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by David J. Robinson, John T. Mayer, and Richard R. Wyer

Lewis Research Center
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ABSTRACT

A test program was conducted to evaluate the NERVA control drum actuator in the environments of cryogenic temperature, nuclear radiation, and vacuum. The actuator was irradiated for 21.8 hours with a total gamma dose of 1.3×10^{11} ergs per gram (1.3×10^{9} rads) and a neutron fluence of 2×10^{16} neutrons per square centimeter without any degradation in performance. Further irradiation testing was attempted but the actuator malfunctioned. A postirradiation examination revealed extensive radiation damage to the feedback potentiometer. Other actuator components showed no significant radiation damage that would produce detectable changes in actuator performance.

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SUMMARY

An irradiation test program was conducted to evaluate the performance of the NERVA control drum actuator in the combined environments of nuclear radiation, cryogenic temperatures, and vacuum. Actuator performance during the test program was measured in terms of its ability to function in a closed-loop positioning system.

During the irradiation test program the actuator received a gamma dose of 1.3×10^{11} ergs per gram (1.3×10^{9} rads) and a neutron fluence of 2×10^{16} neutrons per square centimeter. This corresponds to the estimated NERVA value for neutrons at full power and is 26 times the estimated NERVA value for gammas at full power. The actuator was irradiated a total of 21.8 hours before it malfunctioned. Prior to the malfunction, no significant degradation in performance was noted.

A postirradiation examination of the actuator revealed extensive radiation damage to the feedback potentiometer. Other components showed no significant radiation damage that would produce detectable changes in actuator performance.

INTRODUCTION

In the NERVA engine a change in the power level is accomplished by varying the reactivity of the associated nuclear reactor. To obtain a variation in reactivity, control drums are rotated to change the amount of reflecting surface exposed to the reactor core. Electropneumatic actuators, capable of operating on hydrogen, helium, or nitrogen supply gas, are used to rotate the control drums. These actuators were chosen to make use of the existing cryogenic gas supply in the engine which minimizes the actuator electrical power requirements.

In use, the control drum actuators will experience the combined environments of radiation, vacuum, and cryogenic temperatures. Previous test programs have considered these environments only on an individual basis. Extensive low temperature testing using helium as a gas supply (ref. 1) and hydrogen as a gas supply (ref. 2 and previously obtained unpublished data by the author) has been performed. Selected critical actuator components were irradiated (ref. 3) to determine effects due to a nuclear environment.

This report presents the results of a test program conducted by the Lewis Research Center that examined actuator performance in the combined environments. The program was conducted at the NASA Plum Brook Reactor Facility. In the test program, the actuator performance was measured in terms of its ability to function in a closed-loop positioning system. A simulated control drum was incorporated into the experiment to approximate the friction and inertia of a NERVA control drum.

Included herein is a description of the test program, a discussion of the data acquired, and a discussion of the postirradiation examination of the actuator components.

NERVA ACTUATOR DESCRIPTION

The control drum actuator used in the NERVA test program is an electropneumatic device which converts an electrical input command signal into rotational output motion. Figure 1 is a cutaway view of the actuator. The basic components of the actuator are a torque motor, servovalve, piston assembly, and a rack and pinion. The torque motor is a two-coil permanent magnet type with the coils connected in parallel. The torque

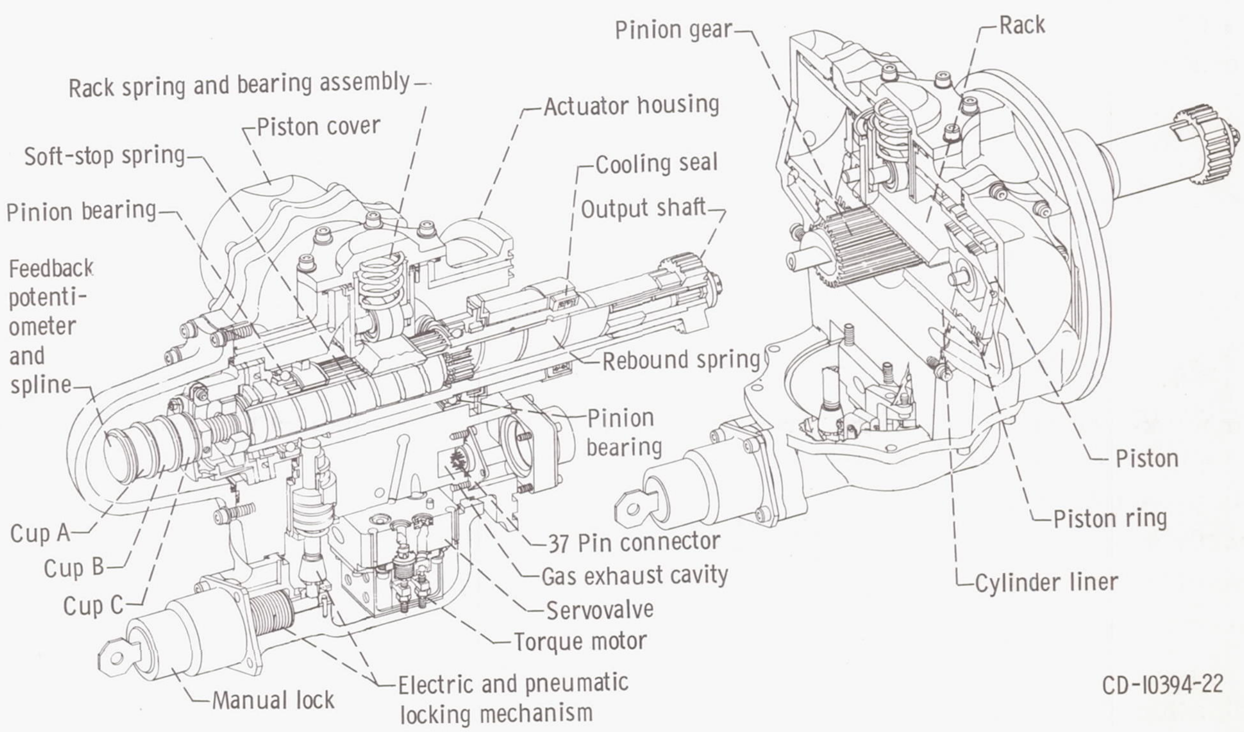


Figure 1. - NERVA control drum actuator.

motor converts an electrical input signal into a mechanical force capable of driving the servovalve. The servovalve is a two-sided, single-stage, four-way valve with dynamic pressure feedback. Drive gas is supplied to the servovalve at a constant pressure of 215 psia (148 N/cm^2). The servovalve is designed to operate using ambient or cryogenic helium, nitrogen, or hydrogen drive gas.

Drive gas is ported by the servovalve to opposing pistons attached to each end of a rack. A pressure differential across the pistons results in motion of the pistons and rack. The rack engages the pinion gear on the output shaft to change the linear piston motion into rotational output motion. A bearing and spring arrangement is used to maintain continuous engagement between rack and pinion. The pinion gear is supported by two radial ball bearings to provide optimum support for the rack and pinion assembly. Maximum rotational movement is 180°.

Helical springs are located inside the pinion gear to provide soft mechanical stopping at the extremities of the output shaft travel and to limit load rebounding. Soft-stop action takes place from 15° to 0° in the decreasing direction and from 165° to 180° in the increasing direction.

A feedback potentiometer is coupled to the output shaft to provide continuous monitoring of the output shaft's relative position. The potentiometer is a three cup, conductive plastic rotary type with two cups electrically connected in a redundant feedback circuit.

The actuator has a double locking mechanism provided to prevent inadvertent operations. The locking mechanism consists of a key operated manual lock and a remote operated electropneumatic lock. For the irradiation, the manual lock mechanism was removed.

Coolant gas is supplied to the actuator to control component heating caused by the radiation environment. The actuator housing is sealed with lead-coated apex seals to form a closed pressure vessel that contains the coolant gas. The coolant gas, which can be either helium, nitrogen, or hydrogen, is supplied through a filter that surrounds the actuator's output shaft, and it is exhausted through a cavity surrounding the electrical input connector. Coolant gas pressure can be maintained as high as 650 psia (448 N/cm^2). However, the operating pressure is determined primarily by the temperature environment that the actuator is subjected to.

ACTUATOR CONTROL SYSTEM APPARATUS

Precise positioning of the NERVA control drum is done by connecting the actuator in a closed-loop system as shown in figure 2. The position of the drum is measured by the actuator's feedback potentiometer and fed back to a summing junction. Here the actual

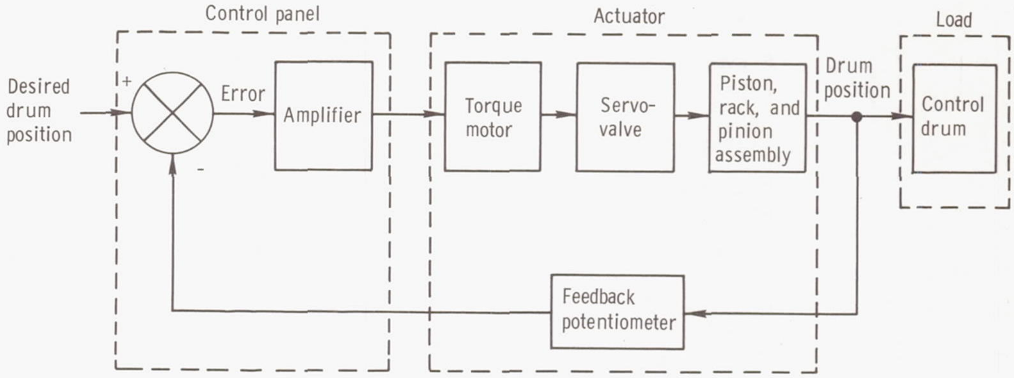


Figure 2. - NERVA actuator closed-loop positioning system.

drum position is compared with the desired drum position. Any difference between the signals is amplified and sent to the actuator to correct the drum position. This procedure is continued until the difference between the input and output signals is zero.

Actuator Control Panel

The summing junction and amplifier portion of the closed-loop control system are mounted in a control panel (see fig. 3) remotely located from the actuator. Also mounted in the control panel are the following:

(1) A manually adjustable position command potentiometer

(2) Visual indication of the input command, output position, and error or torque motor current

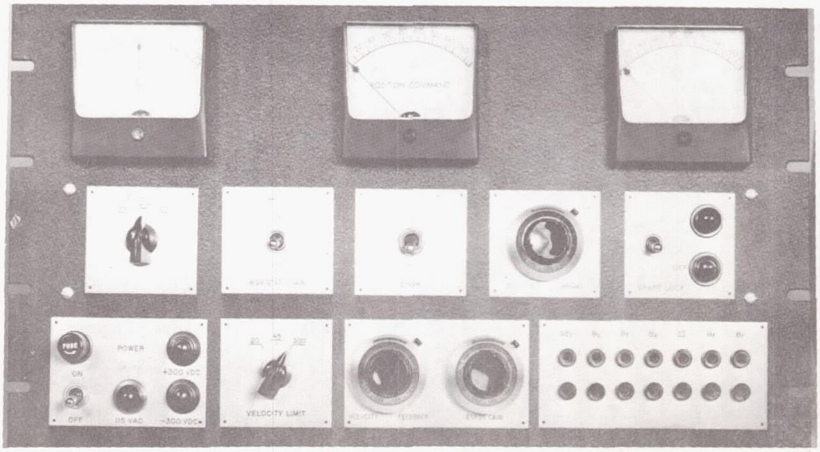


Figure 3. - Control drum actuator amplifier (front panel).

(3) Adjustable system error and rate gain potentiometers

(4) Electrical lock control

(5) Lock indication lights

(6) Manual scram command switch

(7) Adjustable velocity limiting potentiometers with a selection of 20°, 45°, or 300° per second

The amplifier is a conventional operational amplifier type, using plug-in modules. Included in the amplifier is a lead-lag network to compensate for the actuator-load dynamics.

Simulated Control Drum Assembly (Load)

During irradiation testing the control drum actuator was attached to a simulated control drum assembly. The simulated control drum, as shown in figure 4, contains the inertia, Coulomb friction, and spring system necessary to simulate a NERVA control drum. In addition, the simulated control drum provided a convenient interface between the actuator and the irradiation capsule.

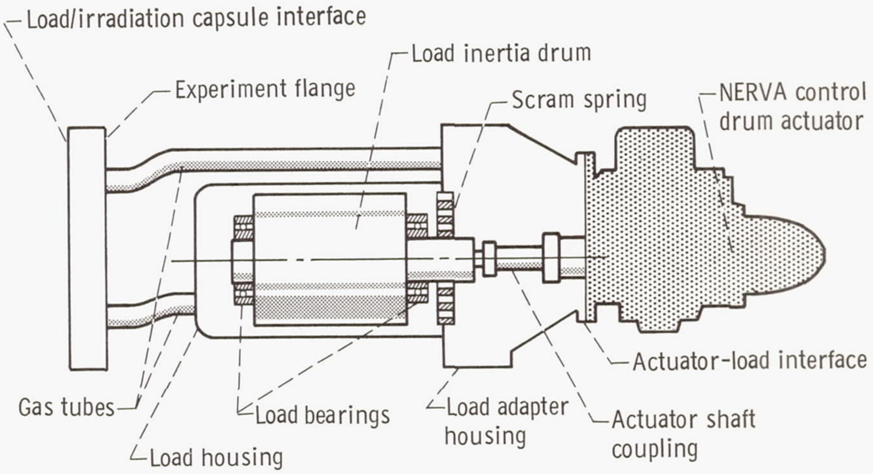


Figure 4. - Simulated control drum assembly.

IRRADIATION FACILITY

The NERVA actuator irradiation test program was conducted at the Lewis Research Center's Plum Brook Reactor Facility (PBRF). The reactor, as shown in figure 5, is mounted in a vertical, cylindrical pressure tank. Also shown in figure 5 are the loca-

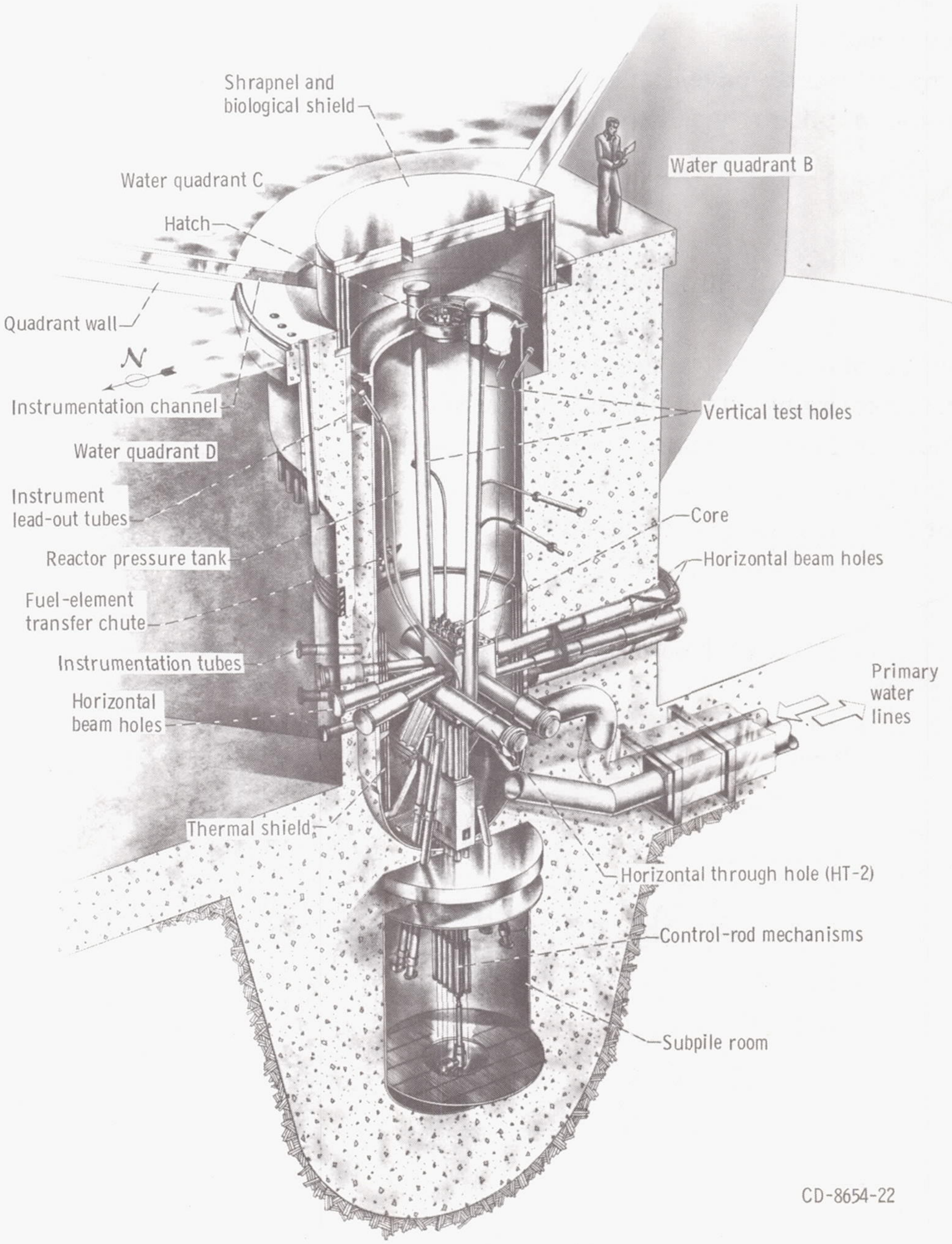


Figure 5. - Cutaway view of NASA Plum Brook Reactor tank showing core.

tions of various horizontal and vertical test holes, with respect to the reactor, that are used for experiments. For the actuator irradiation test program, horizontal through hole 2 (HT-2) was utilized. HT-2 is located adjacent to the reactor and traverses the reactor tank. For the irradiation program, entrance to HT-2 was made from quadrant C. For biological shielding, quadrant C is filled with 25 feet (7.6 m) of water. (A complete description of the PBRF can be found in an unpublished NASA report: Davis, A. B.; Lubarsky, B.; and Hallman, T. M.: Final Hazards Summary, NASA Plum Brook Reactor Facility. Parts 1, 2, and 3. December 1959.)

IRRADIATION TESTING SYSTEM

The irradiation testing system is described in detail in reference 4. Presented in this section is a brief summary of the major system components.

Irradiation Capsule

The irradiation capsule that positions the actuator in the HT-2 test hole is shown in figure 6. The capsule is divided into 2 portions, a snout and an equipment box. The front portion of the snout contains the actuator and the simulated control drum assembly. A partial vacuum of approximately 25 microns of mercury (3.3×10^{-4} N/cm^2) is maintained in the volume surrounding the actuator and load. The remainder of the snout serves to transmit the drive and coolant gas supplies and electrical connections to the actuator. The equipment box at the back of the capsule contains the vacuum system and the final control valves for the cryogenic gas supplies.

Capsule Insertion Table

The irradiation capsule was supported by a table which can insert the capsule into HT-2 while the reactor is in operation. The table operates under 25 feet (7.6 m) of water and is of ball nut and screw design. The ball screw is driven by a three-phase induction motor and inserts or withdraws the experiment capsule at a rate of 56 centimeters per minute.

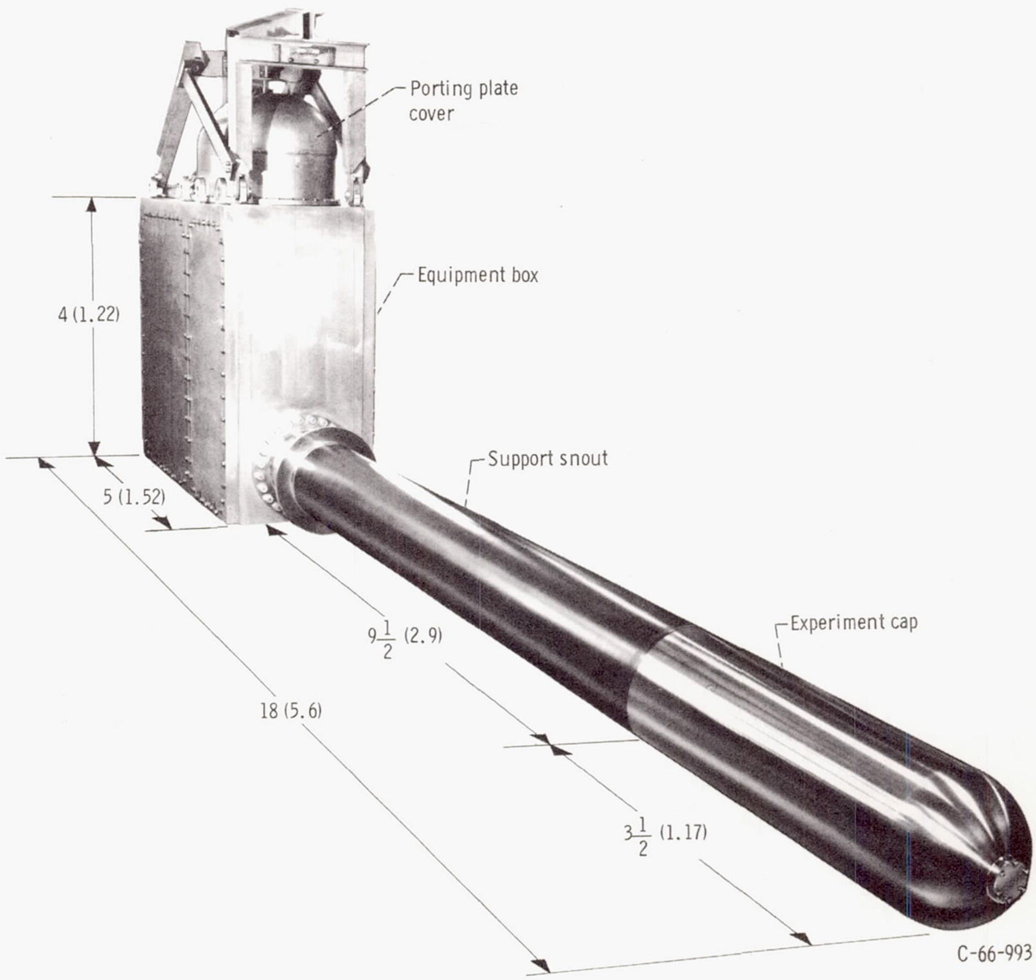


Figure 6. - Experiment capsule. All dimensions are in feet (m).

Cryogenic Gas Supply

In NERVA applications, the actuator will use hydrogen drive and coolant gas supplies. However, because of safety requirements, helium gas was chosen as the drive and coolant gas for the irradiation test program.

The cryogenic gas supply provides for independently controlled drive and coolant gas. The drive gas supply is capable of maintaining a minimum gas temperature of 55.5 K and a maximum pressure of 700 psi (483 N/cm^2). Both supplies are capable of being maintained during insertion or withdrawal of the irradiation capsule in HT-2.

NUCLEAR ENVIRONMENT

The gamma dose rate and fast neutron flux that the actuator was subjected to in HT-2 during the irradiation testing were determined from tests conducted in the Plum Brook Mockup Reactor (MUR). The purpose of the mockup facility is to permit flux mapping and reactivity measurements to be taken independent of the PBR, thus allowing a more efficient utilization of the PBR for high power radiation experiments. (A complete description of the MUR can be found in an unpublished NASA report: Final Hazards Summary, Mockup Reactor, NASA Plum Brook Reactor Facility. Sept. 1962.)

In the mockup facility, the actual experiment and capsule can be inserted into simulated test holes. Thus flux mapping obtained from the mockup facility is based on a simulation of the conditions in the test hole that an experiment would experience in the main reactor facility test holes.

For the mockup tests, radiation instrumentation was placed at ten locations around the periphery of the actuator. The gamma dose rate was determined by using thermal luminescence dosimeters. The neutron flux was determined from sulfur, indium, aluminum, and nickel foils.

Measurements of the gamma dose rate and neutron flux in HT-2 were made as a function of the actuator distance from core centerline. Initial measurements were taken with the actuator inserted into the mockup reactor such that the tip of the actuator's potentiometer cover was on the reactor core centerline. Succeeding measurements were made with the tip of the cover located at 34, 61, 91.5, and 122 centimeters from core centerline.

Figure 7 presents the gamma dose rate and the fast neutron flux ($E > 1.0$ MeV) along the centerline of HT-2 as a function of the distance from the reactor core centerline.

Figures 8(a) to (c) show the gamma dose rate and neutron flux distribution about the actuator. The actuator is positioned in HT-2 such that the tip of the potentiometer cover is 61 centimeters from core centerline.

As an aid in checking the validity of the flux measurements, foils were also placed on the experiment during the irradiation in PBRF. Correlation was obtained by ratioing the PBRF data with the MUR data.

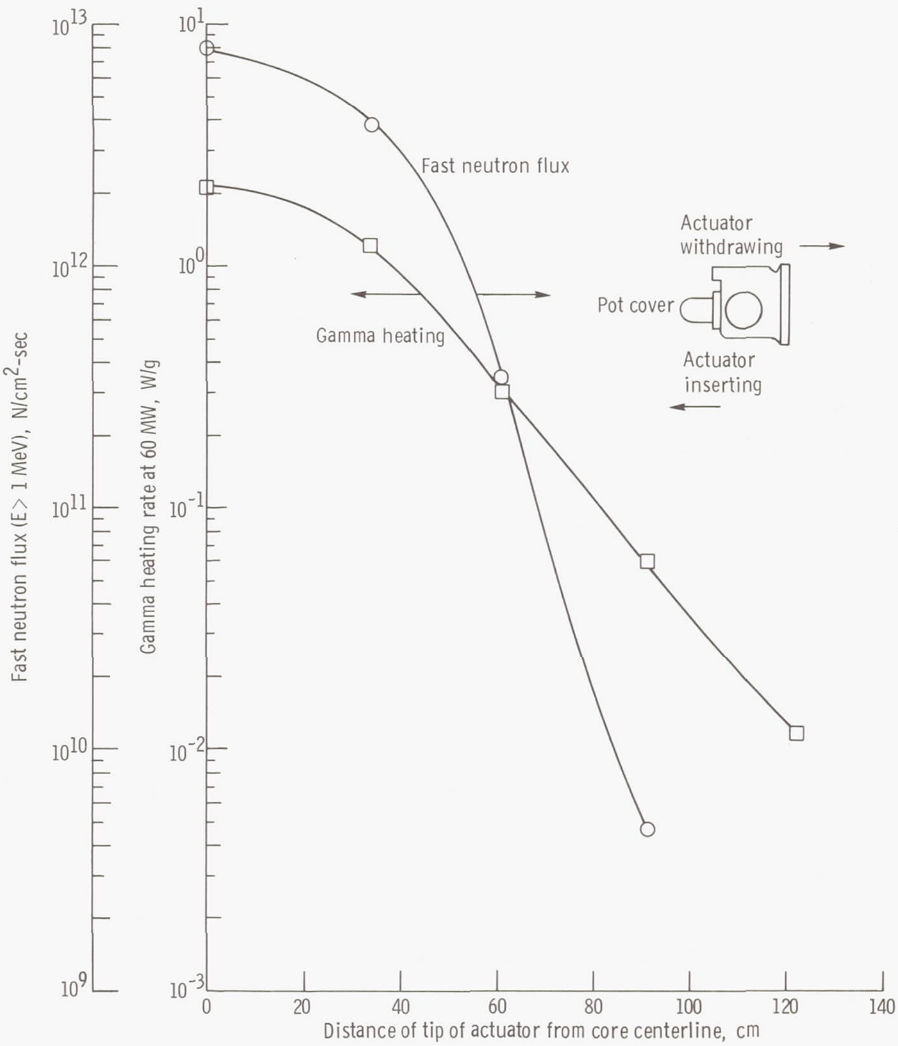


Figure 7. - Radiation level along centerline of HT-2 on tip of NERVA actuator.

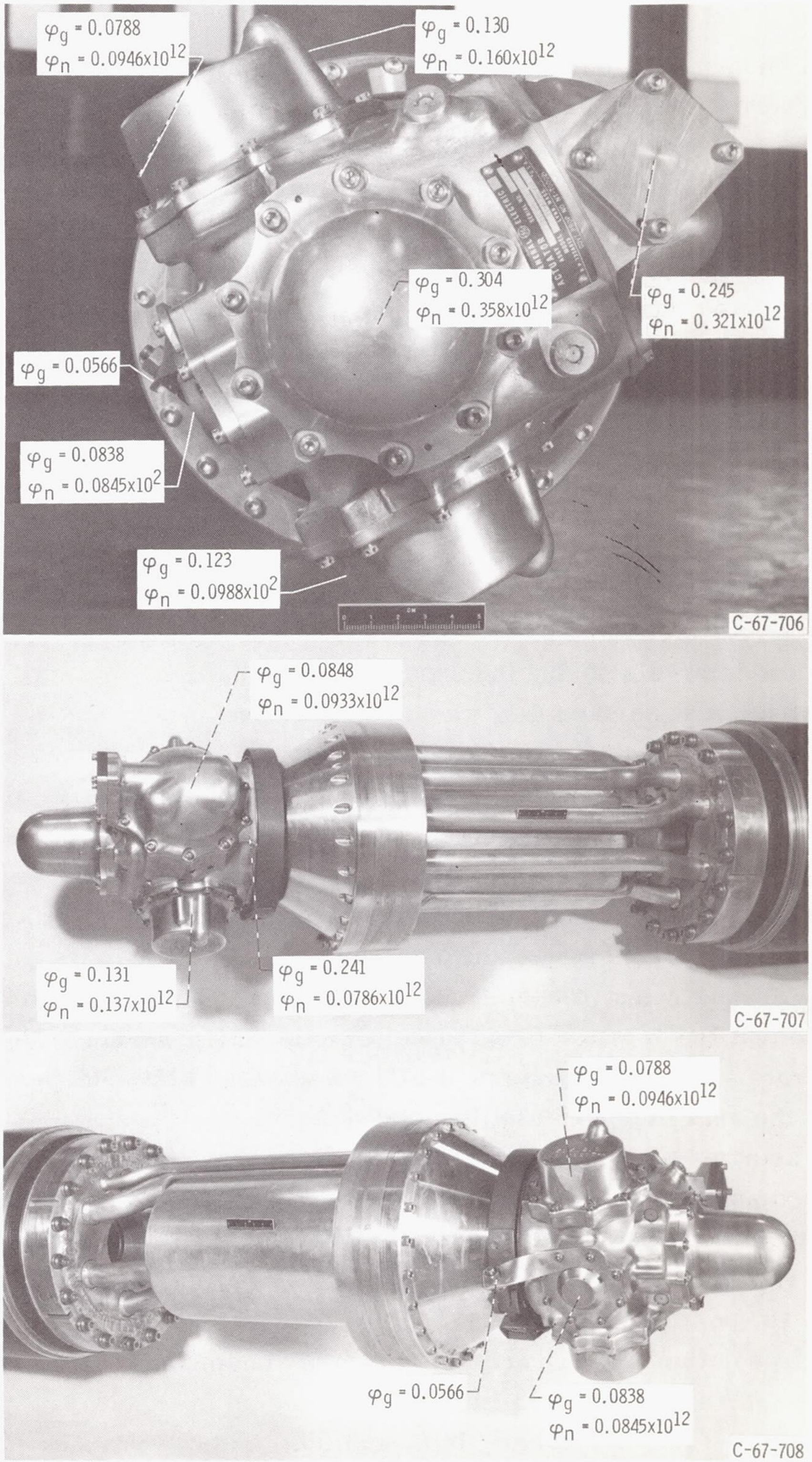


Figure 8. - Gamma dose rate and neutron flux distribution about the actuator. Gamma dose rate, φ_g, watts per gram; neutron flux at 60 megawatts (E >1 MeV), φ_n, neutrons per square centimeter per second; distance from core centerline, 61 centimeters.

THERMAL ENVIRONMENT

The thermal environment during irradiation was established by inserting the experiment as near to core centerline as possible without excessive component temperature rise due to gamma heating. To monitor the temperature rise, thermocouples were placed on selected experiment components. The type and location of these thermocouples is described in the instrumentation section of this report.

For periods of actuator operation outside the nuclear environment, minimum experiment temperature was a function of maximum coolant pressure obtainable while maintaining a partial vacuum of 25 microns of mercury (3.3×10^{-4} N/cm^2) around the actuator and load.

TEST PROGRAM

Actuator performance was investigated as a function of irradiation time. The test program consisted of establishing preirradiation base-line data and recording comparison data at various time intervals during the experiment irradiation. A set of post-irradiation out-of-pile comparison data was also recorded.

For the test program, actuator performance was measured in terms of its ability to function in a closed-loop positioning system. In establishing the base-line data and in obtaining comparison data, the actuator was subjected to a series of six performance tests.

(1) Manual sweep - The manual sweep test is accomplished by rotating the manual command potentiometer. This forces the actuator to rotate through its entire working range. The test demonstrates that the locking system has released the actuator from its shelf position and that the actuator is operable over its entire working range.

(2) Static scram - The actuator is manually commanded to its 90° position. The scram switch on the amplifier panel is then placed in the "on" position. This grounds the signal to the actuator torque motor coils and causes the actuator to drive towards the 0° position at maximum unlimited velocity. The test provides a measurement of the maximum acceleration of the actuator as it drives toward the 0° position and as it rebounds from the 15° soft-stop spring. The test also measures the maximum amount of rebound past the 15° position.

(3) Dynamic resolution - The actuator is manually commanded to its 90° position. A 3° per second, $\pm 50^\circ$ ramp input is then superimposed on the manual command. The actuator then ramps between its 40° and 140° position. This test measures the ability of the actuator to follow the ramp input and provides a means of calculating dynamic position error. Dynamic position error is calculated by comparing the output position trace to the input command trace.

(4) Step response - The actuator is manually commanded to its 90° position. A 1 hertz, $\pm 9^{\circ}$ square wave is then superimposed on the manual command. This test provides data for the calculation of rise time and settling time. For this test program, rise time is defined as the time required to travel 62.5 percent of command travel. Settling time is defined as the time required to travel to within 1° of final position.

(5) Dynamic scram - The actuator is manually commanded to its 15° position. A positive step input is then superimposed on the manual command and the actuator ramps toward its 180° position at maximum limited velocity. When the actuator reaches the 140° position the step input is reversed and the actuator then ramps toward the 0° position at maximum limited velocity. The test provides data for the calculation of the scram turnaround time and the time to scram 30°. The scram turnaround time is defined as the time required, from initiation of scram signal, to reach zero velocity in the outward direction (towards 180°). The time to scram 30° is defined as the time required for the actuator to move 30° in the inward direction after initiation of the scram signal. The maximum velocity is defined as the maximum time rate of change of actuator position during a step change of actuator position in either the outward or inward direction. For the actuator tests covered in this report, the actuator control amplifier was adjusted to limit actuator velocity to approximately 300° per second, except for the static scram tests.

(6) Frequency response - The actuator is manually commanded to its 90° position. A variable-frequency, $\pm 2^{\circ}$ sinusoidal input is then superimposed on the manual command. This test provides data for the calculation of actuator gain and phase lag. Actuator gain is defined in decibels and is numerically equal to 20 times the logarithm (base 10) of the ratio of output position to command position. Phase lag is the number of degrees which the output position lags behind the commanded position.

RECORDED DATA

The data recorded for the irradiation test program included the following:

(1) Recording of key closed-loop parameters required to determine actuator performance

(2) Recording of cold gas system temperatures and pressures to determine the condition of the drive and coolant gas supplies

(3) Recording of actuator and load component temperatures

The closed-loop parameters measured were recorded on a recording oscillograph. Drive, coolant, and exhaust gas temperatures and pressures were recorded on individual strip chart recorders. Temperatures of individual components in the actuator and load were recorded on a multipoint strip chart recorder. The type and location of each thermocouple is shown in table I.

TABLE I. - EXPERIMENT THERMOCOUPLE CHART

Thermo-couple	Type	Location[a]	Type of measurement
Pot TC	Copper constantan	Actuator pot	Wall thermocouple
Brg TC	Copper constantan	Actuator bearing	
TC a	Chromel constantan	Experiment flange	
TC b			
TC c			
TC d			
TC e			
TC f	↓	↓	↓
TC 1	Copper constantan	Load adapter	Gas thermocouple
TC 2			Gas thermocouple
TC 3			Wall thermocouple
TC 4			
TC 5			
TC 6		↓	
TC 7		Load housing	
TC 8		Load housing	
TC 9		Load bearing	
TC 10		Load bearing	
TC 11		Load housing	
TC 12			
TC 13			
TC 14		↓	
TC 15		Load drum	
TC 16			
TC 17			
TC 18	↓	↓	↓

[a]Refer to fig. 4.

RESULTS AND DISCUSSION

Actuator Performance During Operative Period

The actuator, operating in a closed-loop positioning system, was irradiated for 21.8 hours. The total irradiation time was accumulated during 4 insertion cycles into the reactor. These cycles are summarized in table II. The actuator received a gamma dose of 1.3×10^{11} ergs per gram (1.3×10^{9} rads) and a neutron fluence of 2×10^{16} neutrons per square centimeter. This corresponds to the estimated NERVA value for neutrons at full power and is 26 times the estimated NERVA value for gammas at full power.

The actuator performance did not change significantly during the irradiation testing. The only detectable changes in actuator performance during the 21 hours of irradiation

TABLE II. - IRRADIATION CYCLE DATA

Date	Irradiation cycle	Total time in pile, hr	Average gamma dose rate, rads/hr	Accumulated gamma dose, rad	Days between irradiation cycles
11/9/67	1	1.14	1.3×10^{6}	1.4×10^{6}	0
11/29/67	2	5.40	3.9×10^{7}	2.1×10^{8}	20
12/6/67	3	6.76	8.14×10^{7}	5.4×10^{8}	7
12/21/67	4	8.50	6.92×10^{7}	5.7×10^{8}	15
Total		21.80	--------	1.3×10^{9}	--

were probably due to a decrease in the system friction. The decrease in system friction can probably be attributed to wear on the actuator components during the total irradiation test program. The actuator accumulated over 30 hours operating time in preirradiation testing. The major portion of this preirradiation testing was at cryogenic temperatures and was used to establish the low temperature operating characteristics of the actuator.

Dynamic response measurements displaying actuator performance with irradiation time are shown in figures 9 to 13. These figures represent measurements of preirradiation data compared with data compiled during the inpile testing and data obtained out of pile after 21.8 hours of irradiation. The inpile data were recorded at 3 different levels of absorbed gamma dose and are labeled runs A, B, and C.

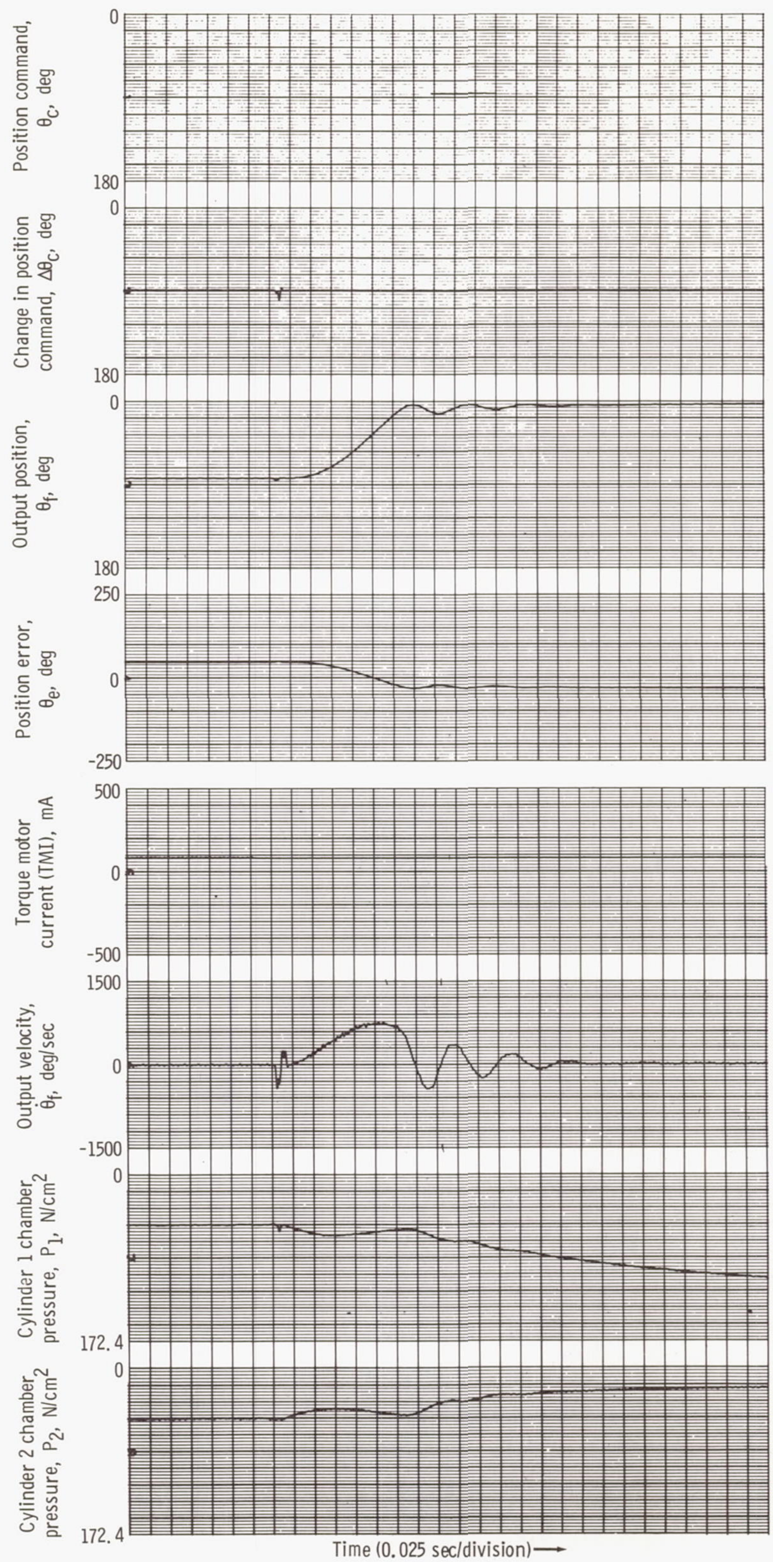
The out-of-pile data recorded after 21.8 hours of irradiation are listed as postirradiation data and represent the last data recorded during the actuator's operative period. Table III lists the temperature and radiation environmental conditions for each period when the data were recorded.

Static scram response data. - Figures 9(a) to (e) show oscillograph traces of the time response to a static scram. In this test the electric signal was removed from the torque motor coils and the output shaft driven mechanically toward the 0° position. During this test there were no electrical limits on velocity, thus the output velocity ($\dot{\theta}_f$) trace shows the unlimited velocity of the actuator's output shaft. The velocity and acceleration increased with irradiation time.

The output position traces (θ_f) show rebounding at the 15° position due to the mechanical soft-stop spring. The rebounding increased slightly with irradiation time.

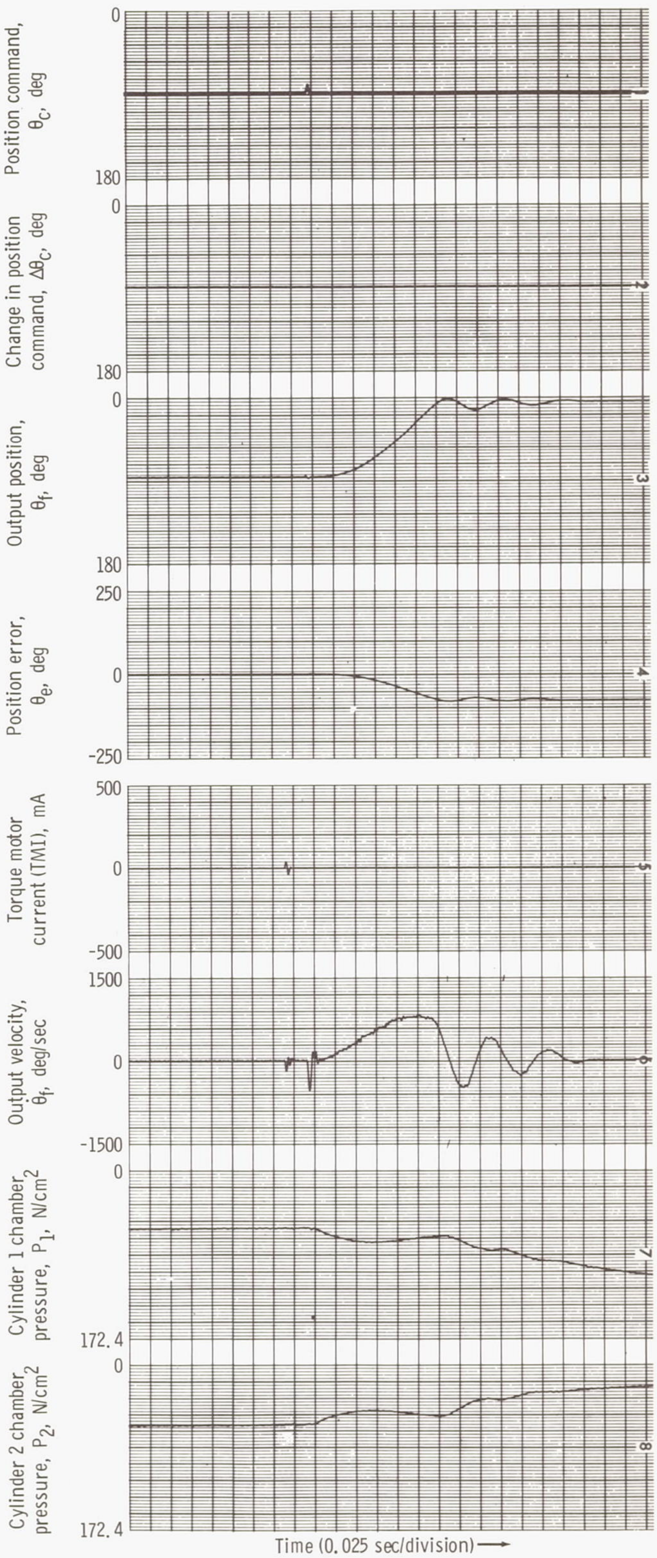
Dynamic resolution response data. - Figures 10(a) to (e) show oscillograph traces of the time response to a 100° p-p, 3° per second position ramp command. The dynamic resolution data showed no significant change during the irradiation test program.

Step command response data. - Figures 11(a) to (e) show oscillograph traces of the time response to an 18° p-p position step command. As shown on the output position



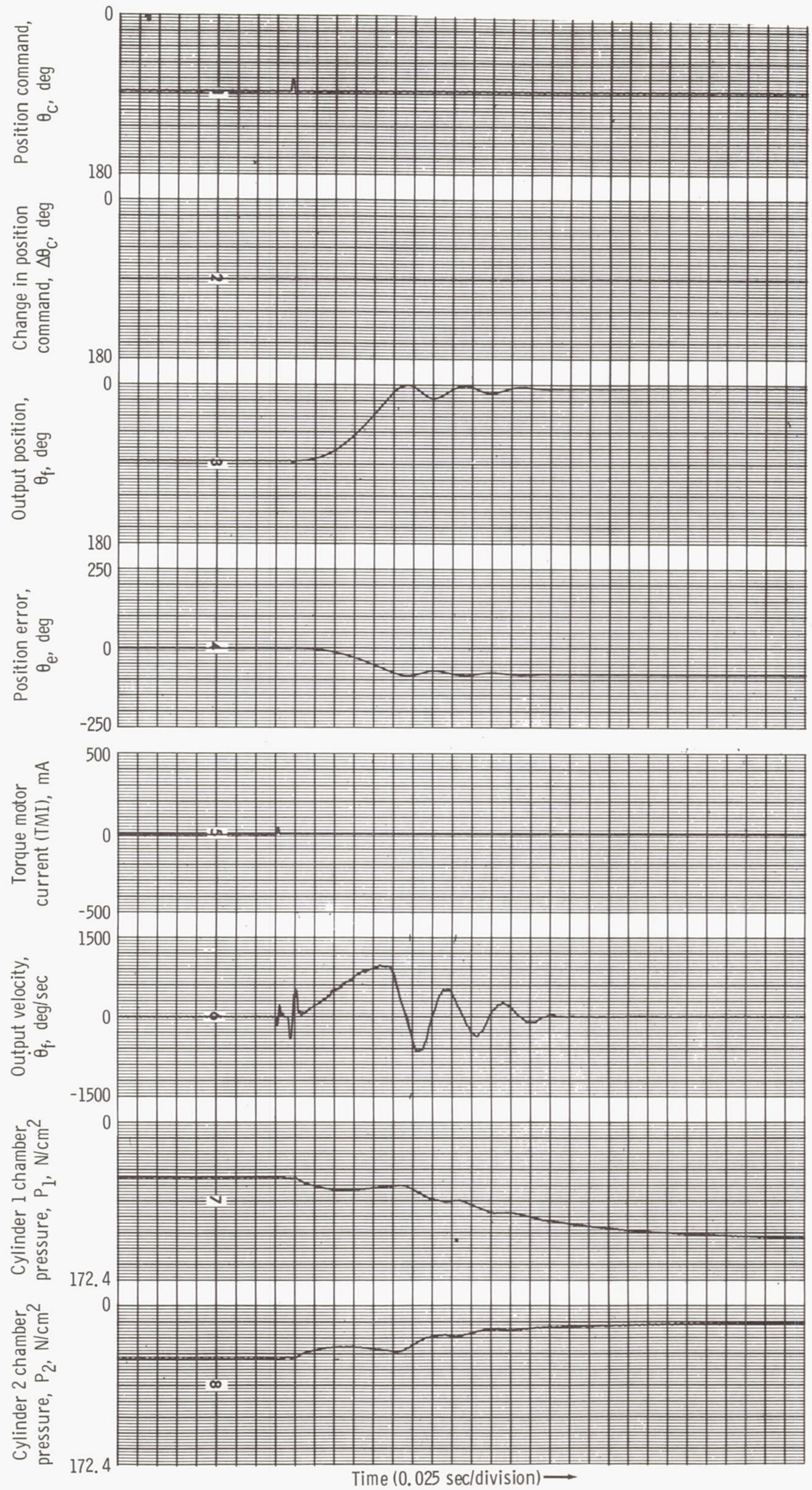
(a) Base-line data.

Figure 9. - Time response to a static scram.



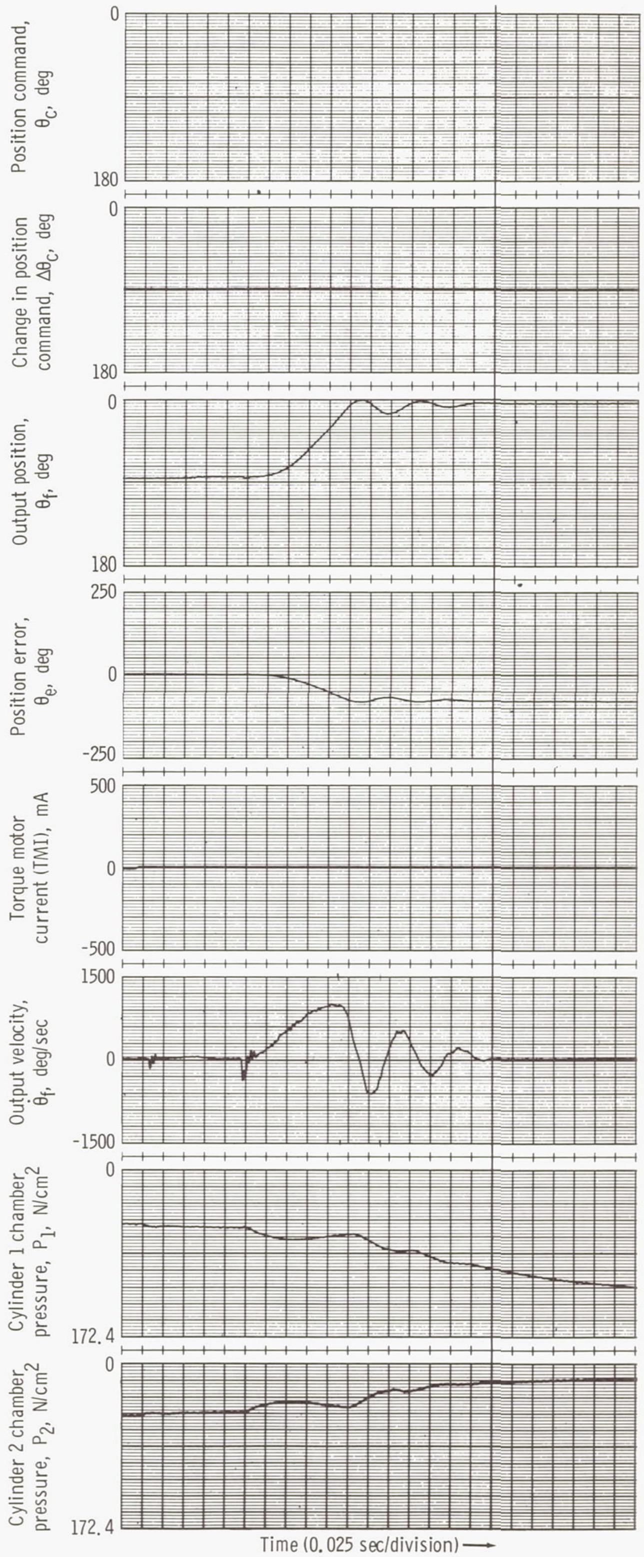
(b) Irradiation data. Run A. Gamma dose, 1.1×10^9 ergs per gram.

Figure 9. - Continued.



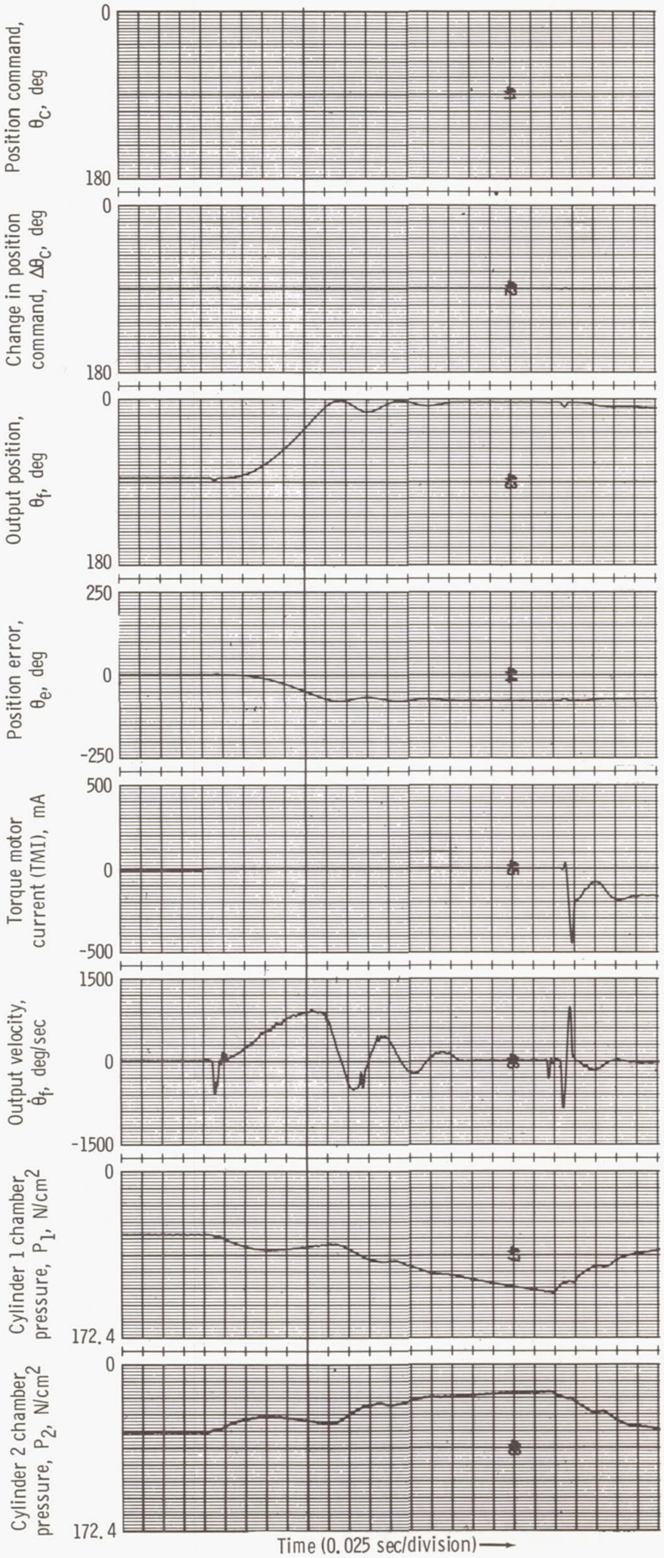
(c) Irradiation data, Run B. Gamma dose, 1.3×10^{10} ergs per gram.

Figure 9. - Continued.



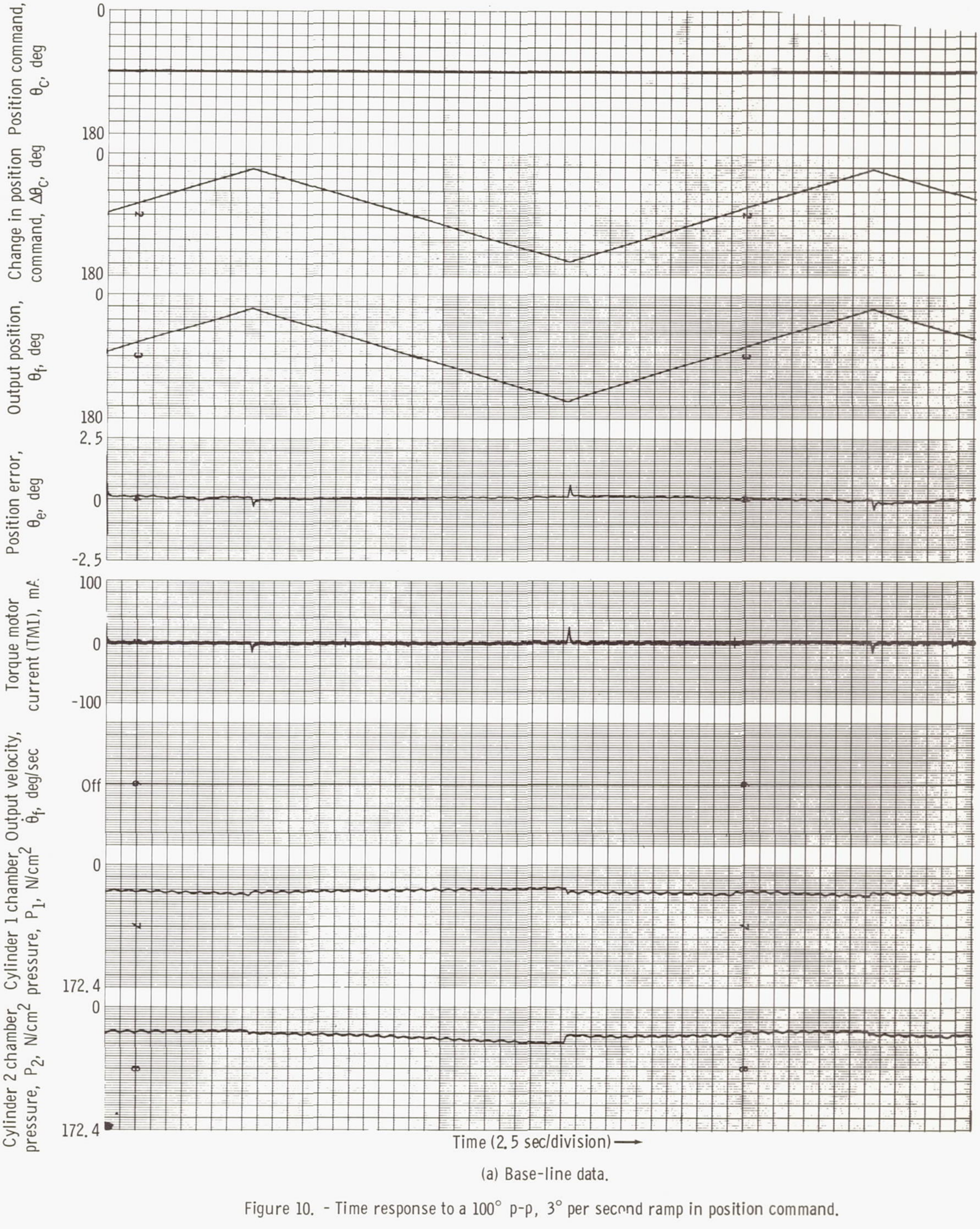
(d) Irradiation data. Run C. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 9. - Continued.



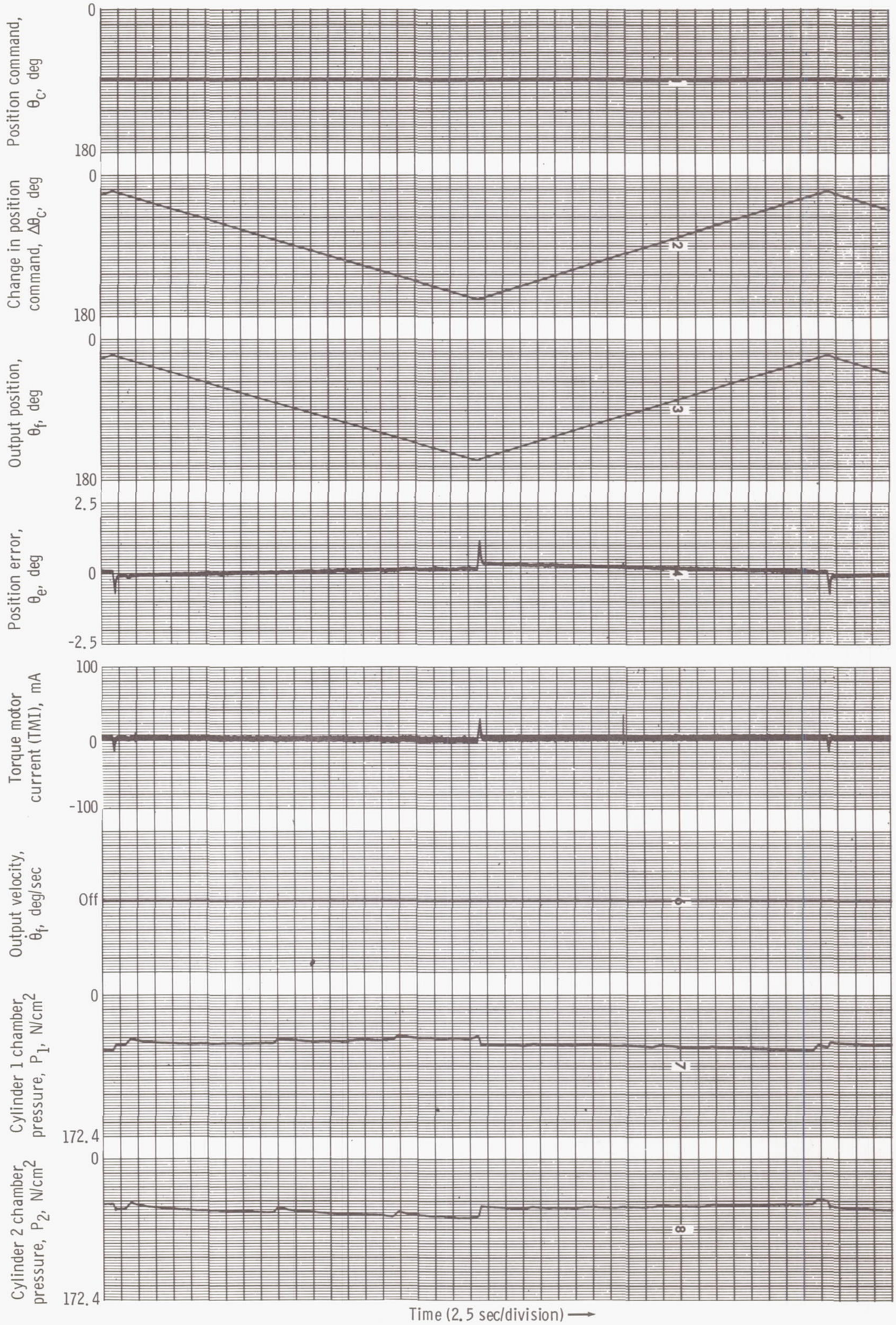
(e) Postirradiation comparison data. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 9. - Concluded.



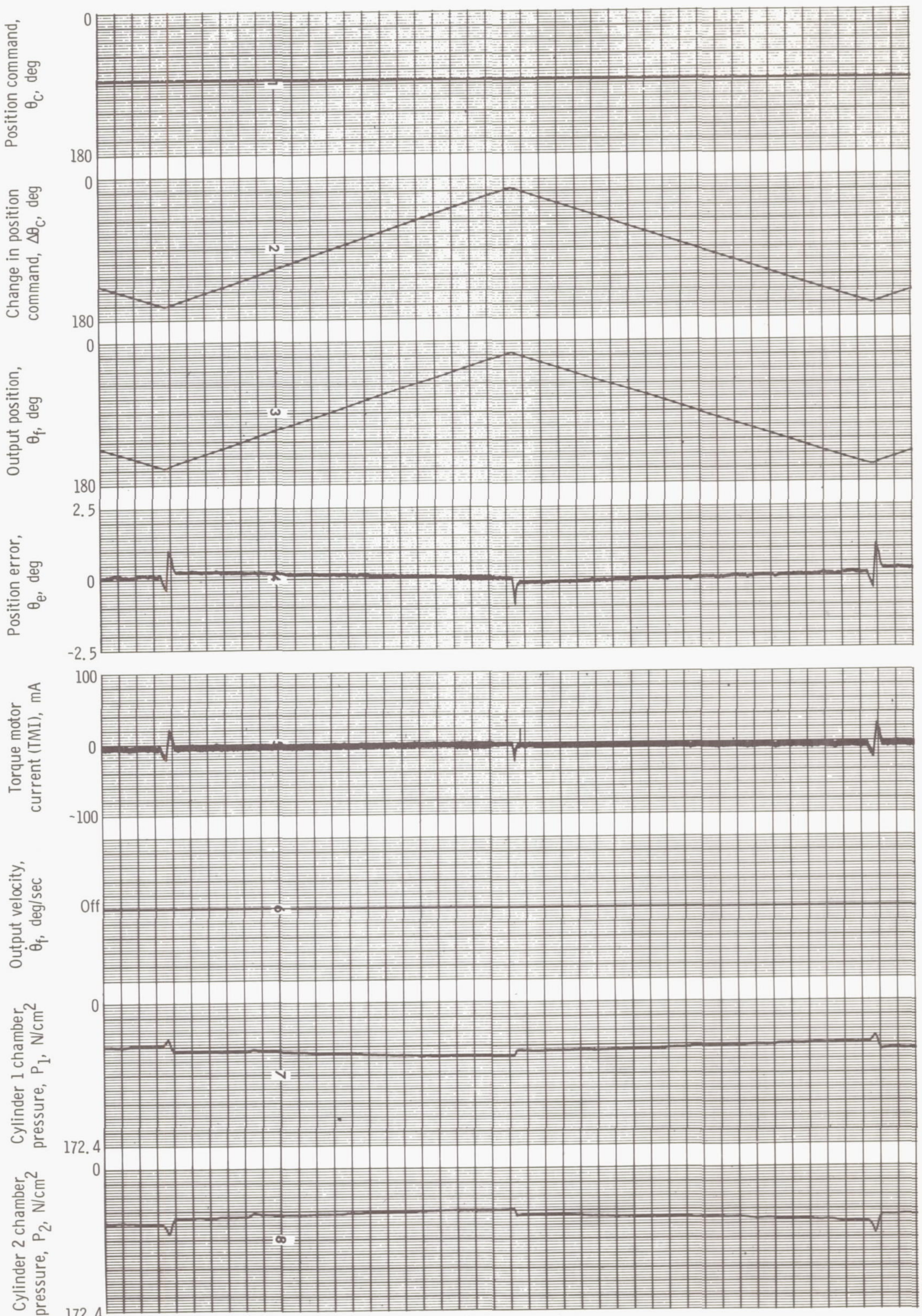
(a) Base-line data.

Figure 10. - Time response to a 100° p-p, 3° per second ramp in position command.



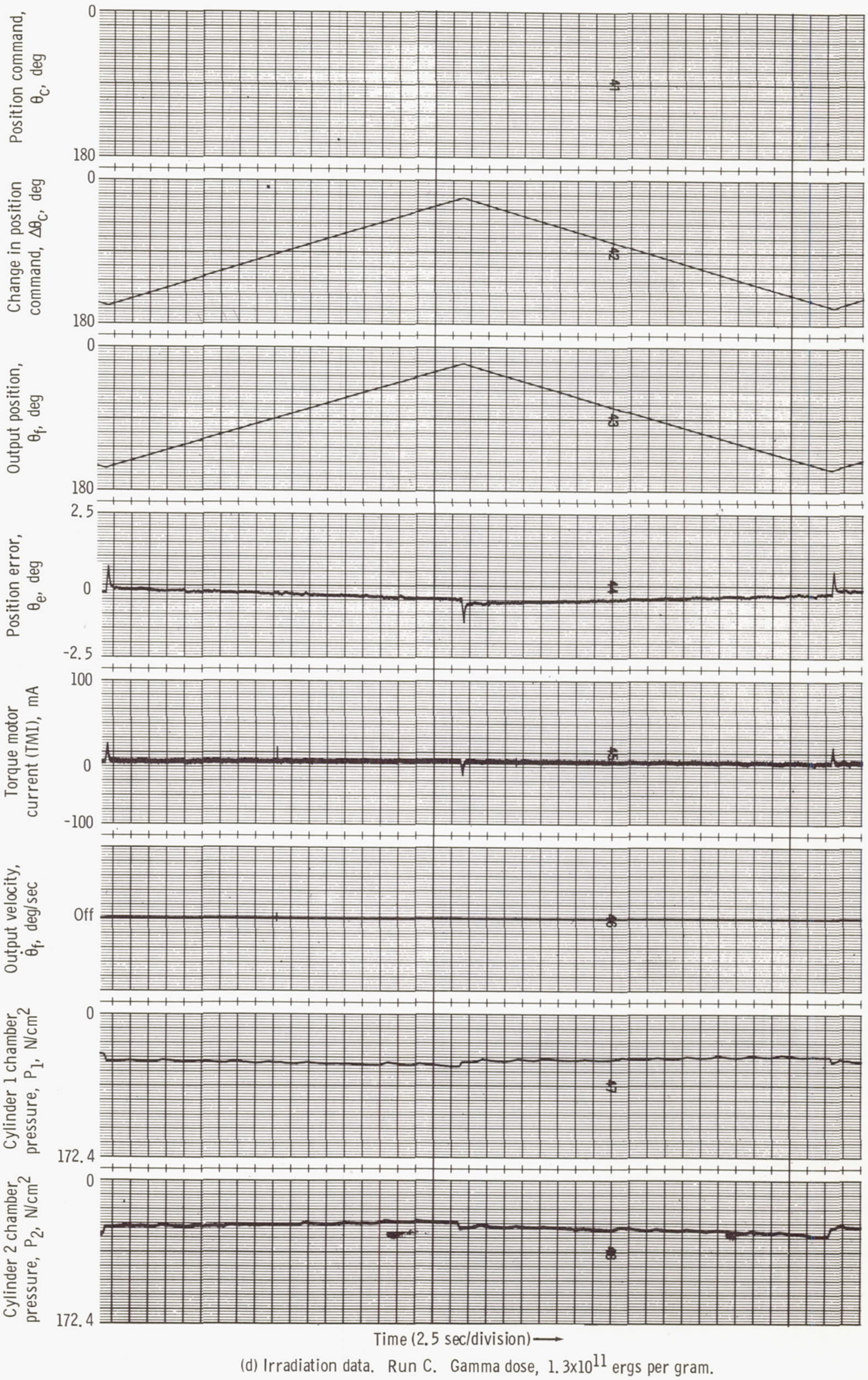
(b) Irradiation data. Run A. Gamma dose, 1.1×10^9 ergs per gram.

Figure 10. - Continued.



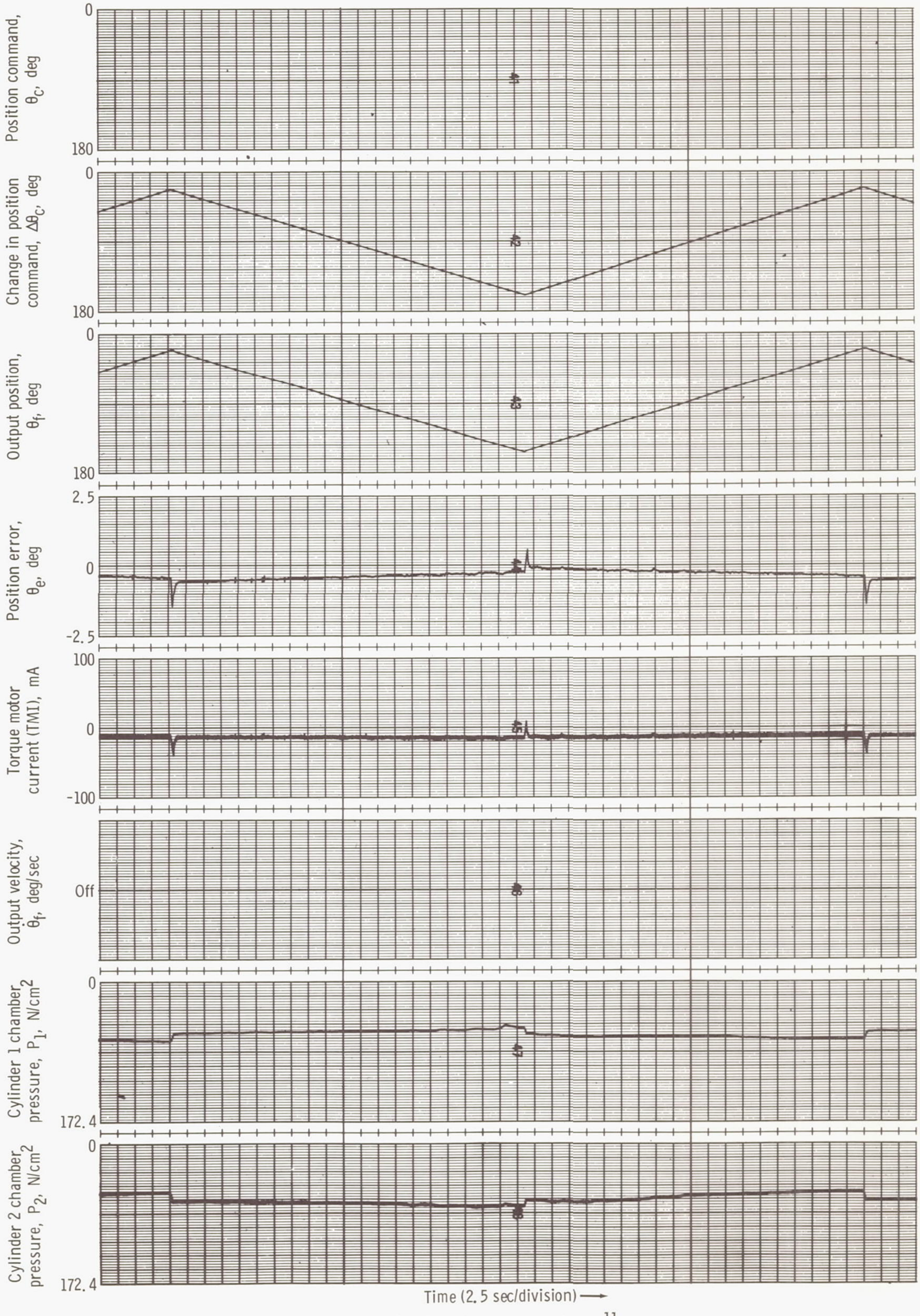
(c) Irradiation data. Run B. Gamma dose, 1.3×10^{10} ergs per gram.

Figure 10. - Continued.



(d) Irradiation data. Run C. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 10. - Continued.

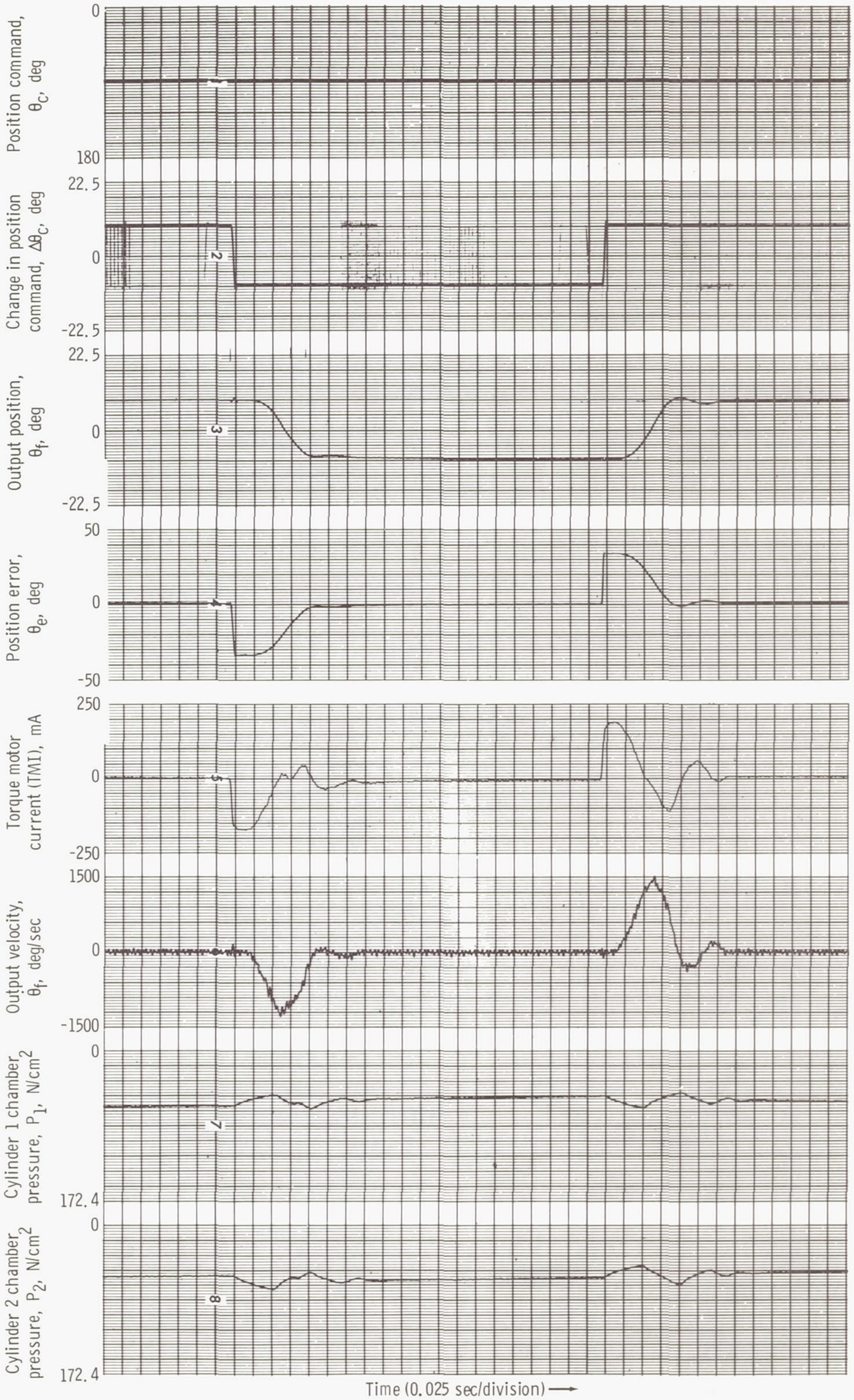


(e) Postirradiation data. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 10. - Concluded.

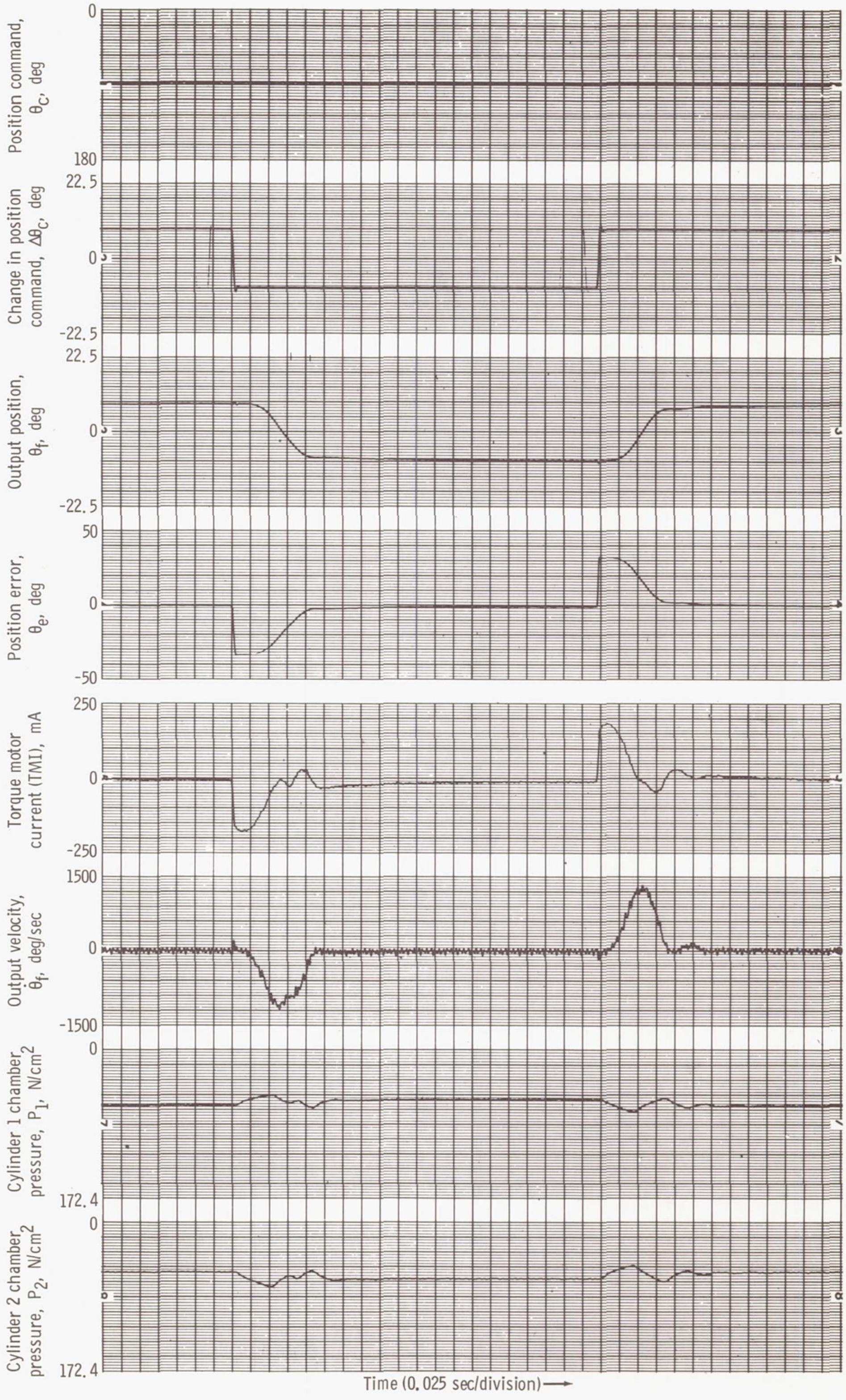
(a) Base-line data.

Figure 11. - Time response to an 18° p-p step in position command.



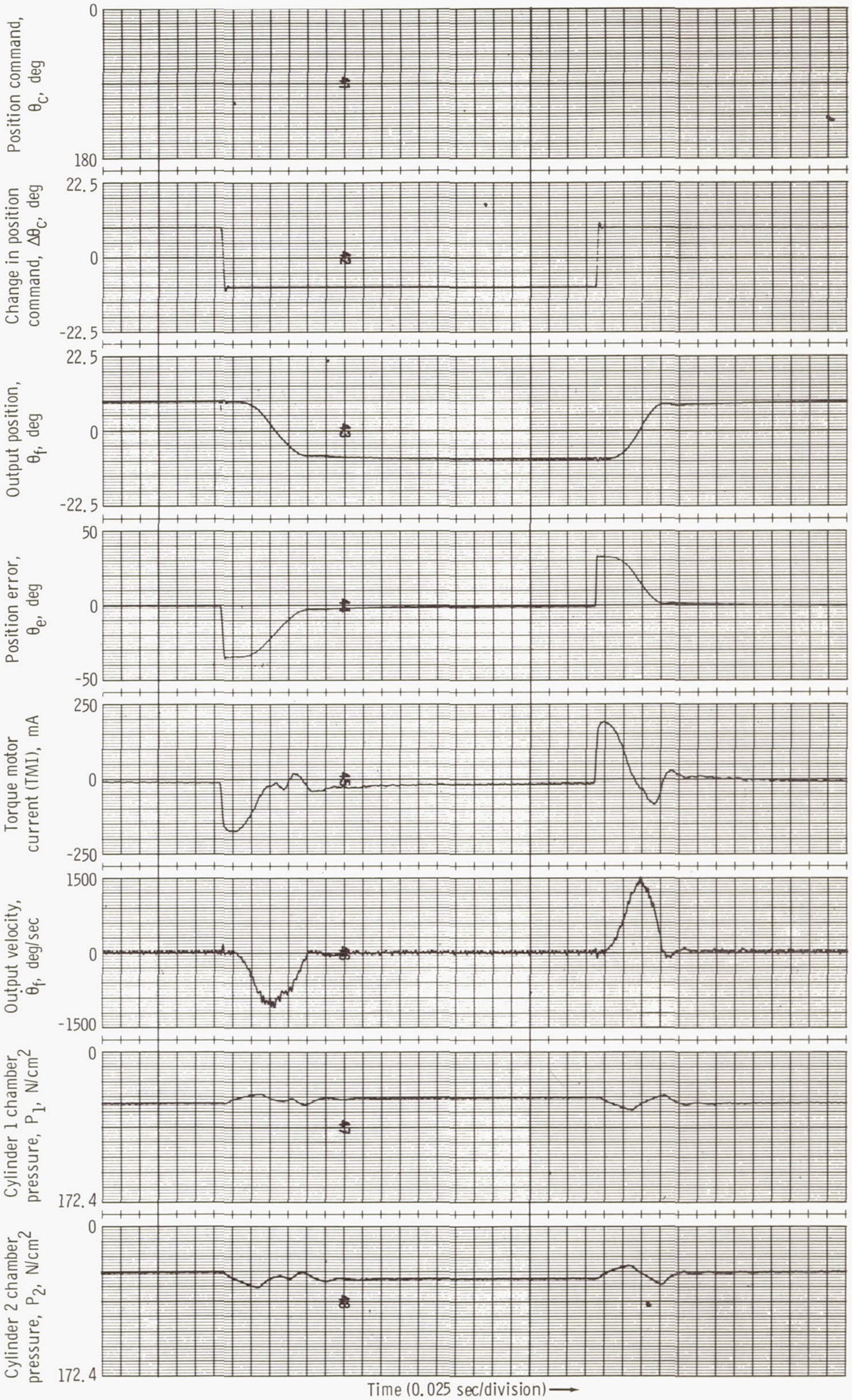
(b) Irradiation data. Run A. Gamma dose, 1.1×10^9 ergs per gram.

Figure 11. - Continued.



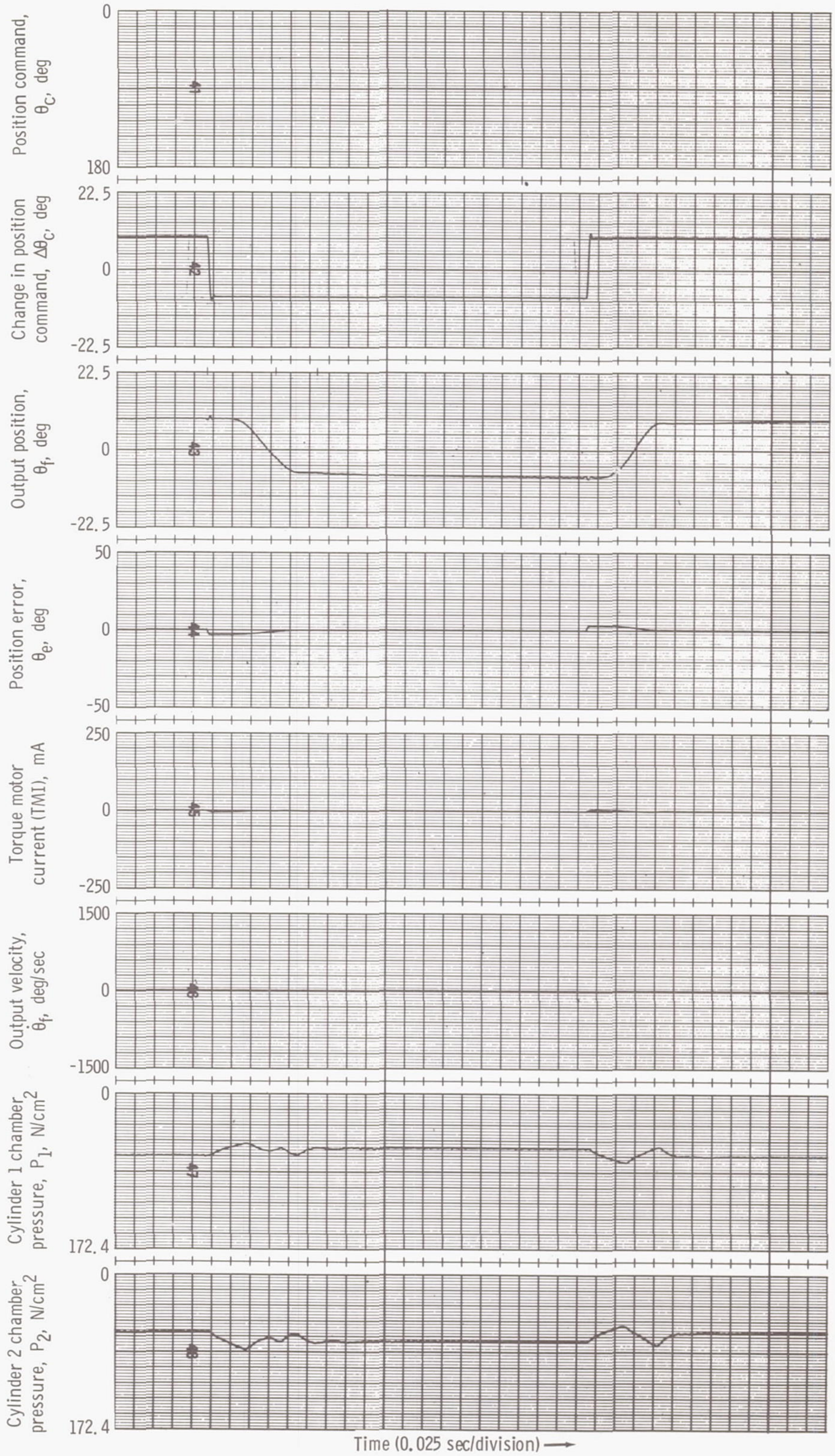
(c) Irradiation data. Run B. Gamma dose, 1.3×10^{10} ergs per gram.

Figure 11. - Continued.



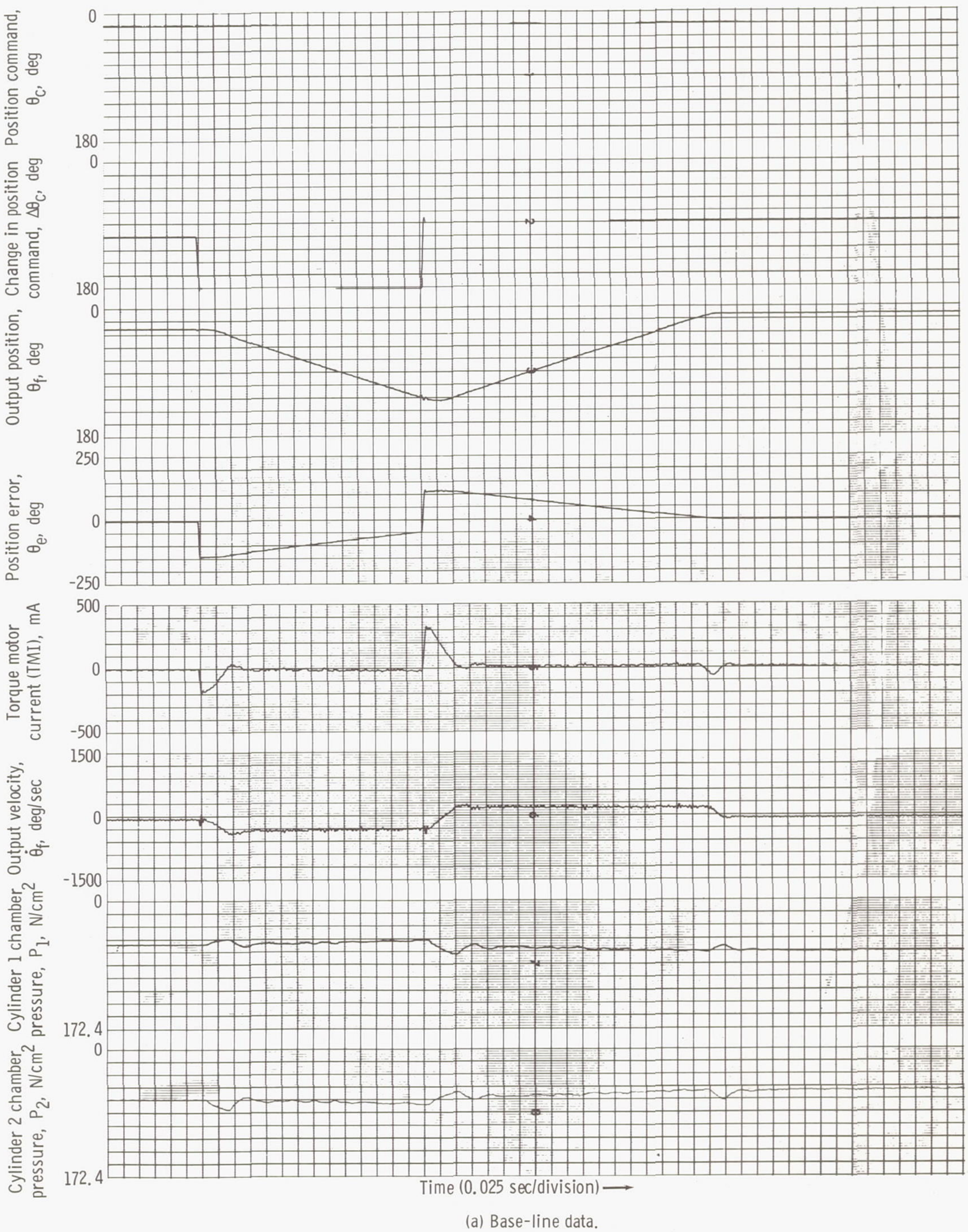
(d) Irradiation data. Run C. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 11. - Continued.



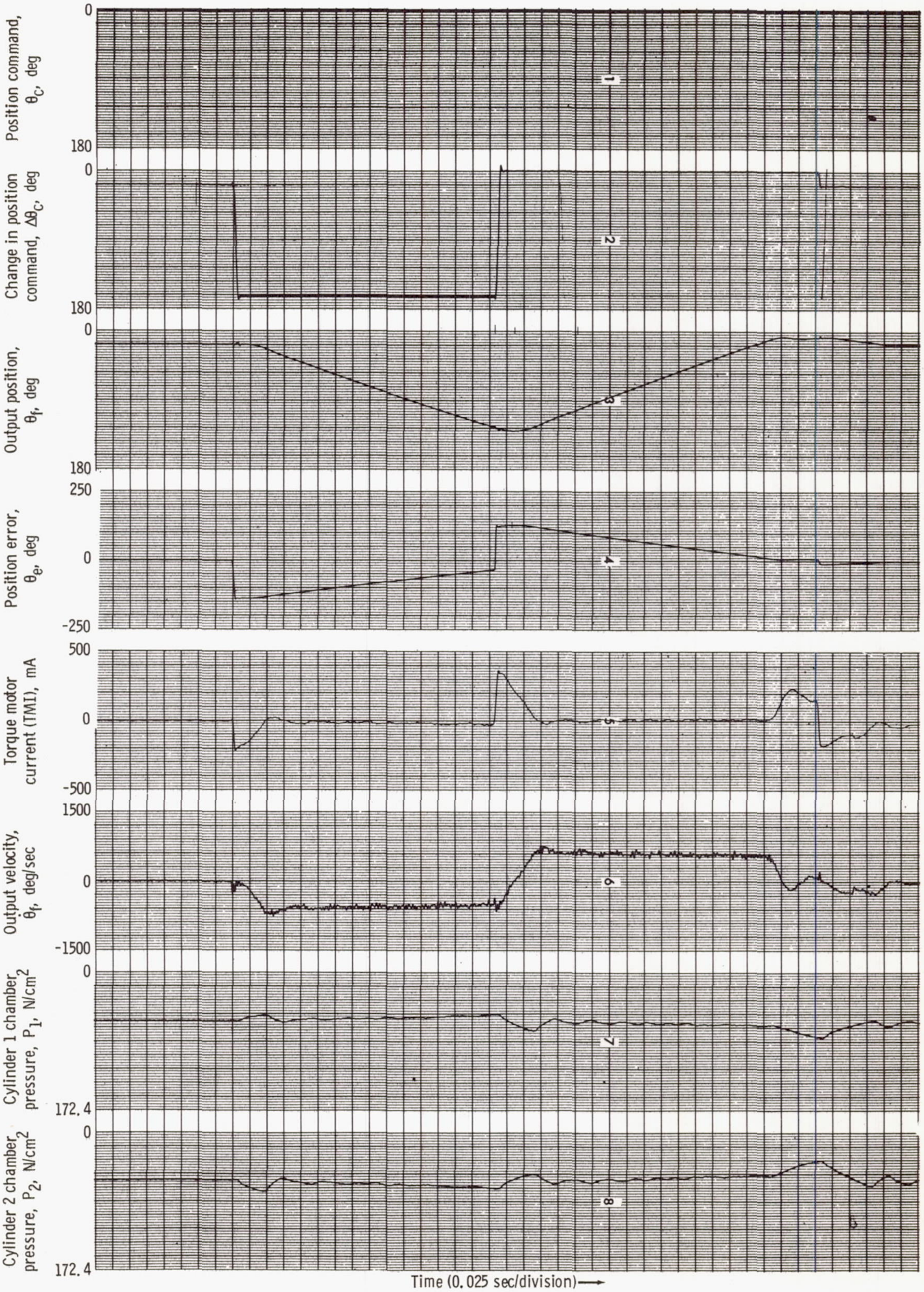
(e) Postirradiation data. Gama dose, 1.3×10^{11} ergs per gram.

Figure 11. - Concluded.



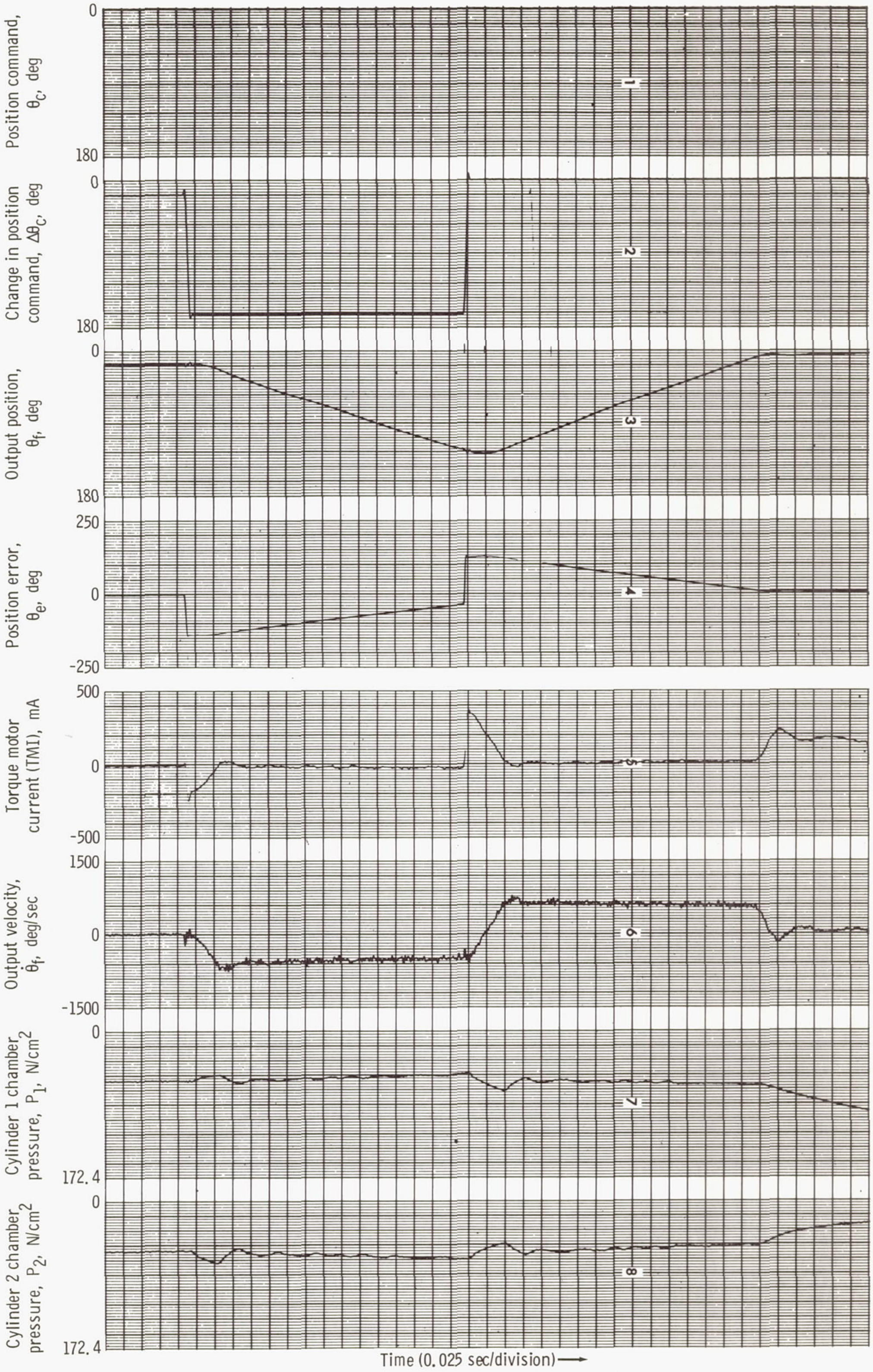
(a) Base-line data.

Figure 12. - Time response to a dynamic scram test.



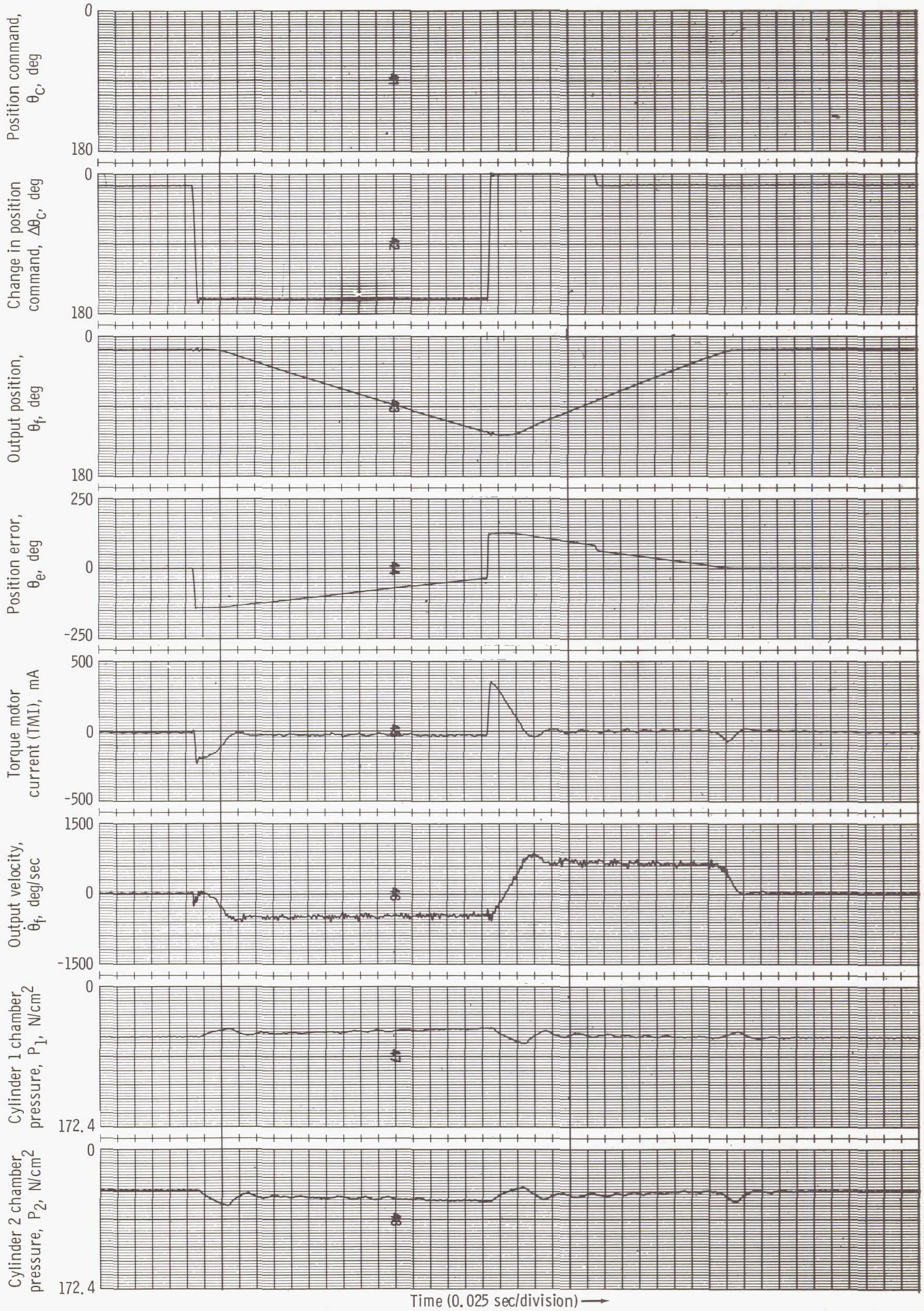
(b) Irradiation data. Run A. Gamma dose, 1.1×10^9 ergs per gram.

Figure 12. - Continued.



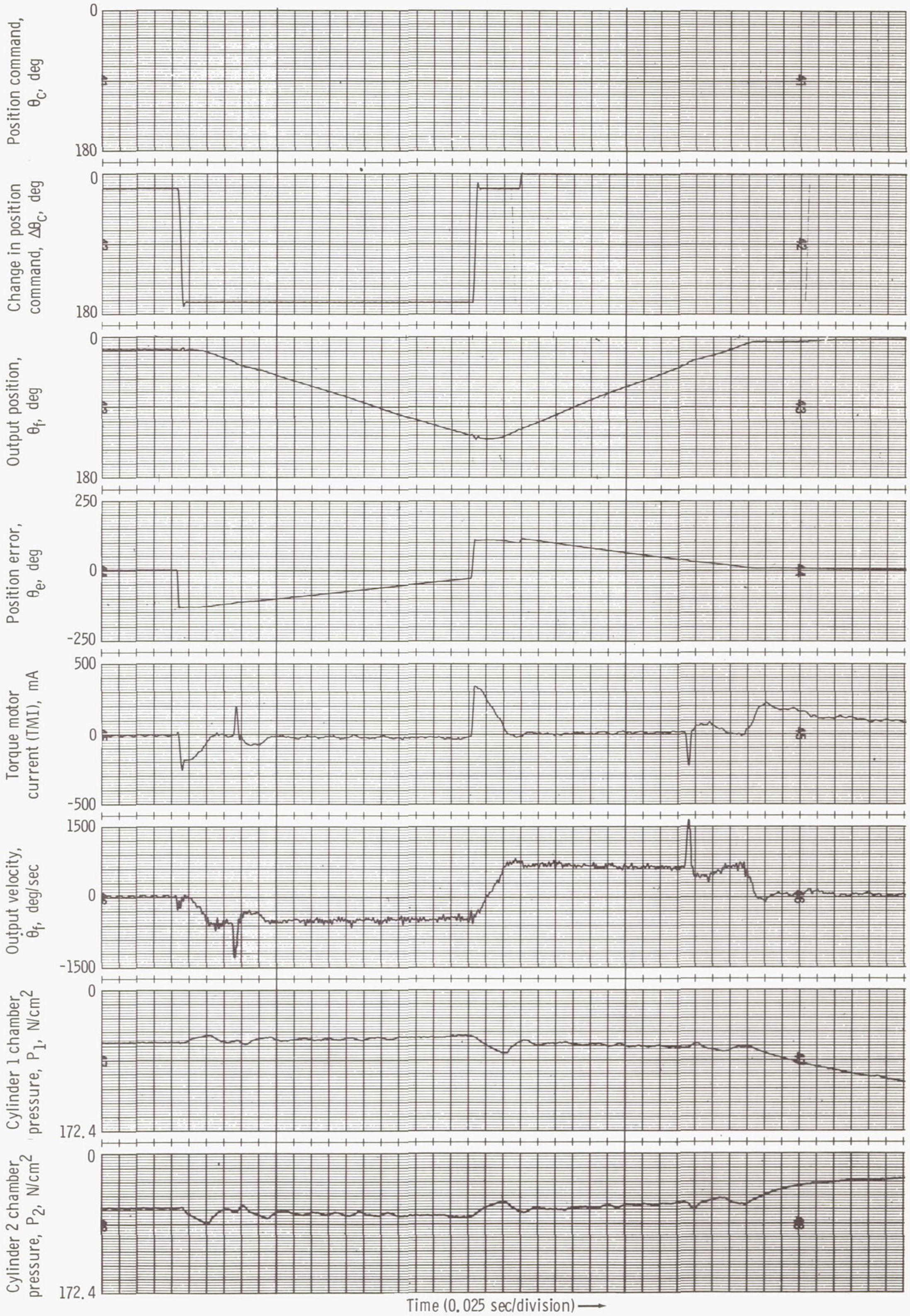
(c) Irradiation data. Run B. Gamma dose, 1.3×10^{10} ergs per gram.

Figure 12. - Continued.



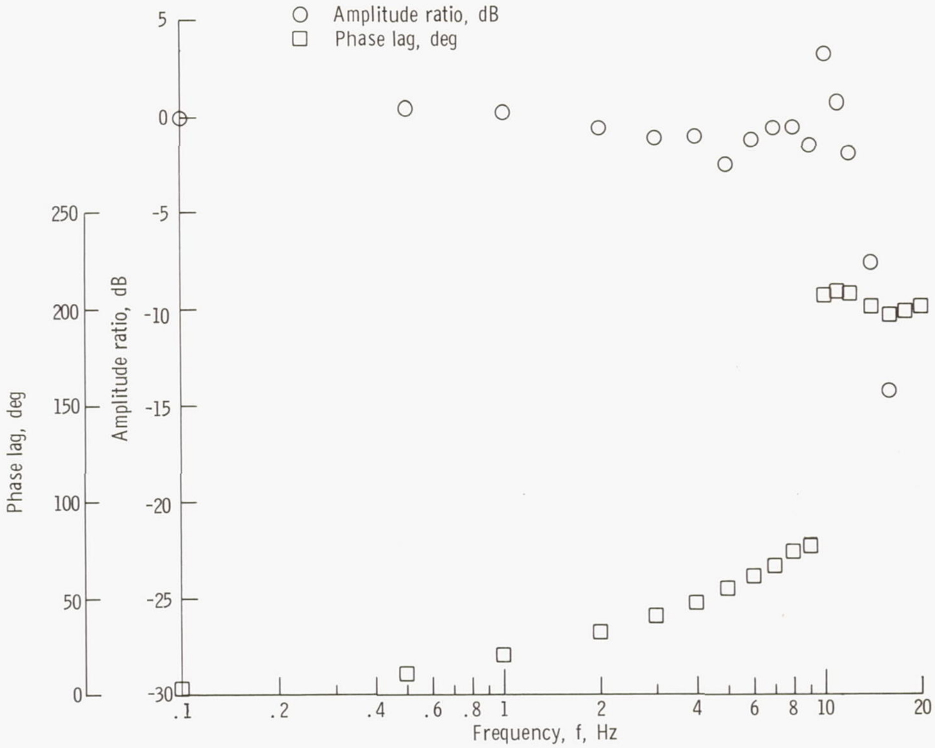
(d) Irradiation data. Run C. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 12. - Continued.

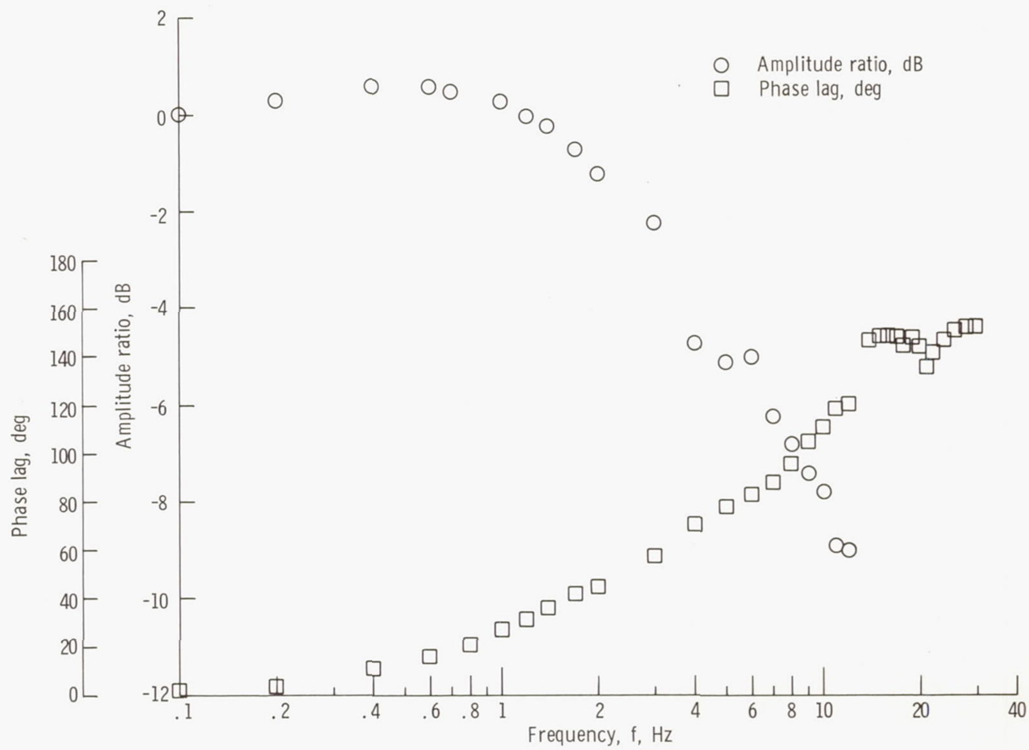


(e) Postirradiation data. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 12. - Concluded.

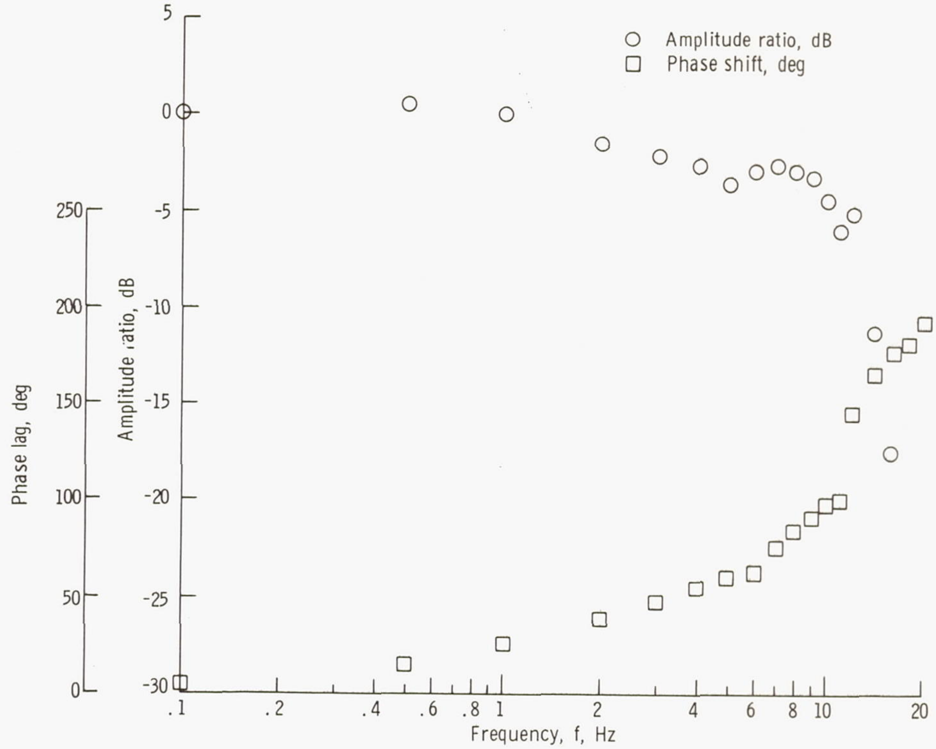


(a) Base-line data.

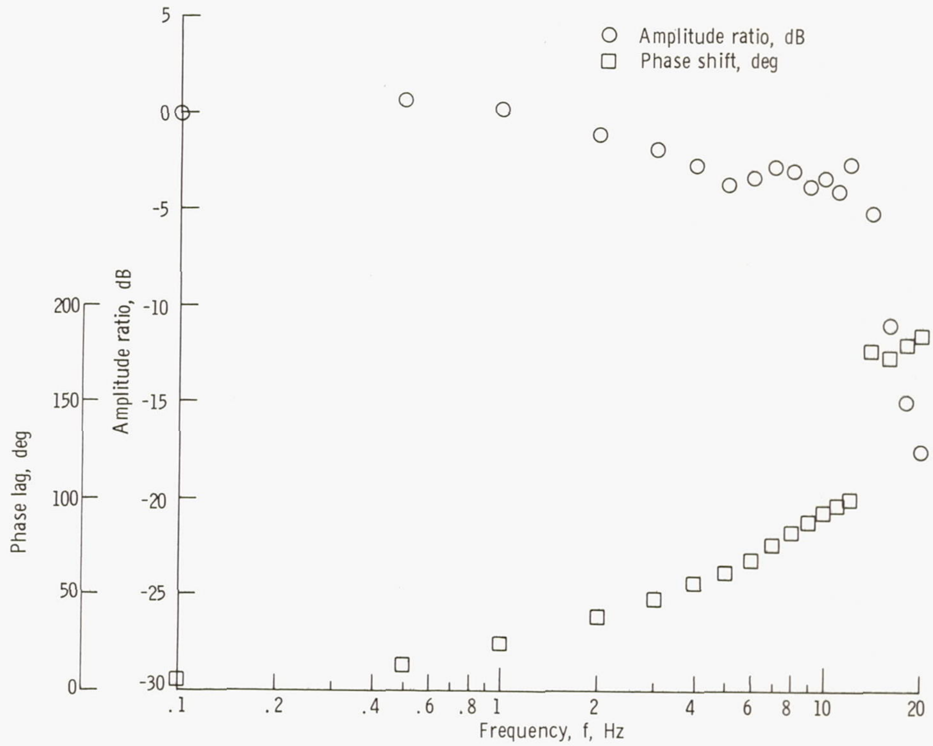


(b) Irradiation data. Run A. Gamma dose, 1.1×10^{9} ergs per gram.

Figure 13. - Actuator frequency response.

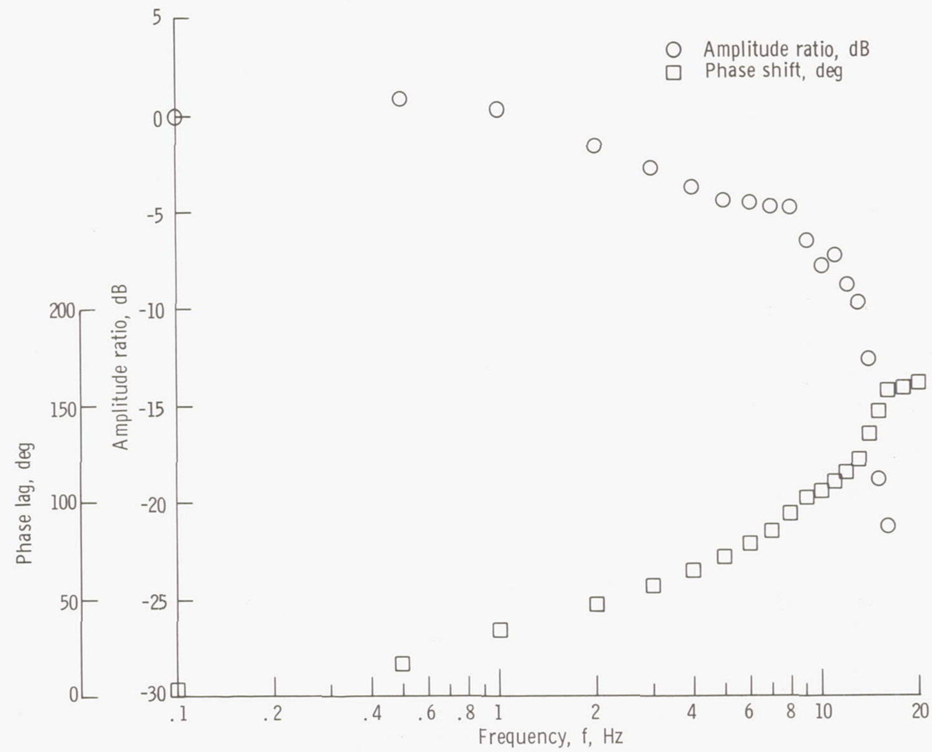


(c) Irradiation data. Run B. Gamma dose, 1.3×10^{10} ergs per gram.



(d) Irradiation data. Run C. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 13. - Continued.



(e) Postirradiation data. Gamma dose, 1.3×10^{11} ergs per gram.

Figure 13. - Concluded.

TABLE III. - ENVIRONMENTAL CONDITIONS DURING DATA RUNS

Description	Preirradiation base-line data	Data run			Post-irradiation data
		A	B	C	
Drive gas temperature, K	183	195 (Nominal)	195 (Nominal)	195 (Nominal)	195
Coolant gas temperature, K	161	167 (Nominal)	167 (Nominal)	167 (Nominal)	190
Actuator pot temperature, K	167	220	244	236	195
Actuator bearing temperature, K	167	226	280	300	195
Gamma dose rate, rads/hr	---	8.7×10^{6}	8.1×10^{7}	6.9×10^{7}	--------
Gamma dose, rads	---	1.1×10^{7}	1.3×10^{8}	1.3×10^{9}	1.3×10^{9}
Neutron flux ($E > 1.0$ MeV), N/cm^2-sec	---	5×10^{9}	3.7×10^{11}	2.9×10^{11}	--------
Neutron fluence ($E > 1.0$ MeV), N/cm^2	---	1.3×10^{13}	1.6×10^{15}	2×10^{16}	2×10^{16}

trace (θ_f), the rise time t_r remained essentially constant at a value of 80 milliseconds during the irradiation testing after rising from a preirradiation value of 60 milliseconds. For the same position change, the settling time increased during the irradiation period, rising from 75 to 150 milliseconds. This increase in settling time did not appear to significantly affect the closed loop performance of the actuator during its operative period.

Dynamic scram response data. - Figures 12(a) to (e) show oscillograph traces of the time response to a dynamic scram test. The output position trace (θ_f) indicates that the time to scram 30^o (t_{sc}) decreases from 140 to 100 milliseconds during the testing, consistant with other data. The scram turnaround time t_o remained at a value of 20 milliseconds throughout the irradiation testing.

The postirradiation dynamic scram response indicates a deviation in performance. Examination of the output position trace (θ_f) indicates a trace discontinuity at about the 36^o position. This occurs both in the outward and inward directions. This discontinuity is also evident in the torque motor current (TMI) and output velocity ($\dot{\theta}_f$) traces. The traces imply that there is a discontinuity in the feedback position signal. However, the inertia of the system is sufficient to carry the actuator through the discontinuity.

Frequency response data. - Figures 13(a) to (e) are plots of amplitude ratio and phase shift of data from the preirradiation, irradiation, and postirradiation testing. The input amplitude of the sine wave used in all tests was 4^o p-p and the tests were performed about the 90^o position. These curves indicate that the bandwidth increased with irradiation time. This also appears to be a result of a decrease in system friction.

ACTUATOR MALFUNCTION

After the fourth irradiation cycle, all of the recorded data obtained from each of the irradiation cycles was examined for changes in actuator performance. Finding no significant performance change, it was decided to attempt another irradiation cycle. Thirty-four days after the fourth irradiation cycle, the actuator was operated out of pile. The actuator moved erratically during the initial cycling. However, the erratic movement ceased and the out of pile data obtained compared favorably with all previous data. Further irradiation was not attempted at this time. The actuator control panel was inspected and recalibrated. No evidence of a malfunction in the control panel was noted.

Fixty-six days after the fourth irradiation cycle another irradiation cycle was attempted. When the actuator was restarted prior to being irradiated, it was found that it would not operate in a closed-loop system. Subsequent investigation found that, while the actuator would function, the feedback potentiometer would not send back a position signal. The actuator and load were then removed from the reactor area and placed in a hot cell facility for disassembly.

POSTIRRADIATION FEEDBACK POTENTIOMETER DISASSEMBLY

After disassembly, an initial inspection was performed to determine the cause of the actuator malfunction. Figure 14 shows the actuator with the feedback potentiometer cover removed. The inspection showed that cups B and C had changed color from dark grey to medium brown. Also, the wire harness leading to the potentiometers had turned from a white color to light brown.

Resistance measurements showed that each cup read the expected value of 1000 ohms across their end terminals. However, when using the wiper, each cup indicated infinite resistance.

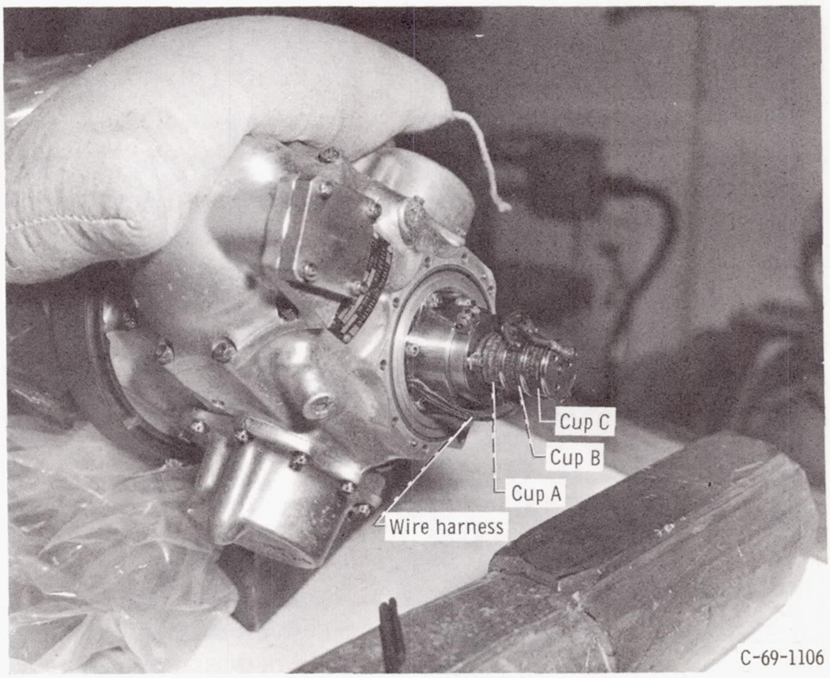
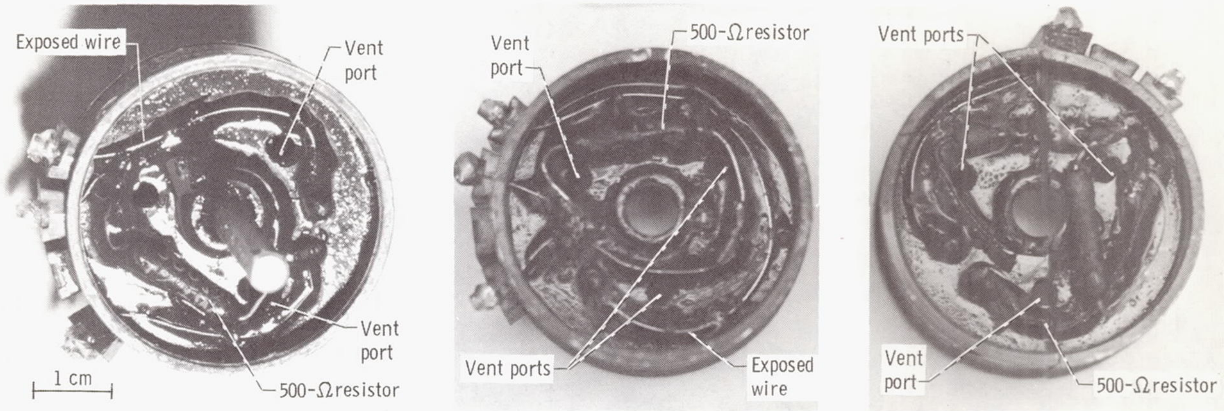


Figure 14. - Postirradiation actuator disassembly with potentiometer cover removed.

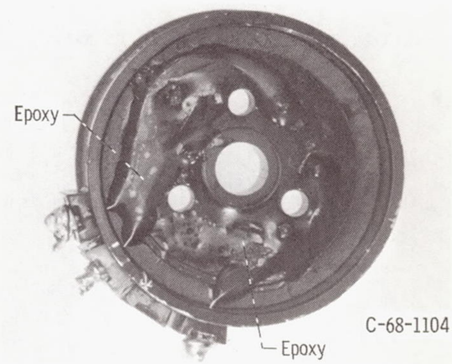
The potentiometer was removed from the actuator and disassembled. The disassembled potentiometer showed severe damage to the potting compound used to encapsulate the internal wiring in each cup. The extent of the damage is shown in figures 15(a) to (c). Figure 15(a) shows the upper portion of each cup after the irradiation compared to a similar type cup that has not been irradiated. Except in the case of the irradiated cup A, the output shaft and bearings have been removed. The electrical connections that lead to the outside of the potentiometer case are located here. Also located here is a fixed 500-ohm resistor used in the wiper circuit. Figure 15(b) shows the reverse view of that

Cup A Cup B Cup C



Irradiated potentiometer cups

P-68-3036



Typical cup prior to irradiation

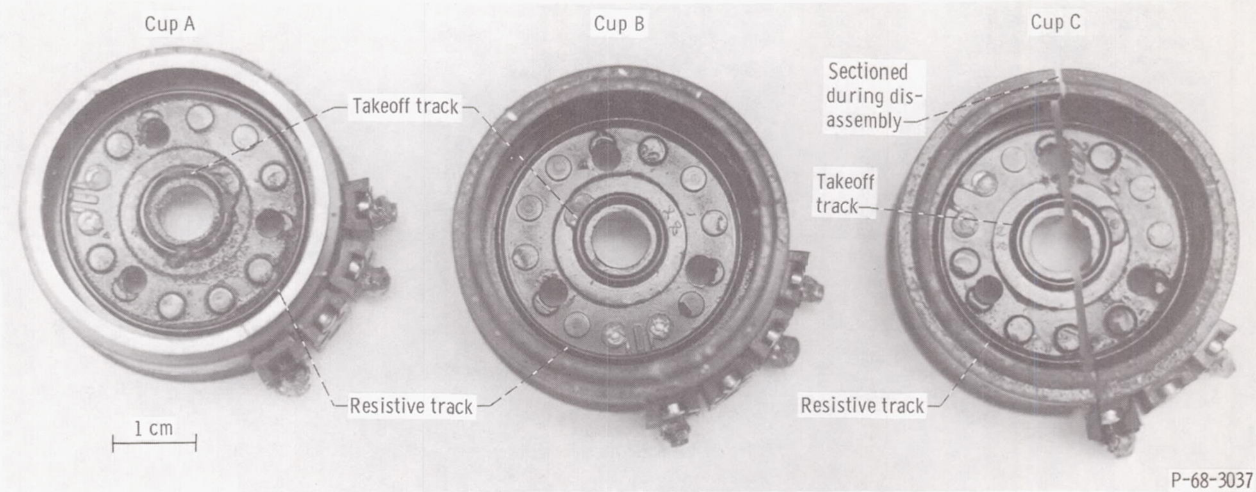
(a) Top view before and after irradiation showing electrical connections.

Figure 15. - Postirradiation disassembly of feedback potentiometer.

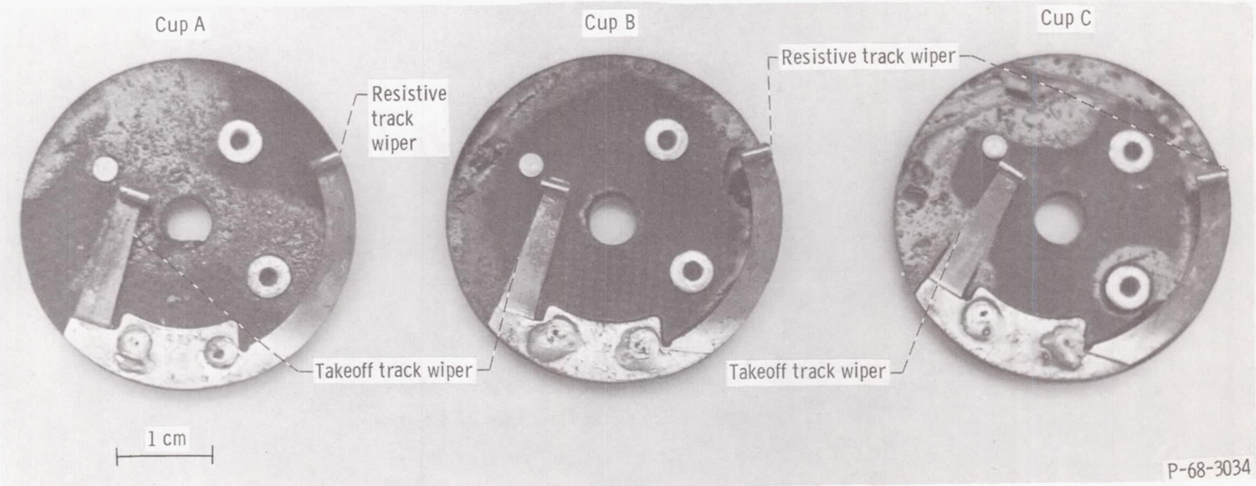
shown in figure 15(a). On this side, the resistive track and a takeoff track, which provides transfer from the rotating wiper to a stationary wiper terminal, are located. Cup C was sectioned during the disassembly. Figure 15(c) shows the potentiometer wiper assembly. There are two wipers, one is in contact with the resistive track and one is in contact with the takeoff track. With irradiation the potting compound became soft and tended to flow from the electrical components as evidenced by the exposed wiring in figure 15(a).

The movement of the potting compound had two effects. First it flowed into the potentiometer bearings causing excessive wear. When the potentiometer was examined during the disassembly, it was noted that its shaft rotated very roughly and the balls were worn flat.

Of a more serious nature, the potting compound, aided by the coolant gas stream, seeped through the potentiometer vent ports and onto the resistive and takeoff tracks and wiper assemblies. Figures 15(b) and (c) show the extent of this flow.



(b) Bottom side showing resistive and takeoff tracks.



(c) Wiper assembly.

Figure 15. - Concluded.

It is impossible to determine at what time during irradiation the damage began to occur since no indication of malfunction was indicated by the system instrumentation. Apparently when the actuator was in motion the wiper arm would wipe the resistive and the takeoff tracks clean. Detectable failure occurred only when the potting compound buildup on the wiper contact points was sufficient to act as an insulator between the wiper and the resistive and takeoff tracks. Cups A and B were connected externally in a redundant circuit, and both failed. Cup C was monitored on a panel meter and also failed.

The potting compound used in the potentiometer was a thermosetting epoxy resin of low viscosity and contained a diluent. The resin was hardened with an aliphatic amine catalyst.

King, Broadway, and Palinchak (ref. 5) indicate that epoxy resins with aromatic amines have withstood doses up to 9.5×10^{10} ergs per gram (9.5×10^{8} rads) without deterioration. However, with aliphatic amine catalysts, the epoxy resins are considerably less radiation resistant. Breakdown in an aliphatic amine hardened epoxy resin consists of rapid decrease in flexural strength and the formation of gas blisters as the irradiation proceeds.

It appears that the radiation damage exhibited by the feedback potentiometer is consistent with the observations presented in reference 5.

Postirradiation Actuator Disassembly

After examining the feedback potentiometer the remainder of the actuator was disassembled and examined for radiation damage. None of the other components suffered as severe damage as did the feedback potentiometer. All components other than the feedback potentiometer were judged as operative at the time of disassembly. The following section discusses each component that showed a change.

Lock solenoid. - Although the solenoid was still operative at the termination of irradiation testing, its insulation was very brittle and the solenoid coil was loose in its mounting.

Main actuator wiring. - The insulation was brittle but still usable. The shrink tubing used to bundle the wiring together was extremely brittle and broke into pieces upon contact.

Torque motor. - The torque motor coil insulation appeared to be in good condition. However, the insulation on the wire from the torque motor coils and the insulating boards used to support the wires were extremely brittle and broke during the actuator disassembly. The torque motor permanent magnets recorded the highest induced activity levels - measuring 3×10^{3} erg per gram per hour (30 rads/hr) gamma at contact.

37 pin connector. - The main actuator connector appeared in good condition except for its insulating ring which was very brittle.

Pistons. - The pistons showed a color change from black to dark brown.

Piston rings. - There was no visible damage to the piston rings. A small deposit of white colored matter was visible on some of the rings.

Rack and pinion assembly. - There was no visible radiation damage to the rack and pinion. Some wear was noted on the edge of the teeth and rust was noted between the teeth. However, these effects appeared to be due to use and not the effect of radiation.

Pinion bearings. - One tandem bearing was worn severely while the other appeared to be in good shape. This effect appeared to be the result of actuator use and not a radiation effect.

SUMMARY OF RESULTS

A test program established to examine actuator performance as a function of irradiation time yielded the following results:

1. The actuator was irradiated for a total of 21.8 hours. During this time no significant degradation in performance was noted. Total gamma dose received during this period was 1.3×10^{11} ergs per gram. Total neutron fluence was 2×10^{16} neutrons per square centimeter.

2. When an additional irradiation cycle was attempted it was found that the actuator would not operate in a closed-loop system. Subsequent examination revealed extensive radiation damage to all three cups of the feedback potentiometer.

3. Postirradiation examination of other actuator components revealed no significant radiation damage that would produce detectable changes in actuator performance.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 19, 1969,
122-29-03-04-22.

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