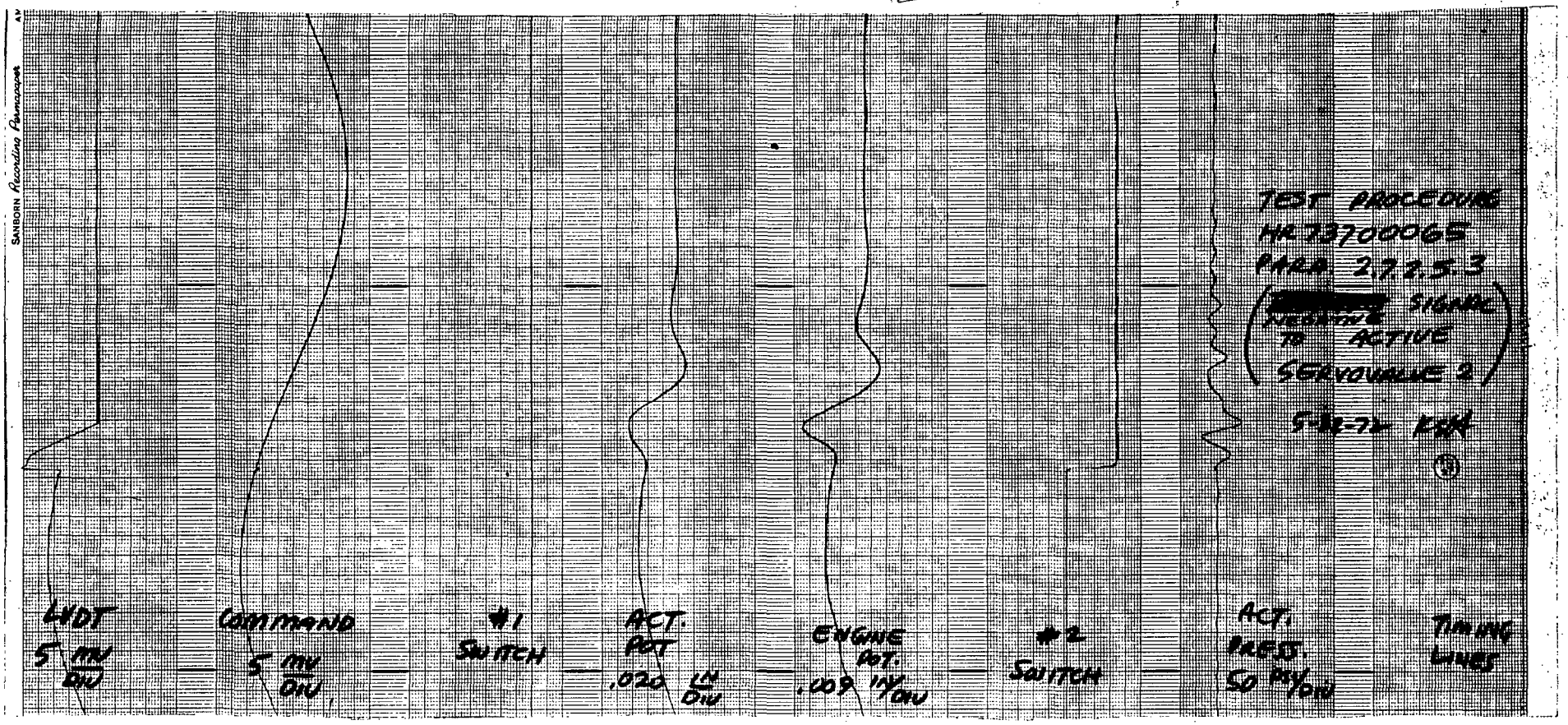
System #2 Failure Indicator Switch (on-off)

Hydraulic Pressure Transducer 50 psi/div

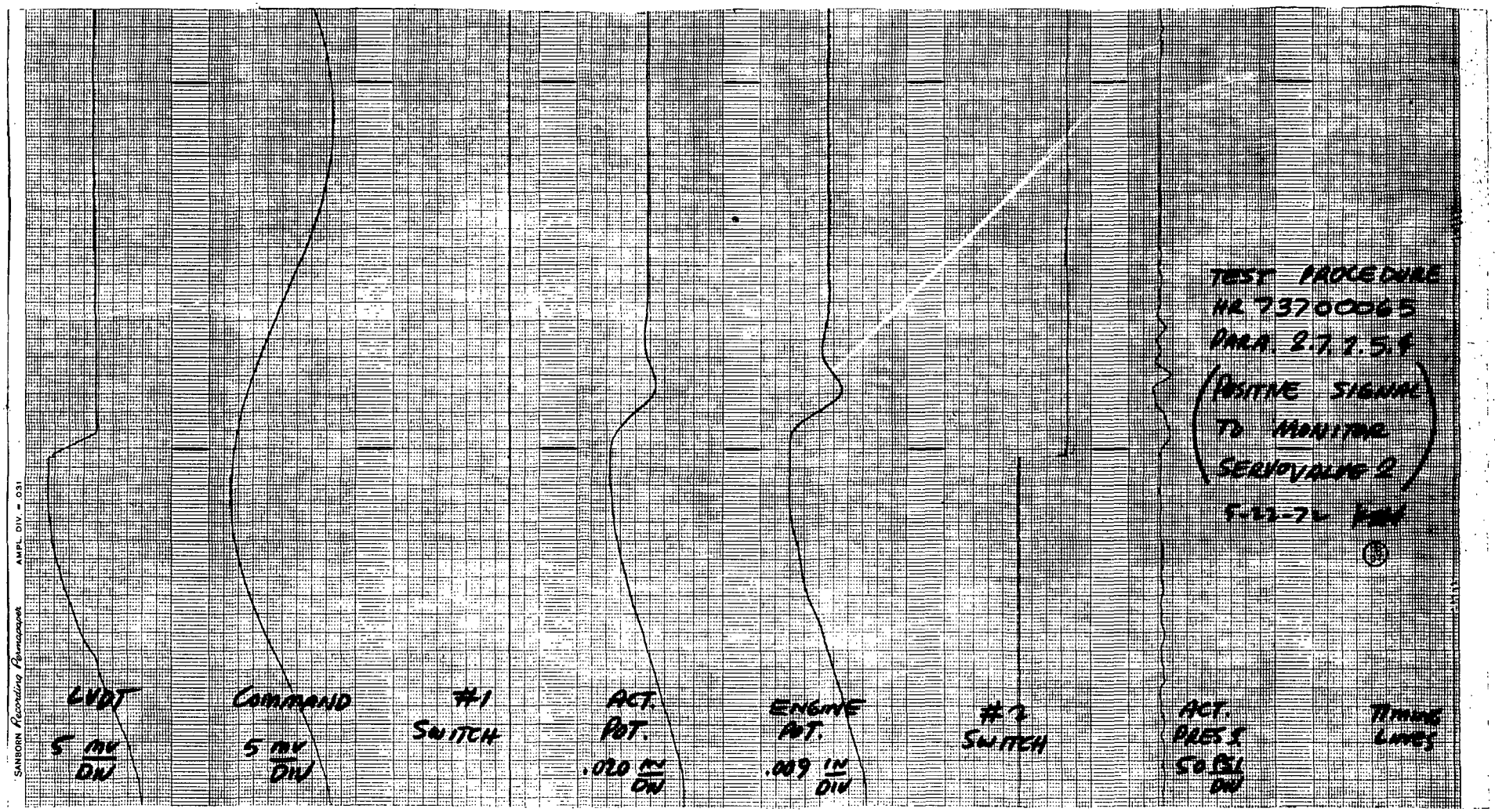
Timing Lines


TEST PROCEDURE
HR 737000G5
PARA. 2.2.2.5.3
(POSITIVE SIGNAL TO ACTUATE SERVOVALVE 2)
5-22-72 FOR
LVDT
5 VOLTS DIV
COMMAND
5 VOLTS DIV
#1 SWITCH
ACT. POT.
.020 VOLTS DIV
ENGINE POT.
.009 VOLTS DIV
#2 SWITCH
ACT. PRESS.
50 PSI DIV
TIMING LINES
SANBORN Recording Permapaper
AMPL. DIV. - 031

Reproduced from
best available copy.



TEST PROCEDURE
MK 73700065
PARA. 2.7.7.5.3
(NEGATIVE SPIKE
TO ACTIVE
SERVOVALVE 2)
5-22-72 KSK
(B)
TIMING
LINES
VOLT
5 MV/DIV
COMMAND
5 MV/DIV
#1
SWITCH
ACT.
POT.
.020 IN/DIV
ENGINE
POT.
.009 IN/DIV
#2
SWITCH
ACT.
PRESS.
50 PSI/DIV


TEST PROCEDURE
HR 73700065
PARA. 2.7.1.5.1
(POSITIVE SIGNAL
TO MOVE THE
SERVOVALVE 2)
5-22-74 PAT
LVDT
5 mv/DIV
COMMAND
5 mv/DIV
#1
SWITCH
ACT.
POT.
.020 in/DIV
ENGINE
POT.
.009 in/DIV
#2
SWITCH
ACT.
PRESS
50 psi/DIV
TIMING
LINES
SANBORN Recording Newspaper
AMPL. DIV. = 031

SANBORN Recording Permanapaper AMPL

TEST PROCEDURE
NR 7370006S
PARA. 2.7.2.5.4.
(POSITIVE SIGNAL TO MONITOR SERVOVALVE 2)
5-22-72 FOR

LVDT
5 MV/DIV

COMMAND
6 MV/DIV

#1 SWITCH

ACT. POT.
.020 IN/DIV

ENGINE POT.
.009 IN/DIV

#2 SWITCH

ACT. PRESS.
50 PSI/DIV

TIMING LINES

TEST MIXEDUCE
MR 737 00065
PARA. 7.7.2.5.4
(NEGATIVE SIGNAL
TO MONITOR
SOLENOID O.
6-22-72

LVDT
5 mv DIV

COMMAND
5 mv DIV

#1
SWITCH

ACT.
POT.
.020 IN DIV

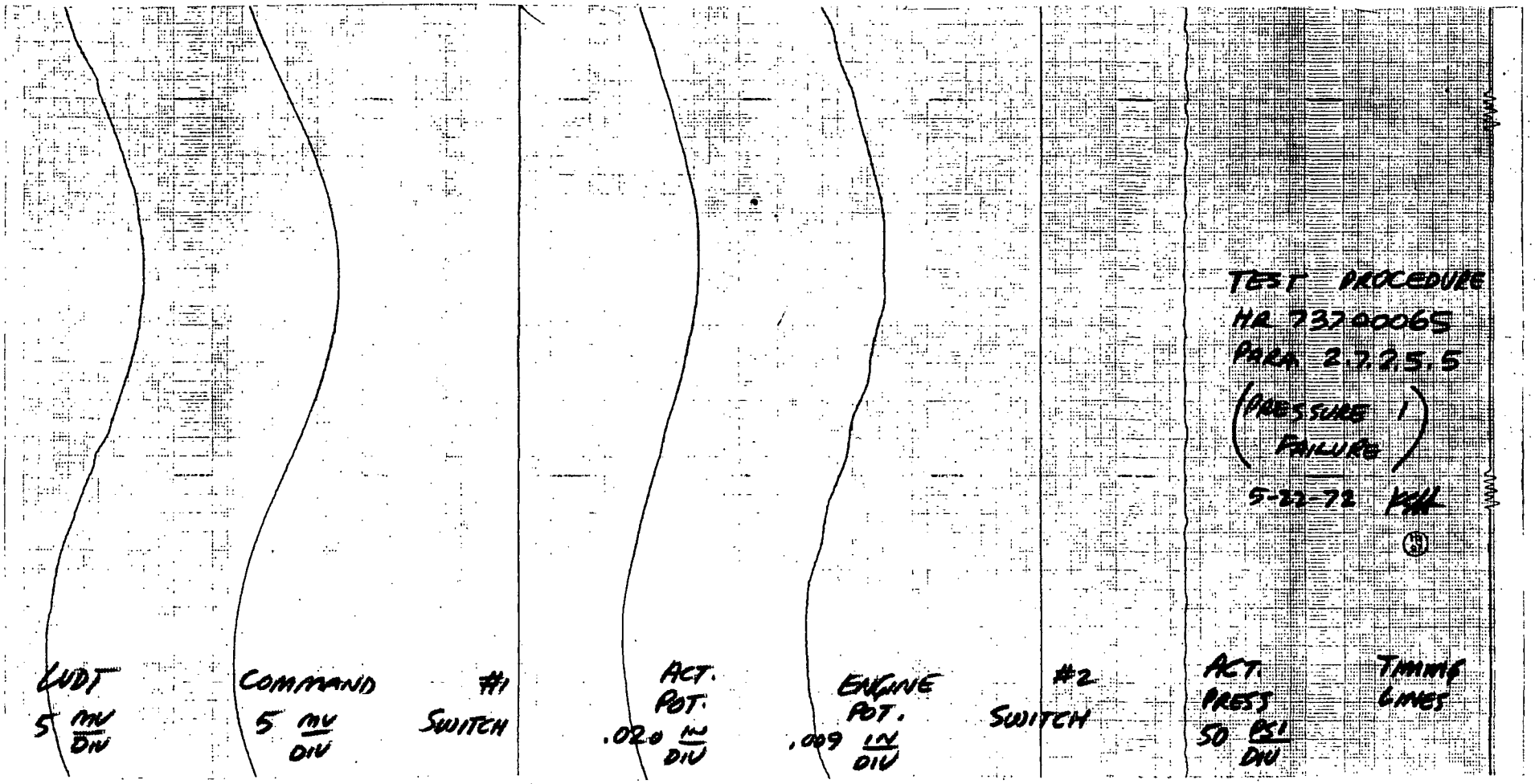
ENGINE
POT.
.009 IN DIV

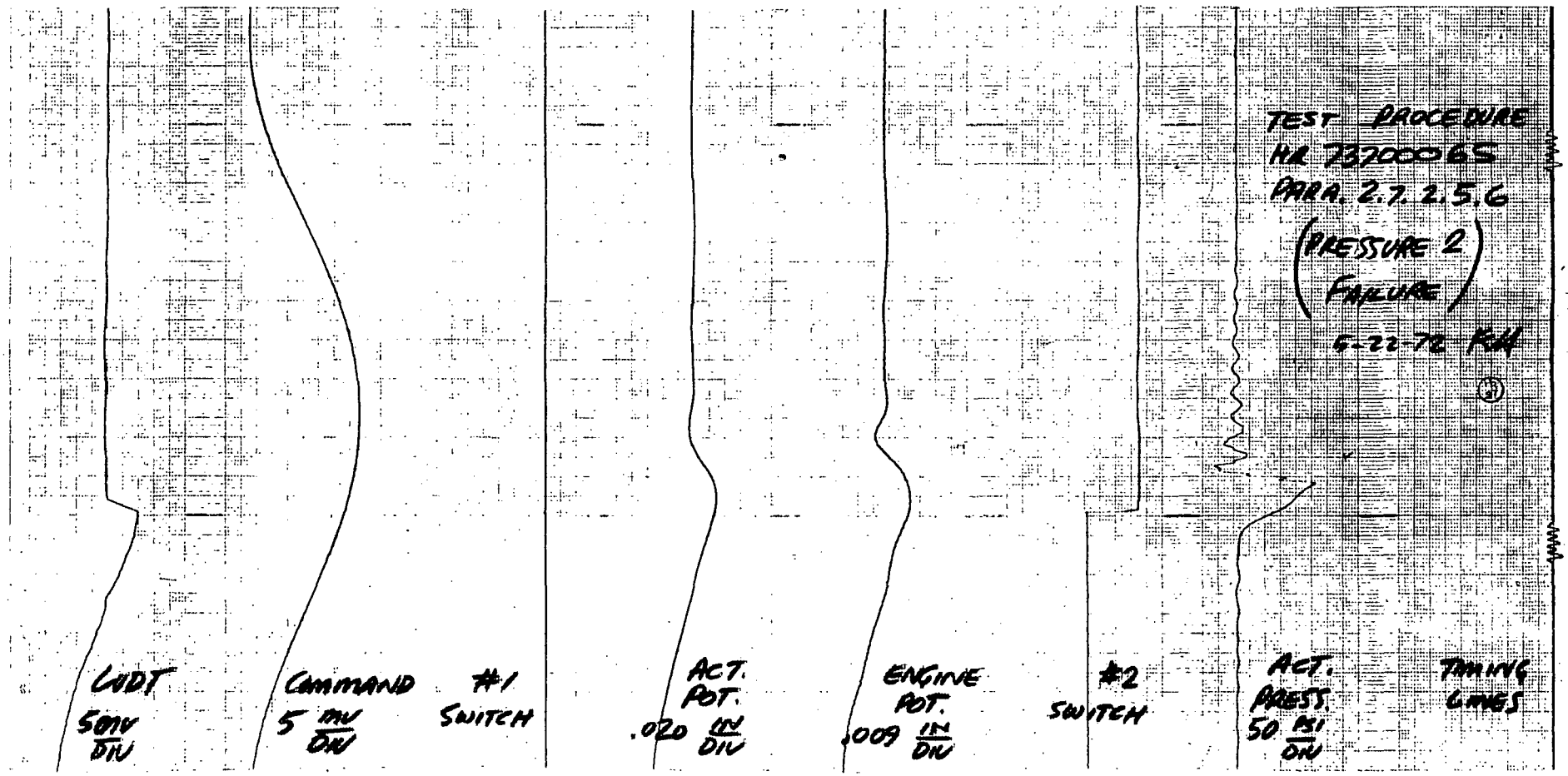
#2
SWITCH

ACT.
PRESS.
50 PSI DIV

TIMING
LINES

LVDT
5 mv/DIV
COMMAND
5 mv/DIV
#1
SWITCH
ACT.
POT.
.020 IN/DIV
ENGINE
POT.
.009 IN/DIV
#2
SWITCH
ACT.
PRESS
50 PSI/DIV
TIMING
LINES
TEST PROCEDURE
MA 73700065
PARA. 2.7.2.3.4
(NEGATIVE SIGNAL
TO MONITOR
SEQUENCE 2)
5-22-72 FGH
SANBORN Recording Permascan
AMPL DIV - 031


TEST PROCEDURE
HR 73700065
PARA 2.7.2.5.5
(PRESSURE 1 FAILURE)
5-22-72
LVDT
5 MV/DIV
COMMAND
5 MV/DIV
#1 SWITCH
ACT. POT.
.020 IN/DIV
ENGINE POT.
.009 IN/DIV
#2 SWITCH
ACT. PRESS
50 PSI/DIV
TIMING LINES


TEST PROCEDURE
HR 7370065
PARA. 2.7.2.5.6
(PRESSURE 2
FAILURE)
6-22-72 FCH
LVDT
5 DIV
COMMAND
5 DIV
#1
SWITCH
ACT.
POT.
.020 IN
DIV
ENGINE
POT.
.009 IN
DIV
#2
SWITCH
ACT.
PRESS.
50 PSI
DIV
TIMING
GAGES

APPENDIX B

HR 73600003

Hydraulic Research

Redundant Thrust Vector

Control Servoactuator

Development Program

HYDRAULIC RESEARCH
and MANUFACTURING COMPANY
textron company
25200 WEST RYE CANYON ROAD • VALENCIA, CALIF. 91355
(805) 259-4030 TWX 910-336-1438
CODE IDENT 81873



REPORT NO. HR 73600003
HR&M JOB NO.
CONTRACT
NO. PAGES 13
DATE February 7, 1972
REV. B

HYDRAULIC RESEARCH

REDUNDANT THRUST VECTOR CONTROL SERVOACTUATOR DEVELOPMENT PROGRAM

PREPARED BY K.E. Hart DATE 2-8-72
CHECKED BY _____ DATE _____
APPROVED BY _____ DATE _____
APPROVED BY _____ DATE _____
APPROVED BY _____ DATE _____

SCOPE

The purpose of this report is to describe the Hydraulic Research and Manufacturing Company Redundant Thrust Vector Control Servoactuator systems which are being developed in coordination with the National Aeronautics and Space Administration. This development program is intended to demonstrate the feasibility of incorporation of redundancy techniques into thrust vector control servoactuator systems as applied to the Space Shuttle Program.

SUMMARY

HYDRAULIC RESEARCH has designed, developed and is producing the P/N 30002150 (formally 301100) Servoactuator which is used to position the gimbaled engines (controlling vehicle attitude) on the S-1C stage (first stage) of the National Aeronautics and Space Administration's Saturn V vehicle. HYDRAULIC RESEARCH technical bulletin No. 45, "Engine Gimbal Servoactuator System for the S-1C Stage of Saturn V", has been written to describe in detail the servoactuator installation, assembly and operating characteristics.

With the above described previous thrust vector control servoactuator experience, HYDRAULIC RESEARCH has been given three separate inter-related contracts by the National Aeronautics and Space Administration for work on redundant TVC servoactuator systems. The following is a description of each of the contracts:

a) 30004610 Thrust Vector Control (TVC) Servoactuator:

Contract provides for one modified 301100 Thrust Vector Control Servoactuator designed for operate/Fail-operate/Fail-center capability for use with

each of the following redundant Servoactuator systems 33000660 or 34000220.

b) 33000660 Redundant Servoactuator (Minilogic):

Contract provides for one active-standby type redundant servoactuator system employing hydraulic comparator monitoring logic concepts with automatic hydromechanical switching and electrical feedback.

c) 34000220 Servoactuator and Electronic Model:

Contract provides for one active-standby type redundant servoactuator system employing electronic comparator monitoring logic concepts with automatic electrical-hydromechanical switching and electrical feedback.

PROGRAM DESCRIPTION

The program provides for development of a thrust vector control servoactuator which, as designed, is capable of demonstrating servoactuator operating and failure mode characteristics when controlled with either a hydraulic comparator monitoring logic or electronic comparator monitoring logic type system. As baseline design for the thrust vector control servoactuator, one GFE (Government Furnished Equipment) HYDRAULIC RESEARCH P/N 301100 servoactuator has been selected as a representative model. This 301100 servoactuator, as originally designed and delivered to NASA, is shown in schematic form in Figure 5 with the servoactuator servo position system summary itemized in Table I.

The following is a brief description of each phase of development, each of which is covered by a separate NASA contract.

a) 30004610 Thrust Vector Control Servoactuator:

The 30004610 Thrust Vector Control Servoactuator is shown schematically in Figure 1 and in system block diagram form in Figure 2. As shown, HYDRAULIC RESEARCH P/N 301100 S-1C Servoactuator has been modified such that all components are utilized in the final design with exception of the three-stage servovalve torque motor assembly. As can be seen, the torque motor assembly has been replaced by mechanical input and feedback linkage together with secondary actuators (modulating pistons). The electrical command input to the three-stage servovalve has essentially been replaced by a mechanical command input.

To provide for hydraulic pressure supply redundancy, hydraulic pressure supply selector valves have been included. Two supply pressure failures can be sustained while continuously maintaining one normal pressure supply to the unit.

To provide for unit logic control redundancy, the 301100 S-1C Servoactuator has been modified by adapting either of two types of redundant assemblies. Hydraulic comparator monitoring (33000660 Redundant Servoactuator-Minilogic) or electronic comparator monitoring (34000220 Servoactuator and Electronic Model) can be utilized. The complete system provides for an operate/fail-operate/fail-center capability.

When completely assembled with either type logic system, the 30004610 Thrust Vector Control Servoactuator system is capable of demonstrating operational and functional performance requirements. This will be demonstrated by a test program as follows: Linearity, hysteresis, threshold, position-system stability, frequency response, transient response and failure switching and operating transient response in all modes of operation.

b) 33000660 Redundant Servoactuator (Minilogic):

The 33000660 Redundant Servoactuator (minilogic) system, utilized as a control logic system for the 30004610 Thrust Vector Control Servoactuator, is shown schematically in Figure 1 and in block diagram form in Figure 3. The 33000660 system is essentially an operate/fail-operate/fail-safe type logic system which when operating with the 30004610 unit provides for a total overall operate/fail-operate/fail-center system capability.

It is configured as an active-standby unit. Each system has two servovalves which receive the same command signals. Spool position of these valves is compared by a separate comparator spool. A channel failure will manifest itself as a difference in the valves positions. When this difference exceeds a failure threshold level, the active system switches to the standby system.

Switching will also take place upon loss of system pressure P1 (detected by either the solenoid valve #1

or shutoff valve #1). Upon failure of the operational system No. 2 servovalve (active or monitor #2) or loss in system pressure P2, the secondary actuator pressures are interconnected allowing the secondary and main actuators to center. This is accomplished by centering springs which position the secondary actuator to mechanical null. This centers the main actuator piston thru the linkage, power valve and mechanical feedback mechanism.

c) 34000220 Servoactuator and Electronic Model:

The 34000220 Servoactuator and Electronic Model system, utilized as a control logic system for the 30004610 Thrust Vector Control Servoactuator, is shown in Figure 1 and in block diagram form in Figure 4. The 34000220, as applied to the 30004610 unit, is essentially an operate/fail-operate/fail-safe type logic system which when operating with the 30004610 unit also provides for a total overall operate/fail-operate/fail-center capability. The 34000220 system logic operation is also active-standby whereby one system is in operation while the second system is in a standby mode. Each channel of the system consists of a single servovalve, electronic model and comparator and a shutoff valve. The servovalves are provided with spool position LVDT's. The electronic model is designed to match the servovalve response and develops a simulated spool position signal. An electronic comparator detects difference between actual modeled spool positions and disengages the active system through the torque motor switch.

In the active mode servovalve #1 is controlling while servovalve #2 is standby being blocked by the shutoff valve. System pressure loss is detected by the shutoff

valve and switching is automatically initiated. A second failure causes the secondary actuator piston chamber interconnected, thus providing for main actuator piston centering. Centering mechanism is as previously described in Paragraph b).

Failure detection and switching is identical to that described for System #1.

Modification of the 301100 S-16 Servoactuator will in no way alter the operating characteristics of the servoactuator as originally designed (See Table I).

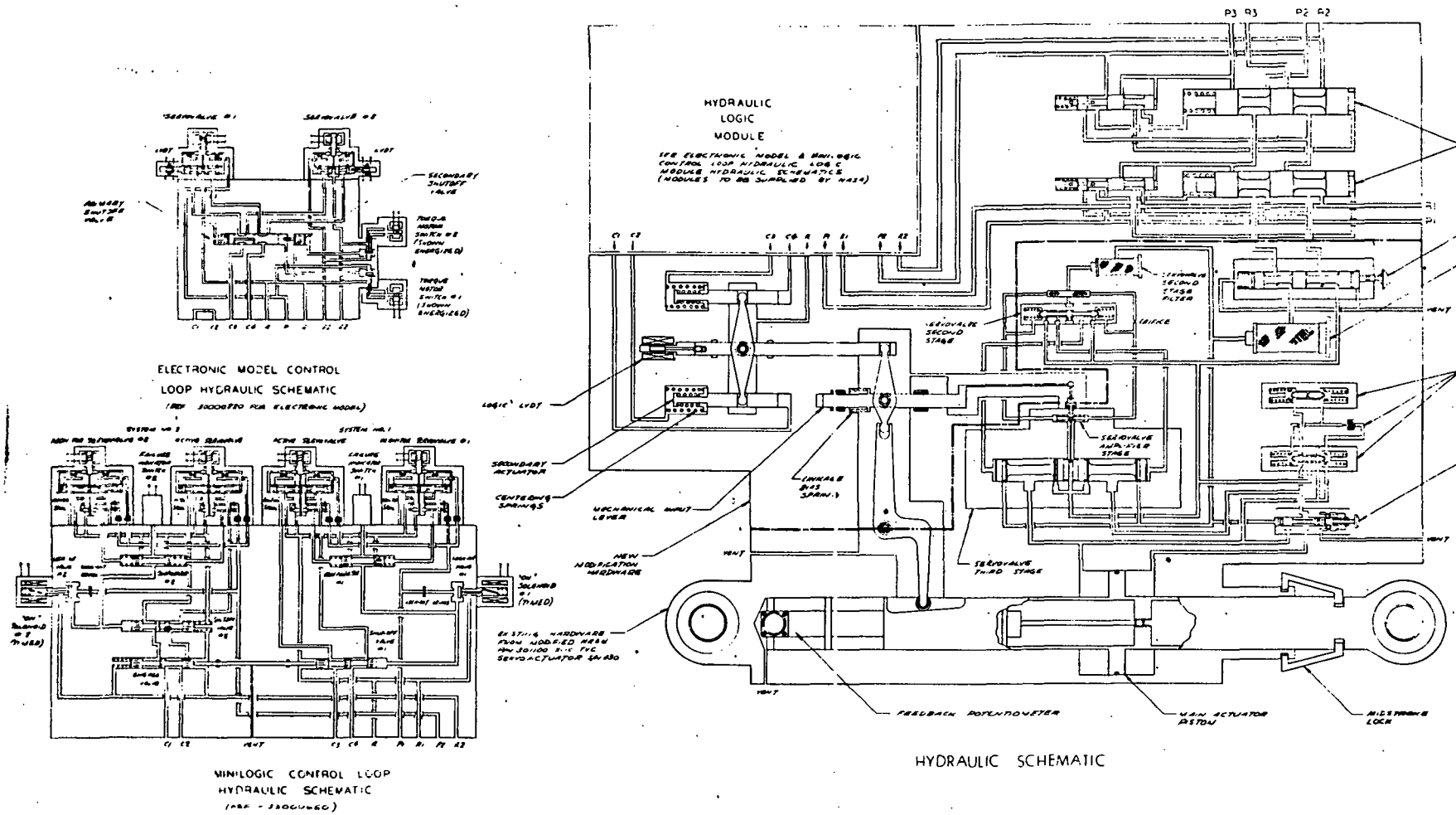


FIGURE 1 - HYDRAULIC SCHEMATIC - 30004610

THRUST VECTOR CONTROL SERVOACTUATOR (Minilogic) SYSTEM

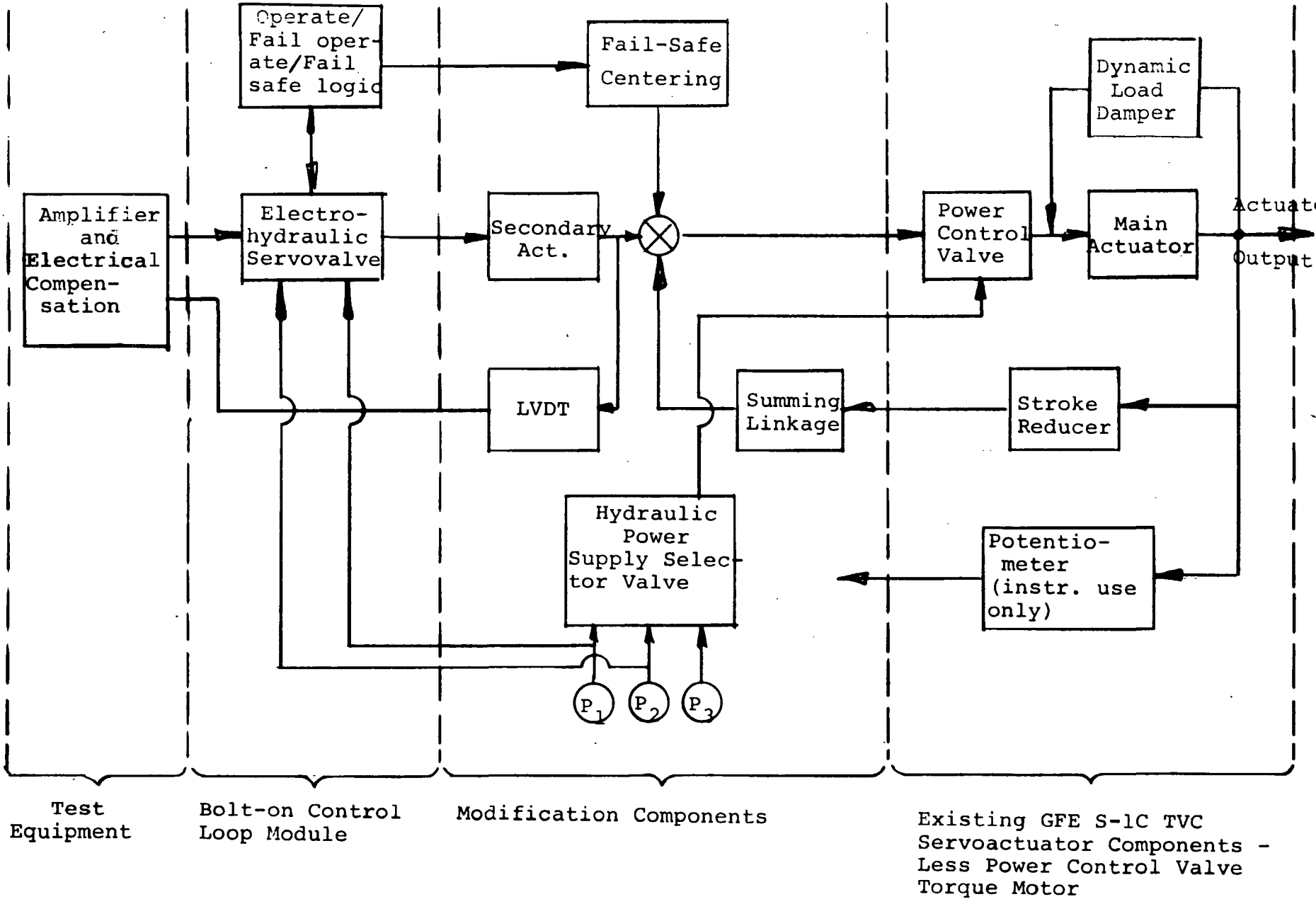
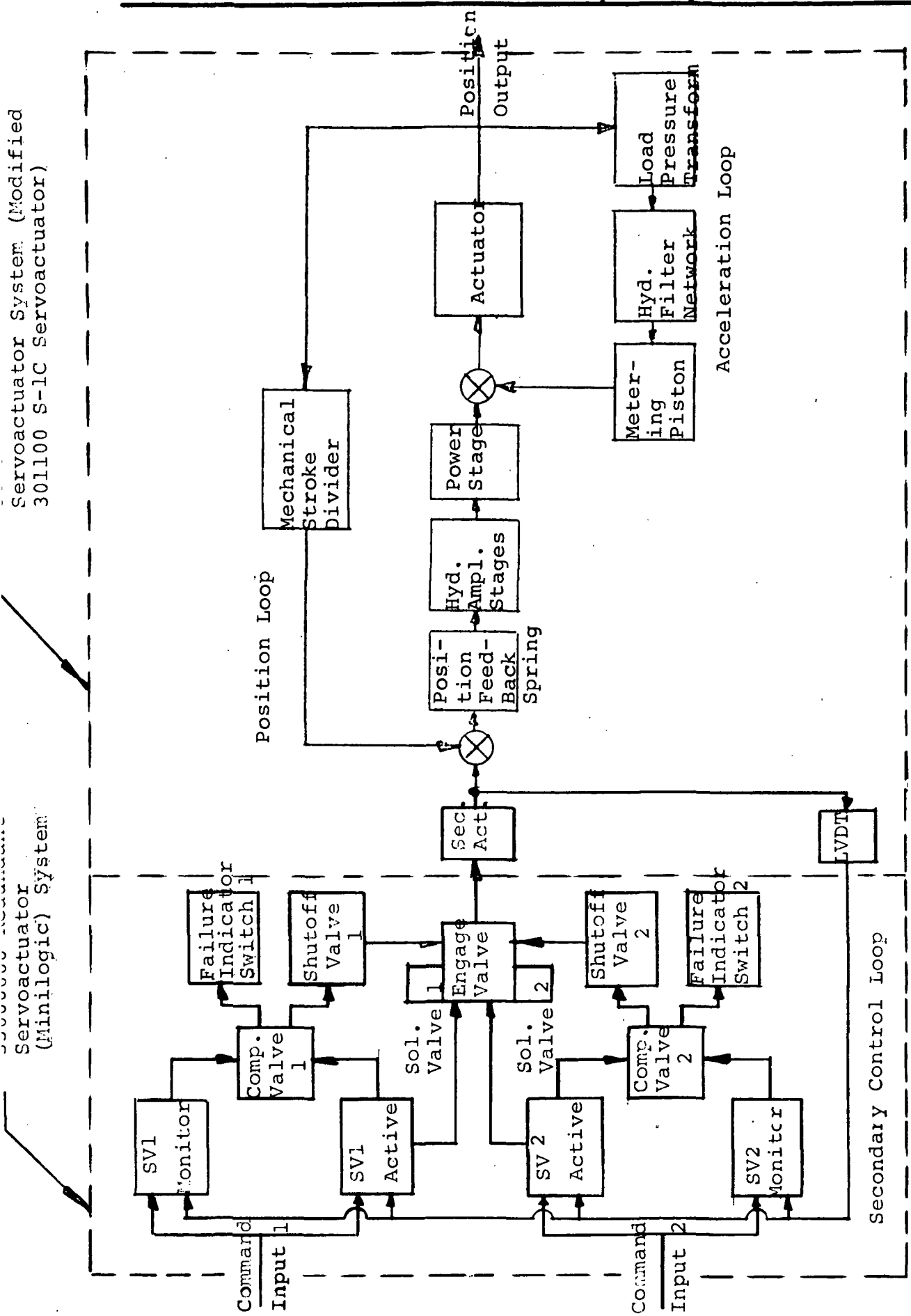


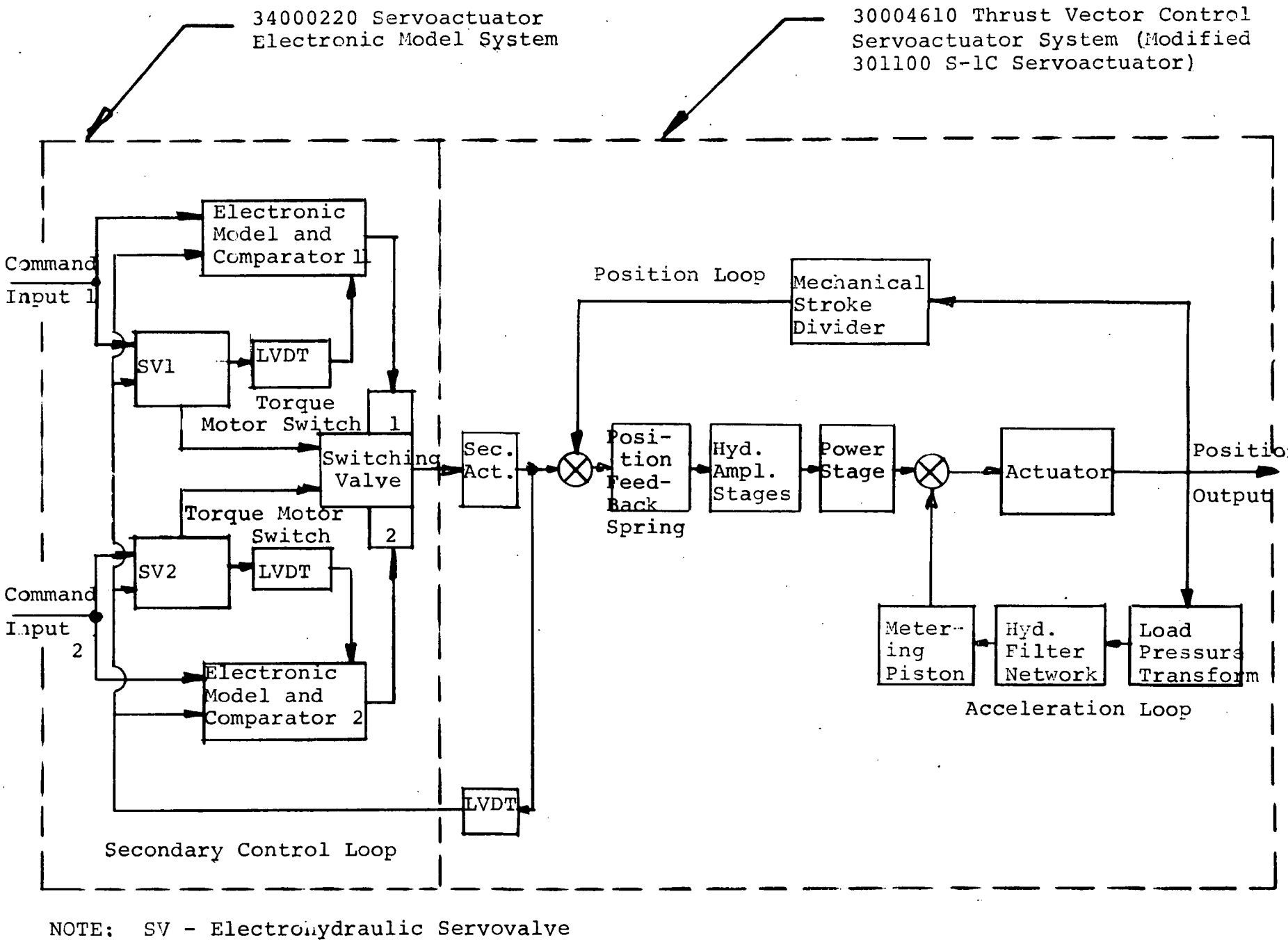
FIGURE 2 - FUNCTIONAL BLOCK DIAGRAM - COMPLETE SYSTEM

HYDRAULIC RESEARCH and MANUFACTURING COMPANY
25200 WEST RYE CANYON ROAD • VALENCIA, CALIFORNIA 91355
REV. B
REPORT NO. HR 73600003
PAGE NO. 9
PART NO.



NOTE: SV - Electrohydraulic Servovalve

FIGURE 3 - BLOCK DIAGRAM - COMPLETE UNIT WITH 3300660 REDUNDANT SERVOACTUATOR (Minilogic) SYSTEM



NOTE: SV - Electrohydraulic Servovalve

FIGURE 4 - BLOCK DIAGRAM - COMPLETE UNIT WITH 34000220 SERVOACTUATOR AND ELECTRONIC MODEL SYSTEM

HYDRAULIC RESEARCH and MANUFACTURING COMPANY
25200 WEST RYE CANYON ROAD • VALENCIA, CALIFORNIA 91355
Textron COMPANY

REV. B

REPORT NO. HR 73600003
PAGE NO. 11
PART NO.

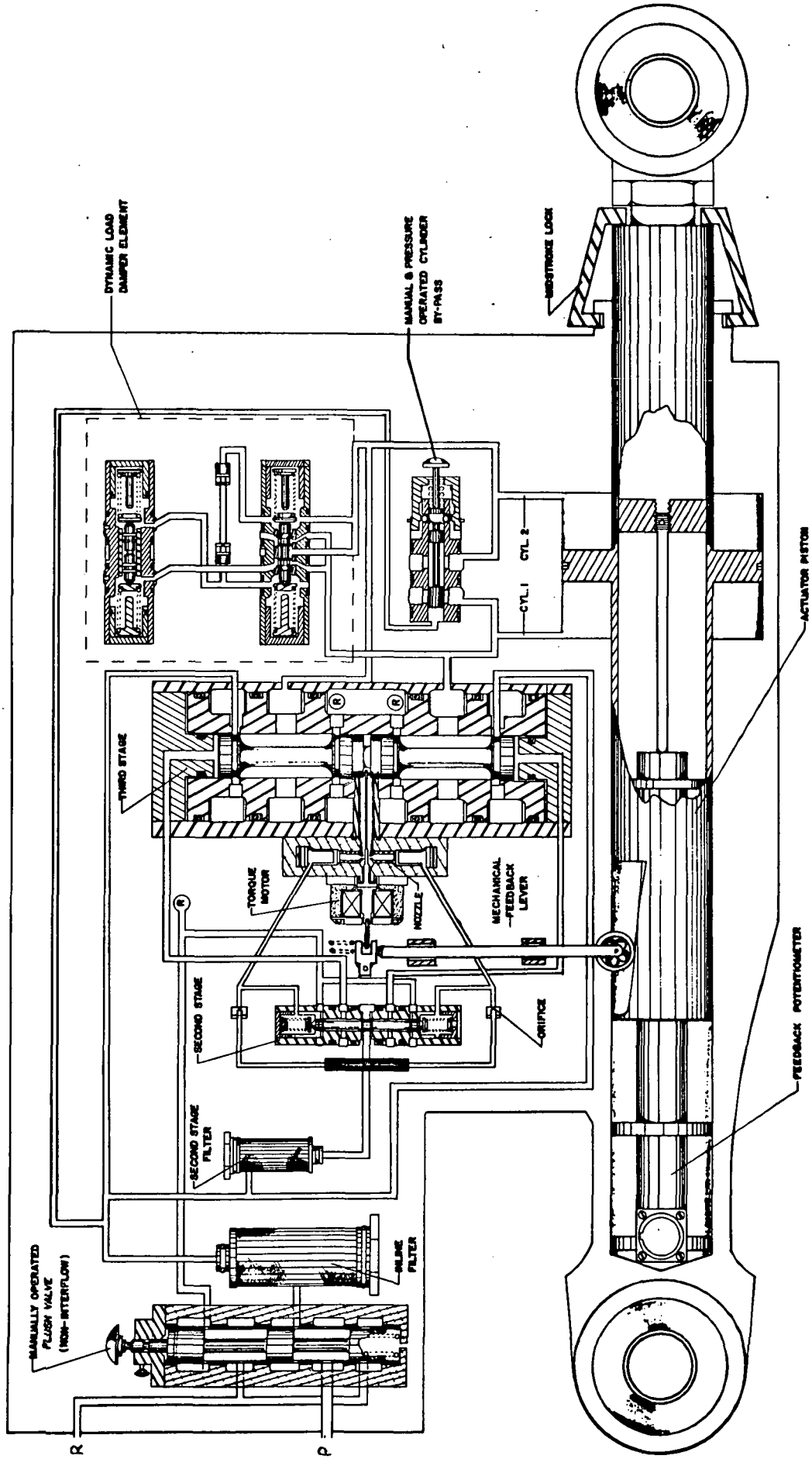


FIGURE 5 - HYDRAULIC SCHEMATIC - 301100 S-1C SERVOACTUATOR

SERVOACTUATOR CHARACTERISTICS	
Input Power, Maximum	.25 watts
Input Current	±50 ma
Stroke	11.48 in.
Area	57 in.²
Force Output	114,000 lbs. (max.)
Torque Output	600,000 ft. lb.
Actuator Weight	320 lbs. (dry)
Actuator Length	60 in. (at null)
No Load Velocity	13 in./sec.
Operating Pressure	2000 psi
Proof Pressure	3300 psi
Burst Pressure	6000 psi
Displacement	±5.74 in.
Linearity	.2%
Threshold	.5%
Hysteresis	3%
Threshold Signal	0.5 ma
Step Response Overshoot	15% (avg.)
Step Response Rise Time	70×10^{-3} sec. (avg.)
Step Response Settling Time	150×10^{-3} sec. (avg.)
Phase lag at 1 cps $\frac{X_o}{i}$	20 degrees
Acceleration	12 g
Shock	100 g
Temperature Range	40 to 120° F.
Ambient Temperature	200° F.

ENGINE-STAGE STRUCTURE CHARACTERISTICS	
Engine Inertia	28,500 slug ft.²
Actuator Bell Crank Radius	63.76 in.
Reflected Load at Actuator	84.13 lb.-sec.²/in
Combined Structural Spring Rate	250,000 lb./in.
Load Resonance	8 cps
Load Damping	.05
Bias Load (All loads except inertia and viscous friction)	0-80,000 lbs.

TABLE I

301100 S-1C TVC SERVOACTUATOR

SERVO POSITION SYSTEM SUMMARY