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WANL-TME-1954

September 19, 1969

Westinghouse Astronuclear Laboratory

XE-1 CONTROL DRUM PNEUMATIC ACTUATOR

QUALIFICATION TEST REPORT

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ABSTRACT

An XE pneumatic control drum actuator, specifically of the XE-1 build, has been subjected to a complete series of environmental tests specified in WANL-TME-1040, Revision A, "Qualification Specifications for Control Drum Pneumatic Actuators for XE Applications". The tests were performed under T-711892, "Qualification Test, Environmental, Control Drum Actuator". These tests were to determine the actuator's capability to operate in the XE environment and to provide input to future NERVA design. A series of formal dynamic and static tests was conducted in environments of vibration; mechanical shock; low temperature and thermal shock; and combined low temperature and vibration. An operating life test was also performed. At the successful conclusion of the above series of tests, a disassembly and inspection of the test actuator gave no indication of wear or damage; therefore, an extended life test to failure was conducted on the same actuator mechanism to provide further information to follow-on programs. The test results were examined and evaluated to determine potential effect on subsystem ability to meet performance requirements. The few anomalies were the result of an overambitious set of limits and in all cases performance was adequate to meet performance requirements.

In addition to the formal life test on this XE-1 unit, the results of the A-6 pneumatic actuator side-by-side radiation test are included in this report. Successful operation during this test and subsequent disassembly and inspection proved conclusively the ability of this design to function successfully in a radiation field. A secondary result of this test was to prove the adequacy of the design cooling to remove gamma generated heat.

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1.0 PNEUMATIC ACTUATOR SYSTEM

1.1 DESCRIPTION

In this section the XE-1 pneumatic control drum actuator is described. This actuator is the type used throughout the tests covered by this report. Figure 1.1 is a cut-away drawing of the XE-1 actuator. The actuator can be broken into five system assemblies:

1. Servovalve Assembly.
2. Drive Train
3. Feedback Potentiometer
4. Lock Assembly
5. Housing Enclosure

1.2 SERVOVALVE ASSEMBLY

The servovalve assembly serves as the interface between the electrical control signal and pneumatic pressure. It consists of a torquemotor, manifold, flapper valves, and bellows. A schematic diagram is shown in Figure 1.2. The torquemotor contains a balanced permanent magnet field and wound field coils. In its de-energized state the flux from the field magnets is equally distributed through both sides of a pivoted armature. The armature is maintained in its center position by a centering spring and by the spring gradient of the bellows. An electrical current in the field coils causes an imbalance of flux in the armature and the armature pivots against the combined spring gradients.

Each end of the armature contains a flapper valve. The flapper valves act to vent the piston cylinders into the exhaust chamber and they operate in push-pull fashion so that an increased exhaust flow in one valve corresponds to a reduced exhaust flow in the other. The piston cylinders are supplied with drive gas through fixed orifices. The net effect of armature motion is a change in the relative pressures on both pistons. The bellows bear upon the armature and are pressurized by the piston pressures through porous orifices to provide a positive pressure feedback to the armature. The feedback gives the valve the low frequency characteristics of an integrator.

Figure 1.2 XE Actuator Schematic

1.3 DRIVE TRAIN

The drive train consists of the pistons, rack, pinion gear, drive shaft, soft stop spring, rebound spring, lock cam, adapter coupling, and upper and lower drive shaft bearings. The pistons are operated in opposition and are separated by the rack. A difference in piston pressure generated by the servovalve causes a force on the rack which is transmitted to the pinion gear by the enmeshed gear teeth. The pinion gear is an integral part of the drive shaft and a torque is thus generated in the drive shaft. This torque is then transmitted to the output spline and thence to the control drum. The soft stop spring limits drive shaft travel to an angle less than 180° . It is disengaged for positions between 15° and 165° and its gradient is such that the maximum actuator torque will deflect it $\pm 7.5^{\circ}$.

1.4 FEEDBACK POTENTIOMETER

Located coaxially with the drive shaft is the potentiometer coupling shaft. This shaft rotates the wipers of the three-deck feedback potentiometer. The potentiometer is able to monitor drive shaft position and hence the control drum position. The three-deck provides redundancy to maintain the necessary reliability of the actuator system.

1.5 LOCK ASSEMBLY

In addition to the preload of the scram spring, mounted on the control drums, a lock assembly is included in the actuator to prevent inadvertent control drum roll-out. The lock assembly consists of a manual lock, lock pin, solenoid valve, and limit switches. When energized electrically the solenoid valve ports drive gas pressure to the lock pin cylinder. This pressure raises the spring loaded lock pin, provided the manual lock is disengaged. The lock pin clears the lock cam and allows the drive shaft to rotate unimpeded. The limit switches are actuated by the lock pin and give an indication when the lock pin is in either the full in or out position.

1.6 HOUSING ENCLOSURE

The actuator system assemblies are mounted within the housing enclosure. The base of the housing forms the interface with the actuator pedestal. Through this interface passes the coolant and drive gases, the drive shaft, the electrical connector, and P_1 and P_2 instrumentation ports. The housing is mounted on the pedestal by means of a marmon clamp and

is sealed from gas leaks by the use of lead coated apex seals. Apex seals are used throughout the actuator. The housing provides porting for the pneumatic drive system and also allows coolant gas to circulate around the actuator components. The flow of coolant is from the pedestal, through the coolant filter, and around the potentiometer. The coolant then passes through the gap seals where it is reduced in pressure and thence around the helical slots in the cylinder liners. The flow path is then split to cool the lock assembly and the servovalve assembly. In the servovalve cover the coolant mixes with the exhausted drive gas and then both pass over the electrical connector. The electrical connector cavity in the pedestal is exhausted to the vent.

1.7 ACTUATOR CONTROL AMPLIFIER

The actuator control amplifier is pictured in Figure 1.3. It is constructed of modular plug-in printed circuit boards. The boards utilize NEXUS operational amplifiers and discrete passive components. A functional block diagram of the amplifier is shown in Figure 1.4. This type of amplifier was used throughout the XE qualification tests. For the extended life test, however, the amplifier was updated to conform to the XE-Prime type. The functional block diagram of the modified amplifier is shown in Figure 1.5.

For a more definitive description and analysis of the XE control drum actuator, the following references are given:

Josephson, J., "Servo-Analysis and Dynamic Testing of the Prototype NERVA XE Pneumatic Actuator-Amplifier Subsystem", WANL-TME-1537, November, 1966.

Armstrong, D., Buckley, S., "A Stability Analysis of the NERVA XE Control Drum Actuator Servovalve", WANL-TME-1625, September, 1967.

Marvin, M. D., "Final Report Control Drum Pneumatic Actuator Program for NERVA XE Series", No. 67-SD-3011, General Electric, Space Power and Propulsion Section, Missile and Space Division, Cincinnati, Ohio.

Figure 1.3. XE Actuator Control Amplifier

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Figure 1.5. XE-2 Actuator Control Amplifier - Functional Block Diagram

2.0 DESCRIPTION OF ACTUATOR PERFORMANCE TEST PROCEDURE

2.1 INTRODUCTION

The tests listed in this section were performed during all phases of the environmental qualification program. These tests were performed prior to the application of a specific environment to determine the Base Line Data (BLD) of the actuator for that test. Any deviations in the results of subsequent actuator performance tests from this established base line data were carefully reviewed, evaluated and finally used as a measure of the actuator's ability to perform satisfactorily during and after the specific test environments.

2.2 PARAMETERS

The parameters measured and/or recorded during these tests were:

2.2.1	Actuator Command (D.C. Value)	θ_d (degrees)
2.2.2	Actuator Dynamic Command (Time Varying Component)	$\Delta\theta_d$ (degrees)
2.2.3	Actuator Position (D.C. Value or Coarse Position)	θ_o (degrees)
2.2.4	Actuator Dynamic Position (Time Varying Component)	$\Delta\theta_o$ (degrees)
2.2.5	Error Signal (Command - Position)	θ_e (degrees)
2.2.6	Torque Motor Current	I_{TM} (ma)
2.2.7	Coolant Pressure	P_c (psig)
2.2.8	Drive Pressure	P_s (psig)
2.2.9	Cylinder No. 1 Pressure	P_1 (psig)
2.2.10	Cylinder No. 2 Pressure	P_2 (psig)

2.3 PRE-TEST SET-UP

Two different load stands were used during the environmental tests. One load stand was used during the life tests and temperature tests, while a second stand, particularly adapted to use with the vibration table, was used during the shock vibration and cold vibration test phases.

An initial set-up and test of the actuator on each load stand was performed to establish the control amplifier settings for optimum transient response of the system. Although this adjustment was probably not required, it was performed in an attempt to eliminate differences in performance due to minor differences in load stand parameters. Consideration was given, however, to obtain control amplifier settings in the range of those to be used in the XE-1 tests in order to simulate the conditions of a reactor run.

2.4 STATIC RESOLUTION AND LINEARITY

The linearity and static resolution of the subsystem was determined by commanding the actuator in 9° intervals over its range of travel (9° to 171° to 9°) and recording the command (θ_d) and the error (θ_e) after all transients had subsided. The difference of the θ_e voltage for the two directions of approaching the data points is a measure of the static resolution. Linearity is the difference between the error voltage at any point and the best straight line drawn through all the points. Refer to Figure 2.1 for a block diagram of the test set-up.

2.5 DYNAMIC RESOLUTION

To obtain the dynamic resolution of the subsystem, the command (θ_d) and position (θ_o) of the actuator were set at 90° while the dynamic command ($\Delta\theta_d$) was a $3^\circ/\text{sec}$ ramp of 100° magnitude. The dynamic command ($\Delta\theta_d$) and error (θ_e) were recorded on the X-Y chart recorder. The trace traversed is a hysteresis curve of error voltage. The dynamic

Figure 2.1. Block Diagram - Resolution Check

resolution at any point is the width of this hysteresis curve. Refer to Figure 2.1 for a block diagram of the test set-up. Because of the close correlation existing between the static and dynamic resolutions and due to the long time required to check the static resolution, the static resolution was deleted from the tests after the first check.

2.6 TRANSIENT RESPONSE

The transient response of the actuator was determined by commanding (θ_d) the actuator output shaft to a position (θ_o) of 90° and applying a dynamic step command ($\Delta\theta_d$) with an amplitude of 18° p-p to the control amplifier. Under the stimulus of the dynamic command, the actuator would alternate position between 81° and 99° . The command ($\Delta\theta_d$) and position ($\Delta\theta_o$) were then recorded on the visicorder. Time response, overshoot and settling time can then be read from the actuator position time trace. Refer to Figure 2.2 for a block diagram of the test set-up.

2.7 SCRAM RESPONSE

To check the scram turnaround performance, the test set-up remained the same as for the transient response check except that the dynamic command ($\Delta\theta_d$) was increased to assure that the actuator would move out to an angle greater than 120° . This is because a Schmidt trigger, sensitive to actuator position, was used to de-energize the scram relay when the position reached 120° . Actuator position (θ_o) and torque motor current (I_{TM}) were recorded on the visicorder. The time when torque motor current was shut off was considered as the start of the scram operation. Scram turnaround was defined as the point when the position time trace reached a zero slope. Refer to Figure 2.2 for a block diagram of the test set-up.

2.8 FREQUENCY RESPONSE

The frequency response of the actuator was measured using an IMC Frequency Response Analyzer and recorded on an X-Y-Y' Chart Recorder. The actuator was

Figure 2.2. Block Diagram Transient and Scram Check

commanded (θ_d) to a position (θ_o) of 90° and a sinusoidal dynamic command ($\Delta\theta_d$) of 4° p-p amplitude was applied to the control amplifier. The dynamic command ($\Delta\theta_d$) and dynamic position ($\Delta\theta_o$) signals were then processed by the IMC analyzer to obtain the closed loop frequency response which was plotted using the X-Y-Y' recorder. Refer to Figure 2.3 for a block diagram of the test set-up.

Figure 2.3. Block Diagram Closed Loop Frequency Response

3.0 VIBRATION TEST

3.1 INTRODUCTION

3.1.1 The vibration qualification test was conducted within the guidelines specified in WANL-TME-1040, Revision A, Qualification Specifications for Control Drum Pneumatic Actuators for XE-1 Applications (see Appendix A), and performed under T-711892A, Qualification Test, Environmental, Control Drum Actuator (see Appendix B), with a few minor exceptions noted herein. The basis for the vibration levels was AGC Specification 90016-C. The vibration levels equaled or exceeded these specified values.

3.1.2 The purpose of the vibration test was to determine what changes in performance, if any, the XE control drum actuator would undergo when operated in a vibration environment. The vibration environment consisted of sinusoidal accelerations at levels as specified in Appendix A. The vibrations as specified were selected to closely approximate the anticipated environment to which the actuator will be subjected during both ground handling and engine operation.

3.1.3 The method of testing was to operate the actuator with various command inputs before, during and after vibrating and to record actuator performance for each condition. A comparison of the various records defines the effects of the induced environments on the performance of the actuator system.

3.2 DESCRIPTION OF TEST SET-UP

3.2.1 The vibration testing of the XE-1 actuator was performed in the WANL Mechanisms Laboratory between November 8, 1967 and November 15, 1967. The actuator used was an XE-1 Series, Serial Number A-58608, and the actuator control amplifier was Serial Number A-62960. The combination of actuator and amplifier comprises the closed

loop position control system. Only the actuator was subjected to the induced environments as the amplifier is mounted in the Test Cell Building.

3.2.3 To provide vibration and to monitor acceleration, the following equipment was used:

Unholtz-Dickie Water-Cooled Shaker Table, Model 201

Philips Driver Amplifier (10 KVA), Model EL 6473-12

M-B Automatic Vibration Exciter Control, Model N572-73

Endevco Accelerometers, Model 2226 - Three accelerometers to measure tri-axial accelerations on the actuator.

Unholtz-Dickie Dial-A-Gain Signal Conditioner, Model AV604-R

Honeywell Visicorder, Model 906-C

3.2.4 The following equipment was used to determine actuator performance:

Honeywell Visicorder, Model 1508

Industrial Measurements Corp. (IMC) Frequency Response Analyzer, Model 101

Hewlett Packard Function Generator, Model 202

Honeywell X-Y-Y' Chart Recorder, Model 480

Honeywell Digital Voltmeter, Model 6305

Trygon Power Supplies, Model PS 32-2.5

CEC Pressure Transducers - P_s , P_c Pressures

Statham Pressure Transducers - P_1 , P_2 Pressures

CEC Data Amplifier, Type 155

Honeywell Gage Balance Unit

3.2.5 Helium drive gas (P_s) and nitrogen coolant gas (P_c) at controlled pressure and ambient temperatures were supplied to the actuator through the vibration load stand.

3.2.6 The three axes of vibration were chosen as:

Vibration parallel to actuator output shaft (a_z).

Vibration parallel to direction of piston travel (a_y).

Vibration perpendicular to direction of piston travel and perpendicular to actuator output shaft (a_x).

3.2.7 The actuator is shown mounted for vibration in the a_z direction in Figure 3.1. In Figure 3.2, the actuator is shown mounted for vibration in the a_y direction, and in Figure 3.3 the mounting for vibration in the a_x direction is shown. Block diagrams of the actuator system and associated control and instrumentation components as interconnected for obtaining performance data during the vibration test series are detailed in Figures 2.1, 2.2 and 2.3.

3.3 DESCRIPTION OF TEST PROCEDURE

3.3.1 The vibration test was divided into three parts corresponding to the three axes of the actuator as defined in Section 3.2.6. A schedule of vibration tests is given in Figure 3.4, wherein all the vibration tests are shown. Only selected tests from those listed in Figure 3.4 were performed in any given direction of vibration. Prior to vibration in a given axis, a test was performed to establish the base line data for use in subsequent performance evaluations.

3.3.2 The vibration tests performed on the actuator in the a_z direction (parallel to the output shaft) were 1, 2, 3, 5 and 6 as listed in Figure 3.4. This series of tests was performed in the order given. Test No. 3 was a sweep of different frequencies and amplitudes as shown in Figure 3.5. While Test No. 3 was being performed, a dynamic resolution test (Section 2.5) was performed and the results recorded. Immediately after Test No. 3, dynamic resolution (Section 2.5) and transient response tests (Section 2.6) were performed and the results recorded. Test No. 6 was performed at any and all resonance frequencies

Figure 3.1. Actuator Mounted for Vibration in the α_z Direction

Figure 3.2. Actuator Mounted for Vibration in the a_y Direction

Figure 3.3. Actuator Mounted for Vibration in the α_x Direction

Phase	Actuator Condition	Vibration Plane	Performance Tests					Resonance Dwell		
			Test No.	Sweep Frequency (cps)	No. of Sweeps	Time/Sweep	Applied Force (g)	Test No.	Dwell Time at Resonance	Applied Force (g) Vector
Low Level Vibration Search	Non-Operational	All 3	1	5-2000-5	2	3 min	1.0	---	---	---
Shipment and Storage	Non-Operational	All 3	2	10-30-10	3	2 min	4.0	5	30 min	4.0
Ground Firing	Operating	Vertical	3	5-2000-5	1	30 min	See Figure 3.5	6	10 min	See Figure 3.5
Ground Firing	Operating	Horizontal	4	5-500-5	2	15 min	See Figure 3.6	7	10 min	See Figure 3.6

Figure 3.4. Test Sequence and Specifications

Figure 3.5. Vibration Environment, Sinusoidal Vibration in a_z Direction

observed during Test No. 3. While Test No. 6 was being performed, a dynamic resolution test (Section 2.5) was performed and the results recorded. After Test No. 6, which was the last test in the a_z direction, a complete actuator performance test was conducted and recorded (Sections 2.5, 2.6, 2.7 and 2.8).

3.3.3 The vibration tests performed on the actuator in the a_y direction (parallel to piston travel) were 1, 2, 4, 5 and 7 as listed in Figure 3.4. This series of tests was performed in the order given. Test No. 4 was a sweep of different frequencies and amplitudes as shown in Figure 3.6. A dynamic resolution (Section 2.5) was recorded both during and after Test No. 4 and a transient response (Section 2.6) was recorded after Test No. 4. Test No. 7 was performed at any and all resonance frequencies observed during Test No. 4. A dynamic resolution (Section 2.5) was recorded during Test No. 7 and a complete actuator performance test was conducted and recorded (Sections 2.5, 2.6, 2.7, 2.8) after Test No. 7.

3.3.4 For vibration in the a_x direction (perpendicular to piston travel) the same tests were performed as in the a_y direction (1, 2, 4, 5 and 7) and the same actuator performance tests were conducted as specified in 3.3.3.

3.4 DISCUSSION OF TEST RESULTS

3.4.1 The results of the scram turnaround, transient response, and dynamic response tests were reduced from visicorder and X-Y plots and tabulated in Figure 3.7, and a typical scram response is shown in Figure 3.8.

3.4.1.1 Scram turnaround time was determined as the period between torque motor current shut-off (opening of scram relay) and the point where the actuator ceased its outward motion (zero angular velocity). The scram turnaround times did not change appreciably throughout the vibration tests. Changes in scram turnaround and scram velocity

Figure 3.6. Vibration Environment, Sinusoidal Vibration in a_x and a_y Direction

	<u>Vibration BLD</u>	<u>Vertical (a_z) Test No. 3</u>	<u>Vertical (a_z) Test No. 6</u>	<u>Horiz. (a_y) Test No. 4</u>	<u>Horiz. (a_y) Test No. 7</u>	<u>Horiz. (a_y) Test No. 4</u>	<u>Horiz. (a_y) Test No. 7</u>
Scram Turnaround							
Time (sec)	0.034		0.033		0.033		0.032
% BLD			-2.96		-2.96		-5.88
Rise Time (in)							
Time (sec)	0.149	0.114	0.119	0.114	0.117	0.109	0.116
Δ% BLD		-23.5	-20.2	-23.5	-21.5	-26.9	-22.2
Rise Time (out)							
Time (sec)	0.149	0.122	0.174	0.129	0.134	0.129	0.135
Δ% BLD		-18.1	+16.8	-13.4	-10.1	-13.4	-9.4
Overshoot (in)							
Degrees	0.4	0.6	0.7	0.3	0.5	0.5	0.6
% 18°	2.22	3.33	3.88	1.67	2.78	2.78	3.33
Overshoot (out)							
Degrees	0.2	0.6	0.3	0.2	0.5	0.3	0.3
% 18°	1.11	3.33	1.67	1.11	2.78	1.67	1.67
Settling Time (in)							
Time (sec)	0.208	0.171	0.177	0.184	0.175	0.168	0.178
Δ% BLD		-17.8	-14.9	-11.5	-15.9	-19.2	-14.9
Settling Time (out)							
Time (sec)	0.224	0.189	0.258	0.200	0.210	0.201	0.208
Δ% BLD		-14.4	+13.9	-9.8	-5.7	-9.4	-6.6
Dynamic Resolution							
During			0.16				
Vibration (o)		0.22	0.11	0.09	0.27	0.41	0.22
After							
Vibration (o)		0.40	0.56	0.16	0.23	0.34	0.20

Figure 3.7

Table of Vibration Test Data

Figure 3.8. Typical Scram Response

would not have been surprising since scrams are open loop measurements. Open loop performances are very sensitive to small changes in system parameters. Later modifications to the XE actuator systems incorporated a closed loop scram to reduce the effects of parameter variations on performance results.

3.4.1.2 Transient response rise time was defined and measured as the period between an 18° step command signal and the time when the actuator position reached 63% of its final value. After the first sweep of vibration, some of the data changes to what appeared to be new base line points. This change was felt to be due to a settling of the load stand and coupling into its point of lowest friction as a result of the vibration. The observed rise times and settling times are indicative of lower values of system friction.

In general, the values changed from base line data more than anticipated, but after a careful evaluation the difference was not felt to be of significant consequence. Part of the difference can be attributed to the selection of the parameters to be measured. For all step commands the actuator travels to its commanded position at a velocity determined by its velocity clamp which is a subsystem setting. This velocity limit is a subsystem specification and is used as a measured parameter in all actuator subsystem performance evaluations. In order to more closely define the shape of the step response for the environmental test series, the rise time, settling time and overshoot parameters were specified instead of the single velocity parameter. The more detailed parameter specification appears to have been an over ambitious attempt to tighten a design specification, whereas the real parameter, that is, velocity at clamp, is not intended to be a precise specification value, but only a backup safety to the reactor control system clamps which are of lower value. In any event, the average velocity of the actuator during these rise times, settling times and overshoot measurements is within acceptable limits; therefore, it was decided to continue the test series pending anymore serious anomalies.

Figure 3.9. Typical Dynamic Response

Figure 3.10. Closed Loop Frequency Response Base Line Data

Figure 3.11. Closed Loop Frequency Response - after Vibration in a_z Direction

Figure 3.12. Closed Loop Frequency Response - after Vibration in y Direction

Figure 3.13. Closed Loop Frequency Response - after Vibration in a_x Direction

3.4.1.3 The values for overshoot listed in Figure 3.7 were less than 5% of the total 18° travel throughout the test. The change in overshoot is the difference between the percent overshoot of the base line data and the percent overshoot for the subsequent tests. No ringing was observed but a period of approximately 0.5 seconds was required for the actuator drive shaft to reach its final value. This subsiding time was due to the extremely low frequency component of the transfer function contributed by the servovalve bellows feedback.

3.4.1.4 The settling time of the transient response was the period between the time the actuator was commanded to $(\pm 18^\circ)$ and the time when the actuator position remained within 5% of its final value. Since no overshoot was greater than 5% of 18° , the time of first approach determined settling time.

3.4.1.5 The dynamic response of the actuator listed in Figure 3.7 was obtained from the curve of command (θ_d) versus error (θ_e). A typical dynamic response curve is shown in Figure 3.9. Each curve was compared with the base line data and the greatest deviation was measured. The two values listed for Test No. 6 were for actuator resonances of 1050 Hz (0.16°) and 1350 Hz (0.11°). Because no low frequency, non-operational resonances were experienced, Test No. 5 was not performed. The resonant frequency for the horizontal (a_z) Test No. 7 was 125 Hz and that for the horizontal (a_x) Test No. 7 was 130 hz.

3.4.2 Curves for the closed loop frequency response of the actuator are shown in Figures 3.10, 3.11, 3.12 and 3.13. Figure 3.10 is the base line data curve. The limits for qualification, derived from the base line data curve, are superimposed on the three other frequency response curves. All three curves were within the limits set except for frequencies above 10 Hz where some values went beyond the limits. Because of the low closed loop gain at these frequencies, there would appear to be no problem with slight variations outside the limits.

4.0 MECHANICAL SHOCK TEST

4.1 INTRODUCTION

4.1.1 The mechanical shock test was conducted within the guidelines specified in WANL-TME-1040, Revision A, Qualification Specifications for Control Drum Pneumatic Actuators for XE-1 Applications (see Appendix A), and performed under T-711892B, Qualification Tests, Environmental, Control Drum Actuator (see Appendix B), with a few minor exceptions noted herein. The basis for the shock levels was AGC Specification 90016-C. The shock levels of this test equaled or exceeded these specified values.

4.1.2 The purpose of the shock test was to determine what changes, if any, would occur in the actuator performance when the actuator was subjected to a mechanical shock. The mechanical shock as specified in Appendix A was selected to closely approximate the maximum anticipated environment to which the actuator will be subjected during both ground handling and engine operation.

4.1.3 The method of testing was to operate the actuator with various input commands before, during and after the application of controlled shocks in all three planes and to record actuator performance for each condition. A comparison of the various records defines the effects of the induced environment on the performance of the actuator system.

4.2 DESCRIPTION OF TEST SET-UP

4.2.1 The mechanical shock testing of the XE-1 actuator was performed in the WANL Mechanisms Laboratory between November 16, 1967 and November 21, 1967. The actuator used was an XE-1 Series, Serial Number A-58608, and the actuator control amplifier was Serial Number A-62960. The combination of actuator and amplifier comprises the closed loop position control system. Only the actuator was subjected to the induced environments as the amplifier is mounted in the Test Cell Building.

Plane	Actuator Condition	Load (g's)	Dwell Time (sec)	Shocks in Each Direction	Shocks in Each Plane
Vertical (a_z)	Operating	± 2.0	0.01	3	6
Horizontal (a_y)	Operating	± 1.0	0.01	3	6
Horizontal (a_x)	Operating	± 1.0	0.01	3	6

Figure 4.1. Shock Schedule

Figure 4.2. Typical 3°/Sec Ramp During Mechanical Shock

	<u>Shock BLD</u>	<u>Horizontal (a_x)</u>	<u>Horizontal (a_y)</u>	<u>Vertical (a_z)</u>
Scram Turnaround Time (sec)	0.032	0.026	0.025	0.021
% BLD		-18.75	-21.9	-28.1
Rise Time (in)				
Time (sec)	0.116	0.118	0.124	0.117
$\Delta\%$ BLD		+1.72	+6.89	+0.86
Rise Time (out)				
Time (sec)	0.135	0.139	0.145	0.128
$\Delta\%$ BLD		+2.96	+7.41	-5.18
Overshoot (in)				
Degrees	0.6	0.3	0.3	0.5
% of 18°	3.33	1.67	1.67	2.78
Overshoot (out)				
Degrees	0.3	0.2	0.2	0.5
% of 18°	1.67	1.11	1.11	2.78
Settling Time (in)				
Time (sec)	0.178	0.172	0.190	0.186
$\Delta\%$ BLD		-3.38	+6.74	+4.50
Settling Time (out)				
Time (sec)	0.208	0.212	0.220	0.213
$\Delta\%$ BLD		+1.92	+5.77	+2.41
Dynamic Resolution Max. Deviation from BLD after Shock (Degrees)		0.18	0.33	0.20

Figure 4.3. Table of Shock Test Data

4.2.2 The test set-up used in the mechanical shock tests was the same as that used for vibration testing. The only exception was that a step input voltage was used to produce the shock pulses. For a detailed description of the equipment used and the test set-up, refer to Sections 3.2.3 through 3.2.7, inclusive.

4.3 DESCRIPTION OF TEST PROCEDURE

4.3.1 The schedule for shock testing is given in Figure 4.1. The actual sequence for the test was: horizontal (a_x), horizontal (a_y), and vertical (a_z). The sequence of testing was changed because the actuator was in the horizontal (a_x) position after completion of the vibration test series. To maintain continuity of the overall environmental testing and to avoid needless repetition of the test set-up, this position was chosen to be first in the shock test plan. The base line data for the shock test was that obtained at the end of the vibration test.

4.3.2 During each series of shocks, the actuator was operated with a $3^\circ/\text{sec}$ ramp over a range of 100° . The shocks were applied at some point during the ramp. The actuator parameters were measured and recorded. A typical plot of positions versus time for the $3^\circ/\text{sec}$ ramp is shown in Figure 4.2. No disturbance can be identified with the applied shocks.

4.3.3 After six (6) shocks in each plane, the actuator performance was measured and recorded. The results of these tests were compared with the base line data to detect any deviation and to determine the actuator ability to function properly under conditions of mechanical shock.

4.4 DISCUSSION OF TEST RESULTS

4.4.1 The results of the scram turnaround, transient response and dynamic response tests were reduced from visicorder and X-Y plots and tabulated in Figure 4.3. A typical scram response curve was shown previously in Figure 3.8.

4.4.1.1 After the initial series of six shocks in the a_x direction, the scram turnaround time was reduced by 18.75% of its base line data value and continued to be reduced for each subsequent series of shocks. This reduction of scram turnaround time was probably due to a reduction of internal static friction. These changes are not surprising since the scram measurements are open loop measurements. Later modifications to the XE actuator amplifiers incorporated a closed loop scram circuit to reduce the effects of parameter variations on performance results.

4.4.1.2 The transient response rise times and settling times are tabulated in Figure 4.3. The rise and settling times changed little throughout the test.

4.4.1.3 The overshoot to an 18° step input is also given in Figure 4.3. The percent overshoot was less than 3.33% of the 18° command value while the greatest change in percent overshoot was 2.22%.

4.4.1.4 From Figure 4.3, the greatest deviation from the base line data for the dynamic resolution curves was 0.33° .

4.4.1.5 The closed loop frequency response curves are shown as Figures 4.4, 4.5 and 4.6. The base line data curve is shown as Figure 3.13 of the vibration test. The qualification limits, taken from the base line data curve, are superimposed on the other three curves. The curves for the a_x and a_y direction are within the limits. The curve for the a_z direction shows a decrease in gain and phase for frequencies above 4 Hz. The decrease in gain and phase and the absence of peaking is indicative of a reduction in static friction which agrees with the scram and transient response. The reduction of peaking also suggests an increase in stability of the closed loop system.

Figure 4.4. Closed Loop Frequency Response - Base Line Data

Figure 4.5. Closed Loop Frequency Response - After Shocks in a_x Direction

Figure 4.6. Closed Loop Frequency Response - After Shocks in a_y Direction

Figure 4.7. Closed Loop Frequency Response - After Shocks in a_z Direction

5.0 LOW TEMPERATURE TEST

5.1 INTRODUCTION

5.1.1 The low temperature qualification test was conducted within the guidelines specified in WANL-TME-1040, Revision A, Qualification Specifications for Control Drum Pneumatic Actuators for XE-1 Applications (see Appendix A), and performed under T-711892C, Qualification Test, Environmental, Control Drum Actuator (see Appendix B), with a few minor exceptions noted herein.

5.1.2 The purpose of the low temperature test was to determine what changes in performance, if any, the XE control drum actuator would undergo when operated in a cryogenic environment. An additional objective was to determine the actuator sensitivity to condensible contamination. For this purpose, a cryotrap and counterflow heat exchanger was installed in the drive gas supply line. A bypass around the heat exchanger permitted it to be inserted into or taken out of the flow path as desired. The cryogenic environment was specified to be equal to or lower than that expected during NERVA engine operation.

The basis for the low temperature extreme was originally established by review of appropriate station data from the NRX series full power reactor tests. This review resulted in an actuator design temperature of about 250°R . Subsequent issue of AGC Specification 90016-C reduced the low temperatures limit to about 212°R . All actuator low temperature testing was conducted at the most convenient test point below this limit, that is, the temperature of LN_2 (140°R). This test temperature was felt to provide a large safety margin below the expected low temperature extreme. Further updating of available analyses predicted low reactor power hold, dome temperatures as low as 60°R . Actuator coolant is supplied directly from the reactor dome. Therefore, although pressure at this hold point (and therefore actuator coolant flow) was only about 10% of design, the possibility existed

that actuator temperature could conceivably be below design and below the lowest test temperature. An additional objective of the low temperature test was inserted into the test program to determine the lowest acceptable actuator temperature allowable and still maintain acceptable stability margins of performance.

5.1.3 The method of testing was to operate the actuator at ambient temperature with various position commands to determine the ambient performance characteristics. The actuator temperature was then to be lowered using cryogenic coolant gas and either ambient or cryogenic drive gas. During the cooldown transient, the actuator was operated in various modes. Once a constant temperature was reached, the cryogenic performance characteristics were to be determined.

5.2 DESCRIPTION OF TEST SET-UP

5.2.1 The low temperature testing of the XE-1 actuator was performed at the NASA Lewis Research Center, Cleveland, Ohio, on October 14, 1967 and December 2, 1967. The actuator used for the test was an XE-1 Series, Serial No. A-58608, and the actuator control amplifier was Serial No. A-62960.

5.2.2 The gas system is shown in Figure 5.1. Hydrogen gas was used for both drive and coolant during the actual test while helium gas was used for initial set-up of the actuator and also to purge the system of hydrogen when required. The working fluid, obtained from hydrogen or helium storage trucks, was first reduced in pressure and then cooled as required. The cooling was accomplished by pre-cooling the gas in a liquid nitrogen heat exchanger and then cooling to 50°R in a liquid hydrogen heat exchanger.

The desired temperature gas was then obtained by means of two separate pairs of temperature mixing valves: one pair for coolant and one pair for drive. The required coolant and drive pressures were then set by regulators.

Figure 5.1. Gas Supply System for Low Temperature Test

A counterflow heat exchanger was used in the drive gas supply line. Its purpose was to trap any impurities in the drive gas whenever warm drive gas was delivered to a cold actuator. When not in use, it was bypassed.

To achieve rapid cooldown and warmup of the lines, bypass valves were placed in the coolant and drive lines in close proximity to the actuator. When the bypass lines were opened, the flow of gas in the system was increased and exhausted to the exhaust stack, thus affording the desired piping system rapid cooldown.

Thermocouples were provided at the coolant and drive inputs, the actuator exhaust outlet, the actuator housing and the counterflow heat exchanger inlet.

In order to ensure adequate ventilation in case of hydrogen leakage, the actuator was open to the atmosphere. The load stand was thermally insulated at its base by being mounted on a plywood platform.

5.2.3 The following equipment was used to determine actuator performance:

- Boonshaft Transfer Function Analyzer
- Brush 8 Channel Strip Chart Pen Recorder
- Honeywell X-Y Chart Recorder
- Hewlett Package Function Generator
- Bristol 24-Channel Temperature Recorder

5.3 DESCRIPTION OF TEST PROCEDURE

5.3.1 Prior to cryogenic operation, the actuator was operated on ambient (520°R - 540°R) hydrogen in order to obtain base line data. After ambient operation, the actuator was shut down and the drive and coolant gas was diverted by way of the bypass valves. The reason for this was to cool the drive and coolant gas lines to cryogenic temperature and then apply the cold gas to the actuator to obtain the fastest possible cooldown transient.

5.3.2 The following series of tests was developed to simulate maximum effected temperature transients under various operating and non-operating conditions.

5.3.2.1 Thermal Test No. 1 - No cryogenic trap is operating for this test.

5.3.2.1.1 Start at 530°R, precool facility lines to actuator.

5.3.2.1.2 Introduce 60°R drive gas and coolant gas.

5.3.2.1.3 During thermal transient command actuator on a 100° ramp at 3°/sec.

5.3.2.1.4 When temperatures stabilize (approximately 60°R) run actuator base line data tests.

5.3.2.1.5 Introduce 530°R drive gas and coolant gas.

5.3.2.1.6 During thermal transient command actuator on a 100° ramp at 3°/sec.

5.3.2.2 Thermal Test No. 4 - No cryogenic trap during this test unless freeze-up is noticed; then switch to cryogenically trapped drive gas.

5.3.2.2.1 Start at 530°R, precool facility lines to actuator.

5.3.2.2.2 Introduce 60°R coolant gas and 530°R drive gas.

5.3.2.2.3 During thermal transient command actuator on a 100° ramp at 3°/sec.

5.3.2.2.4 When temperatures stabilize rerun base line data tests.

5.3.2.2.5 During thermal transient command actuator on a 100° ramp at 3°/sec.

5.3.2.3 Thermal Test No. 2 - No cryogenic trap during this test.

5.3.2.3.1 Repeat 5.3.2.1 except keep actuator locked during 5.3.2.1.3 and 5.3.2.1.6.

5.3.2.4 Thermal Test No. 3 - No cryogenic trap during this test unless freeze-up is noticed; then switch to cryogenically trapped drive gas.

5.3.2.4.1 Start at 530°R, precool facility lines to actuator.

5.3.2.4.2 Introduce 60°R drive and coolant gas.

5.3.2.4.3 During thermal transient command actuator on a 100° ramp at 3°/sec.

5.3.2.4.4 When temperatures stabilize rerun base line data tests.

5.3.2.4.5 Switch to 530°R drive gas.

5.3.2.4.6 During thermal transient command actuator on a 100° ramp at 3°/sec.

5.3.2.4.7 When temperatures stabilize rerun base line data tests.

5.3.2.4.8 Switch to 530°R coolant gas.

5.3.3 Only three of the planned thermal cycles were performed on the actuator because of available time. Thermal Cycle No. 1 was performed on October 14, 1967. It consisted of applying a 3°/sec ramp command of 100° amplitude to the actuator as it was cooling down with both cryogenic coolant and drive gas. Thermal Cycle No. 2 was performed on December 2, 1967. It consisted of applying a 3°/sec ramp command of 100° amplitude to the actuator as it was cooling down with cryogenic coolant. The drive gas was maintained at ambient temperature. Thermal Cycle No. 3 was also performed on December 2, 1967. It consisted of locking the actuator and leaving it de-energized during cooldown. Thermal Test No. 4 was not performed due to lack of facility time. The first three (3) tests adequately simulated operating conditions.

5.3.4 Once a cryogenic equilibrium temperature was reached, the actuator was subjected to a series of functional tests. The results of these cryogenic tests were compared with the ambient base line data and the comparison was used to evaluate the performance of the XE-1 actuator under cryogenic temperature conditions.

5.4 DISCUSSION OF TEST RESULTS

5.4.1 The graph of temperature excursion versus time for Thermal Cycle No. 1 is presented in Figure 5.2. The three temperature curves are drive gas, coolant gas, and the actuator skin temperature. During the cryogenic part of Thermal Cycle No. 1, it was noted that the lock indicating light failed to come on. However, the actuator was in a locked condition. Upon completion of the cryogenic test, the actuator was warmed up with the lock energized. Time "A" shows the temperatures where the lock began to function normally. A subsequent evaluation indicated that the lock failure was due to a shifting of the lock indicator switch cam and not due to binding or galling of the lock pin. After Thermal Cycle No. 1, the lock mechanism was disassembled and inspected for any evidence of galling. No evidence was found; therefore, the lock was reassembled in the actuator and recalibrated. This malfunction did not repeat on subsequent tests.

5.4.2 Temperatures for Thermal Cycle No. 2 are represented in Figure 5.3. No anomalies were noted during Thermal Cycle No. 2.

5.4.3 The temperature curves for Thermal Cycle No. 3 are shown in Figure 5.4. From the start of cooldown to time "A", the actuator was locked at the 15° position. At time "A", the actuator was unlocked and commanded to the 90° position in preparation for obtaining actuator performance data. The actuator responded very slowly to the applied commands. This slow response characteristic persisted and gradually resulted in an inability to control the actuator position. This anomaly was attributed to frozen gaseous drive gas contamination collecting in the servovalve flapper nozzles. At time "B", the temperature of the drive gas was increased with the coolant gas left at the same low temperature. This rise in drive gas temperature from about 80°R to about 130°R was enough to free the valve of contamination. Control of the actuator was regained at time "C" and the drive gas temperature was again lowered to see if the contamination freezing

Figure 5.2. Thermal Cycle No. 1 Temperature vs. Time Curve

Figure 5.3. Thermal Cycle No. 2 Temperature vs. Time Curve

Figure 5.4. Thermal Cycle No. 3 Temperature vs. Time Curve

reoccurred. The drive gas temperature stabilized at time "D" and, since no evidence of contamination freezing was present and the actuator was under control, the actuator was subjected to the standard performance tests.

After obtaining the actuator performance data, the actuator was locked and the torque motor current turned off for five minutes. The actuator was then unlocked, commanded to 90° , and scrambled several times. After the scrams and just before time "E", an oscillation of the actuator servovalve appeared. The frequency of oscillation was in the audio range (approximately 800 Hz) and was a servovalve instability induced by the low temperature of the actuator. At time "E", the drive gas was again warmed up and the oscillation stopped at time "F".

Once the oscillation stopped, the drive gas was cooled and at time "G" the actuator was again subjected to performance tests and the test concluded, as was predicted, margins of stability are inadequate when the actuator is operated near LH_2 temperature which is far below its design limit. From these tests, it appears that operating the actuator below about 100°R results in operation in a region where reliable valve control cannot be guaranteed. Therefore, 100°R must be considered the lowest operating temperature with 140°R a more conservative lower limit.

5.4.4 The results of the dynamic resolution, transient response and scram turnaround tests are tabulated in Figure 5.5. Because of the different dates of the tests, Thermal Cycle No. 1 (October 14, 1967) has its own base line data while Thermal Cycles No. 2 and No. 3 (December 2, 1967) have a different base line data. With the exception of Thermal Cycle No. 2, the scram turnaround times tended to decrease while the actuator was at cryogenic temperatures. The drive gas for Thermal Cycle No. 2 was at ambient with a higher viscosity than cryogenic drive gas, which results in the longer turnaround times. Thermal Cycle No. 3 was divided into No. 3A and No. 3B taken before and after the servovalve oscillation. Data for Thermal Cycle No. 3A was taken between times "D"

	<u>14 Oct. BLD</u>	<u>Thermal Cycle No. 1</u>	<u>2 Dec. BLD</u>	<u>Thermal Cycle No. 2</u>	<u>Thermal Cycle No. 3A</u>	<u>Thermal Cycle No. 3B</u>
Scram Turnaround						
Time (sec)	30	30	30	30	26.5	27.5
% of BLD	--	0	--	+3.3	-11.7	-8.3
Rise Time (in)						
Time (sec)	145	160	135	133	121	230
$\Delta\%$ of BLD	--	+10.4	--	-1.5	-10.4	+70
Rise Time (out)						
Time (sec)	160	140	174	153	206	145
$\Delta\%$ of BLD	--	-12.5	--	-12.1	+18.4	-16.7
Overshoot (in)						
Degrees	0	0	0	0	.56	0
% of 18°	--	0	--	0	3.1	0
Overshoot (out)						
Degrees	0	0	0	0	0	0
% of 18°	--	0	--	0	0	0
Settling Time (in)						
Time (sec)	--	--	198	212	187	305
$\Delta\%$ of BLD	--	--	--	+7.1	-5.6	+54
Settling Time (out)						
Time (sec)	--	--	242	234	308	215
$\Delta\%$ of BLD	--	--	--	-3.3	+27.3	-11.2
Dynamic Resolution						
Degrees	--	.09	--	0	.36	--

Figure 5. 5. Table of Low Temperature Test Data

and "E" while Thermal Cycle No. 3B was between time "G" and the end of the test. The overshoot noted for Thermal Cycle No. 3A is within specification values, but relatively larger than other data, and is indicative of a decrease in actuator friction.

5.4.5 The results of the frequency response tests are presented in Figures 5.6 to 5.11. The corresponding line data curves are superimposed on the cryogenic data curves. The increase in peaking and the rapid drop in phase angle of Thermal Cycle No. 3A indicates a reduction in friction and a decrease in stability.

Figure 5.6. Closed Loop Frequency Response Base Line Data Thermal Cycle No. 1

Figure 5.7. Closed Loop Frequency Response during Thermal Cycle No. 1

Figure 5.8. Closed Loop Frequency Response Base Line Data Thermal Cycles No. 2 & No. 3

Figure 5.9. Closed Loop Frequency Response during Thermal Cycle No. 2

Figure 5.10. Closed Loop Frequency Response during Thermal Cycle No. 3A

Figure 5.11. Closed Loop Frequency Response during Thermal Cycle No. 3B

6.0 LIFE TEST

6.1 INTRODUCTION

6.1.1 The life qualification test was conducted within the guidelines specified in WANL-TME-1040, Revision A, Qualification Specifications for Control Drum Pneumatic Actuators for XE-1 Application (see Appendix A), and performed under T-711892-D, Qualification Test, Environmental, Control Drum Actuator (see Appendix B), with a few minor exceptions noted herein.

6.1.2 The purpose of the testing was to determine what changes in performance would result in the actuator when operated for long periods of time. An additional purpose of the test was to determine what effects a simulated liquid nitrogen rain would cause when applied to a localized area of the actuator.

6.1.3 The method of testing consisted of operating the actuator with a repeating sequence of command inputs and recording the actuator performance at specified intervals. Also during the test, the actuator performance was monitored while liquid nitrogen was spilled on selected locations of the actuator to simulate possible operating environment on the engine.

6.2 DESCRIPTION OF TEST SET-UP

6.2.1 The life test of the XE-1 actuator was performed in the WANL Mechanisms Laboratory between January 8, 1968 and January 26, 1968. The actuator used was an XE-1 Series, Serial No. A-58608, and the actuator control amplifier was Serial No. A-62960. The combination of actuator and amplifier comprises the closed loop position control system.

6.2.2 For mechanical support, the actuator was mounted on a load stand. This load stand was designed to simulate the inertia, friction, and spring gradient of a control drum.

A modified actuator pedestal provided the interface between the load stand and the actuator and between the actuator and the gas system. The gas system provided nitrogen gas at a regulated pressure for coolant. Although not needed to cool the actuator, the coolant gas was used to simulate bearing loads and lock pressures that are expected during a reactor run. To reduce the expense that would be incurred by using large quantities of helium, the drive gas supply was selectable between helium and nitrogen. Helium drive gas was used for all performance testing and nitrogen was used while accumulating the specified running time.

6.2.3 A cam switch timer was used to automatically cycle the actuator through the predetermined sequence of various command input signals. The timer had a cycle time of one hour. Four function generators were used to provide the input signals. The appropriate function generator was switched in and out of the mount by the timer at required times in the test sequence.

The following equipment was used to determine the actuator performance:

Honeywell Visicorder, Model 1508

Industrial Measurements Frequency Response Analyzer, Model 101

Hewlett Packard Function Generator, Model 202 (3)

Hewlett Packard Low Frequency Oscillator, Model 202CR

Honeywell X-Y-Y' Chart Recorder, Model 480

Honeywell Digital Voltmeter, Model 6305

Trygon Power Supplies, Model PS 32-2.5

CEC Data Amplifiers, Type 155

CEC Pressure Transducers

Statham Pressure Transducers

Honeywell Gage Balance Units

6.3 DESCRIPTION OF TEST PROCEDURE

6.3.1 Prior to running the life test, a complete set of actuator performance tests were run to determine the base line data. For this portion of the test, the actuator was operated on nitrogen coolant gas at 540°R and 650 psig. The drive gas was helium at 540°R and 200 psig. Any impurities in the helium supply were cryogenically trapped and filtered out of the drive gas supply line before its entry into the actuator.

6.3.2 After obtaining the base line data, the drive gas supply was changed to nitrogen and the actuator was operated for 150 hours. The total accumulated hours for each command signal input are shown in Figure 6.1. Also given in Figure 6.1 is the time for each cycle of the cam switch timer.

6.3.3 At the end of each 25-hour interval, the drive gas was changed to helium and a closed loop frequency response to a 4° p-p sine wave command was recorded. During the test, one liter of liquid nitrogen was poured on each of the following: P₁ cylinder cover, P₂ cylinder cover, servovalve cover, feedback potentiometer cover, and rack back-up bearing cover.

6.3.4 After 150 hours of accumulated operating time, the actuator performance was recorded using helium drive gas and nitrogen coolant.

6.4 DISCUSSION OF TEST RESULTS

6.4.1 The results of scram turnaround, transient response, and dynamic resolution are tabulated in Figure 6.2. The actuator experienced a change in friction as evidenced by the reduced scram turnaround time, the decrease in overshoot and the increase in settling time. The slight changes in measured values did not adversely affect the system performance. Subsequent disassembly and examination did not show any wear which might explain the changes.

<u>Command Input</u>	<u>Total Time</u>	<u>Time Per Cycle</u>
Sine; 6 Hz, 4° p-p	12.5 hr	5.0 min
Scram, Lock and Reset	--	1.8 min
Sine; 0.5 Hz, 40° p-p	20.0 hr	6.0 min
Scram, Lock and Reset	--	1.8 min
Ramp; 0.01 Hz, 3°/sec	45.0 hr	20.0 min
Scram, Lock and Reset	--	1.8 min
Step; 0.1 Hz, 18° p-p	25.0 hr	10.0 min
Scram, Lock and Reset	--	1.8 min
Dwell at 90°	25.0 hr	10.0 min
Scram, Lock and Reset	--	1.8 min
Total Scram, Lock and Reset	22.5 hr	--
Total Time	150.0 hr	1.0 hr

Figure 6.1. Life Test Command Cycle

	<u>Base Line Data</u>	<u>After 150 Hours</u>
Scram Turnaround Time (sec)	0.028	0.024
% BLD		-1.4
Rise Time (in) Time (sec)	0.117	0.109
$\Delta\%$ BLD		-6.8
Rise Time (out) Time (sec)	0.120	0.126
$\Delta\%$ BLD		+5.0
Overshoot (in) Degrees	0.2	0
% 18°	1.11	0
Overshoot (out) Degrees	0.25	0.4
% 18°	1.39	+2.22
Settling Time (in) Time (sec)	0.175	0.159
$\Delta\%$ BLD		-9.1
Settling Time (out) Time (sec)	0.177	0.195
$\Delta\%$ BLD		+10.2
Dynamic Resolution Deviation from BLD Degrees	--	0.49

Figure 6.2. Table of Life Test Data

6.4.2 Figures 6.3 to 6.9 show the closed loop frequency responses obtained for each 25-hour interval. Except for minor variations in phase angle and in the response to frequencies over 10 Hz, the curves were all within the envelope of the base line data. The increase in friction noted in the scram turnaround and transient response data above was not noticeable in the frequency response data. The peaking of the gain curve remained at a nearly constant level throughout the test.

6.4.3 No change in actuator performance was detected while pouring liquid nitrogen on various parts of the actuator housing. The high thermal conductivity of the aluminum housing in conjunction with the flow of coolant gas throughout the actuator appears adequate in eliminating any localized cooling.

Figure 6.3. Closed Loop Frequency Response Base Line Data

Figure 6.4. Closed Loop Frequency Response after 25 Hours

Figure 6.5. Closed Loop Frequency Response after 50 Hours

Figure 6.6. Closed Loop Frequency Response after 75 Hours

Figure 6.7. Closed Loop Frequency Response after 100 Hours

Figure 6.8. Closed Loop Frequency Response after 125 Hours

Figure 6.9. Closed Loop Frequency Response after 150 Hours

7.0 COMBINED LOW TEMPERATURE AND VIBRATION TEST

7.1 INTRODUCTION

7.1.1 The combined low temperature and vibration test was conducted within the guidelines specified in WANL-TME-1040, Revision A, Qualification Specifications for Control Drum Pneumatic Actuators for XE-1 Applications (see Appendix A), and performed under T-711892D, Qualification Test, Environmental, Control Drum Actuator (see Appendix B), with exceptions noted herein.

7.1.2 The purpose of the test was to determine what changes in performance the actuator would undergo when cooled to cryogenic temperatures and then subjected to vibration.

7.1.3 The method of testing was to operate the actuator with various position command signals before, during, and after vibration and cooling, and to record the actuator performance. By comparing this performance data, any changes could be determined.

7.2 DESCRIPTION OF TEST SET-UP

7.2.1 The combined low temperature and vibration of the XE-1 actuator was performed in the WANL Mechanisms Laboratory between April 5, 1968 and April 10, 1968. The actuator used was an XE-1 Series, Serial No. A-58608, and the actuator control amplifier was Serial No. A-62960.

7.2.2 The equipment used in the vibration qualification test was also used in this combined low temperature and vibration test. For a complete listing of this equipment, see the vibration test section of this report (Section 3.0).

In addition to the vibration equipment mentioned above, the following was also used:

Bristol Strip Chart Recorder, Model 24P12H-590-51-B14-E51B-T111-T82K

Pace Thermocouple Reference Junction (150°F), Model BRJ14-18TP-1182

7.2.3 The gas supply system was equipped with heat exchanger in a liquid nitrogen dewar to cool the gas to cryogenic temperatures for the test. The drive gas used was helium at 200 psig and the coolant was nitrogen at 650 psig.

7.2.4 Photographs of the test set-up are shown in Figures 7.1 and 7.2. Close-up photographs of the actuator mounted on the load stand with pressure transducers and accelerometers installed are shown in Figures 7.3 and 7.4. A large path for thermal conduction exists between the load stand and the shaker table which was due to the rigid coupling required to transmit vibration. In view of this large heat gain to the actuator, other paths of heat transfer had to be reduced to achieve the low actuator temperatures required for the test. To reduce heat flow by convection and radiation, the actuator was enclosed in a metallized mylar cover. The actuator is shown with this cover in place in Figure 7.5 and after the removal in Figure 7.6.

7.3 DESCRIPTION OF TEST PROCEDURE

7.3.1 The actuator was first placed on its load stand and tuned for optimum transient response. After this tune-up, a complete set of actuator performance data was recorded. This data was used to establish the base line data.

7.3.2 Having recorded the pre-test actuator performance data, the actuator was given a 3°/sec ramp command of 100° peak-to-peak span about the 90° position. With the actuator undergoing a ramp position change, the drive and coolant gas supplies were diverted through the heat exchangers and the actuator cooled to its equilibrium temperature. Once at equilibrium temperature, the actuator was vibrated at the levels shown in Figure 7.7. Four complete cycles of vibration, from low frequency to high frequency and back to low frequency, were performed and the period of each cycle was 15 minutes. During each

Figure 7.1. Low Temperature and Vibration Test Setup-Vibration Equipment

Figure 7.2. Low Temperature and-Vibration Test Setup-Recording Equipment

Figure 7.3. Test Actuator and Load Stand

Figure 7.4. Test Actuator and Load Stand

Figure 7.5. Test Actuator with Heat Shield Cover Installed

Figure 7.6. Test Actuator with Heat Shield Cover Removed

Figure 7.7. Vibration Input Levels

successive cycle the actuator was given the command inputs shown in Figure 7.8. When the four vibration cycles were completed, the actuator was warmed to ambient temperature and a complete set of performance data was obtained.

7.3.3 A predicted natural frequency of vibration of the engine nozzle is 250 Hz. The resonant frequency of the actuator torque motor armature is also about 250 Hz. To check the actuator performance at this frequency of vibration and to determine if any adverse effects would be caused by engine induced frequencies, the actuator was again lowered to cryogenic temperature and vibrated at 240 Hz, 250 Hz and 260 Hz. The vibration level at each frequency was 5 g and the vibration time was 10 minutes. At each frequency, the actuator was given a static dwell at 90° for 5 minutes and a $3^\circ/\text{sec}$ ramp command of 100° amplitude for 5 minutes. During the 90° dwell, the actuator position, torque motor current, and cylinder pressures were recorded. During the $3^\circ/\text{sec}$ ramp, a dynamic resolution of command versus error was recorded.

7.4 DISCUSSION OF TEST RESULTS

7.4.1 During the cryogenic part of this test, the following equilibrium temperatures were attained:

Drive Gas	175°R
Coolant Gas	167°R
Exhaust Gas	140°R
Actuator Housing	174°R

A large leakage flow at the base of the load stand was noted while at cryogenic temperatures. This was due to the use of a rubber "O" ring seal on the load stand. The highest coolant pressure attainable under this high flow condition was 400 psig. This pressure was considered adequate to achieve the desired effects within the actuator.

INPUT FUNCTION	VIBRATION TIME MINUTES
RAMP, 3°/SEC, 100°p-p	15
STEP, 0.1 Hz, 18°p-p	15
DWELL AT 90° POSITION	15
SINE, 6 Hz, 4°p-p	15
TOTAL	<u>60</u>

Figure 7.8. Command Input Levels

7.4.2 The results of the scram turnaround, transient response, and dynamic resolution tests are given in Figure 7.9. The actuator appeared to have changed its friction level as evidenced by small increases in scram turnaround, rise and settling times. An overall shift in the dynamic resolution curve of 0.55° after the one hour vibration test was noted. Because the shape of the curve remained the same, this shift in dynamic resolution was attributed to a change in the + 10V, + 15V, and the - 15V power supplies. The dynamic resolution curve moved closer to the base line data while the actuator was being vibrated in the 250 Hz range. During the 240, 250 and 260 Hz vibration and while at 90° dwell, the actuator showed no signs of induced oscillation or position potentiometer noise. No hunting greater than $\pm 0.01^{\circ}$ was detected.

7.4.3 The frequency response curves for the base line data and after the cryogenic vibration are shown in Figures 7.10 and 7.11. The post-vibration curve did not deviate from the base line data by any appreciable amount.

	<u>Base Line Data</u>	<u>After Vibration</u>	<u>During 10 Min. Dwell at 5 g</u>		
			<u>240 Hz</u>	<u>250 Hz</u>	<u>260 Hz</u>
Scram Turnaround					
Time (sec)	.025	.029	--	--	--
% BLD	--	16	--	--	--
Rise Time (sec)	.149	.155	--	--	--
Δ % BLD	--	4.0	--	--	--
Overshoot (degrees)	0	0	--	--	--
% 18°	--	--	--	--	--
Settling Time (sec)	.214	.224	--	--	--
Δ % BLD	--	4.7	--	--	--
Dynamic Resolution					
Deviation from	--	.55	.13	.11	.10
BLD Degrees					

Figure 7.9. Table of Combined Low Temperature and Vibration Test Data

Figure 7.10. Closed Loop Frequency Response Base Line Data

Figure 7.11. Closed Loop Frequency Response After Test

8.0 ACTUATOR DISASSEMBLY AND INSPECTION

8.1 Upon completion of the XE-1 environmental qualification tests of vibration, mechanical shock, cryogenic, life and combined vibration/cryogenic, the test actuator was disassembled and inspected for wear or mechanical failure.

8.2 DRIVE SHAFT PINION AND RACK ASSEMBLY

The drive shaft pinion gear is shown in Figure 8.1. Some evidence of use was noted on that part of the gear which mates with the rack. The black oxide finish in this area appeared to be worn. No signs of chips or fractures were evident. Shown in Figure 8.1 and also in Figure 8.2 are six rings at each end of the drive shaft. These were caused by the silver-plating of the gap seals rubbing onto the drive shaft. This silver coating was not enough to cause a dimensional change. The soft stop spring bearing surface appeared to be worn where it comes in contact with the internal diameter of the drive shaft. This area is shown in Figure 8.3. Under normal operating conditions, the soft stop spring moves with the drive shaft and the increase in friction goes unnoticed. The increased friction appears during a scram when the actuator approaches the 15° position and its effect is to reduce penetration into the soft stop. The rack is shown in Figure 8.4. As on the pinion gear, the black oxide coating shows signs of use. No chips, flaking or fractures were noted on the gear teeth. The rack yoke is shown in Figure 8.5. No change in the yoke width was noted. Also, no sign of fracture or strain appeared near the yoke fillets.

8.3 LOCK PIN AND LOCK CAM

The lock pin is shown in Figure 8.6. No sign of wear was noted on the cylindrical surface but the end of the pin did show signs of chipping. This wear is caused by dropping the lock pin down on the lock cam surface during the scram operation. The

Figure 8-1. Drive Shaft and Pinion Gear - Lower End

Figure 8.2. Drive Shaft and Pinion Gear - Upper End

Figure 8.3. Soft Stop Spring

Figure 8.4. Rack and Piston

Figure 8. 5. Piston Coupling Yoke

Figure 8.6. Lock Pin and Solenoid Valve

increased friction has little effect on the dynamic operation performance of the actuator. The chips generated from the lock pin could cause increased friction in the drive shaft bearings if the actuator is operated without coolant gas flow. The lock cam upon which the lock pin rides is shown in Figure 8.7. The wear is apparent on the surface as it was on the lock pin tip. Figure 8.8 shows the lock cam riser surface at the 15° position. The edge has been rounded by wear although the flat surface still provides adequate area for the lock pin to hold the actuator locked securely at the 15° position.

8.4 CYLINDER LINER, CYLINDER COVER AND PISTON ASSEMBLY

Cylinder Cover No. 1 is shown in Figure 8.9 and Cylinder Cover No. 2 in Figure 8.10. A darkened spiral can be seen on both cylinder covers. This is a coating of the molybdenum diselenide used as a lubricant on the rack and which collected in the grooves between the cylinder liners and the cylinder covers. This black dust was also noted in the cylinder. These particles collected in the apex seals at the ends of the cylinder liners. The pneumatic flow resistors are shown inserted in the cylinder covers in Figures 8.9 and 8.10. Piston No. 1 and its cylinder liner is shown in Figure 8.11. Piston No. 2 and its cylinder liner is shown in Figure 8.12. Some wear was noted on the cylinder liners at the full stroke position of the pistons. This wear was more apparent in the cylinder liner of Piston No. 1 which corresponds to the 15° position of the drive shaft. The remainder of the cylinder bore was relatively free of scratches. The piston rings were also free of nicks and scratches and no increase in friction was noted. A comparison of the breakaway friction torque is compared with the original assembly data in Figure 8.13.

8.5 SERVOVALVE ASSEMBLY

The servovalve was removed from the actuator and inspected. The Glyptal on Bellows No. 2 adjustment screw was cracked and is shown in Figure 8.14. The purpose of

Figure 8.7. Lock Pin Cam

Figure 8.8. Lock Pin Cam

Figure 8.9. Cylinder Cover No. 1

Figure 8.10. Cylinder Cover No. 2

Figure 8.11. Piston and Cylinder No. 1

Figure 8.12. Piston and Cylinder No. 2

AVERAGE BREAKAWAY TORQUE:	ASSEMBLY TEST BY VENDOR	TEST DURING DISASSEMBLY OF ACTUATOR
INCREASING SHAFT ANGLE -	33.6 OZ IN	40 OZ IN
DECREASING SHAFT ANGLE -	38.3 OZ IN	35 OZ IN

Figure 8.13. Average Breakaway Friction

Figure 8.14. Servovalve - P_1 Flapper and P_2 Bellows

the Glyptal is to indicate that the screw has been set to its final adjustment and is not intended to serve as a screw locking device. A measurement of the locking torque of this screw indicated that it was above the 5 in-oz minimum. The most probable time for the Glyptal to crack was during a thermal cycle due to the difference in thermal contractions between the metal screw and the Glyptal. The Glyptal is downstream of the servovalve gas porting and therefore cannot enter the nozzle flapper valve. When operated after the environmental tests, the servovalve exhibited a bias current of 29 ma as opposed to 31 ma before the tests. This shift in bias current is considered normal. The crossover pressure, the value of P_1 and P_2 when they are equal, was 67 psig after the tests as opposed to 87 psig before the tests. This reduction in crossover pressure was the result of increased seal leakage and a shift of the flapper valve bullets and it appeared to have little or no effect on actuator performance.

9.0 EXTENDED LIFE TEST

9.1 As a supplement to the XE-1 qualification tests, an extended life test was performed on the XE-1 pneumatic control drum actuator. The purpose of the test was to gain further insight into the reliability and durability of the XE actuator design and to aid in future development of control drum actuator concepts. The extended life test was performed between January and May, 1969 in the WANL Mechanisms Laboratory.

9.2 The test set-up is shown in Figure 9.1. The actuator is mounted on a load stand which simulates a control drum and a scram spring. A modified pedestal serves as the actuator mounting support and provides the electrical, pneumatic, and mechanical interface to the actuator. The actuator control amplifier is mounted in a cabinet which provides lock and scram logic for the system. The visicorder, frequency response analyzer, and chart recorder are used to measure actuator performance. A timing cam system is used for periodic scram commands. The function generator generates the actuator position command.

9.3 The actuator used in this test was the same used throughout the qualification tests (Serial No. A58608). Following the post-qualification test actuator disassembly, the actuator parts were cleaned and the actuator reassembled and adjusted. The actuator control amplifier was of the modified XE-2 type (Serial No. 80823), which reduces the overall system closed loop bandwidth and also incorporates the selectable open or closed loop scram modes.

9.4 The assembled actuator was placed on the load stand and operated with helium drive gas (200 psig, 540°R) and nitrogen coolant gas (600 psig, 540°R). After initial alignment, the actuator performance was recorded to establish the base line data. Having established the base line data, the actuator was given a command signal as listed in the table below:

Figure 9.1. Extend Life Test Setup

100° ramps	3°/sec
100° steps	0.1 Hz
18° steps	0.5 Hz
40° p-p sine	0.1 Hz
4° p-p sine	1.0 Hz

Each input signal was applied for 24 hours with the exception that inputs scheduled for Saturdays were also continued on Sundays for a total of 48 hours. Equal time distribution was given to the inputs throughout the test. An additional scram input command was given to the actuator. The actuator was scrambled every 30 minutes alternately in the open loop mode and the closed loop mode. The net effect was an open loop and a closed loop scram for each hour of operation. To conserve helium gas the drive gas supply was changed to nitrogen (200 psig, 540°R). The nitrogen used for coolant was reduced from 650 to 250 psig.

9.5 At several time intervals, the life test was suspended and the actuator performance was checked. The first performance check was taken after 1990 hours (2000 hour check). The actuator drive gas was changed to helium (200 psig, 540°R) and the nitrogen coolant pressure was raised (650 psig, 540°R) for the performance check in order to repeat the conditions of the base line data check. No serious changes in actuator performance were noted. There was, however, a change in torque motor current from the nominal 30 ma to 21 ma. After the 2000 hour performance check, the extended life test was resumed.

9.6 It was noted that the feedback potentiometer developed noise when the actuator was given a continuous input signal, especially an 18° or a 100° step. This noise would develop in as little as one hour of operation but would disappear when the input signal was changed or the actuator was scrambled. The noise did not appear during the 2000 hour performance check but it did return afterwards in increasing intensity. At 2491 hours

(2500 hour check) the actuator performance was again checked. The potentiometer noise did not affect performance and the torque motor current remained at 21 ma. To further investigate the potentiometer noise, the potentiometer was removed and replaced by a new one. The potentiometer was disassembled and examined for track wear. "C" track showed wear over about a 20° segment near to 90° position. The wiper arm also appeared to be worn. It is believed that the rough worn areas, when operated for extensive periods at low coolant flows, allow the buildup of track particles which cause the wiper arm to skip and cause noise when traveling at high velocities. After the 2500 hour check, the extended life test was resumed.

9.7 With the new potentiometer installed, the test continued until 3213 hours of the extended life test. During this time, the new potentiometer developed no significant noise problems. At 3213 hours, however, the lock pin failed to engage when the actuator was given its periodic scram command. Further testing of the lock showed it incapable of achieving either the fully locked or the fully unlocked positions. Although the lock was inoperable, it was retracted enough not to interfere with the drive shaft rotation. The actuator performance was checked and it did not change significantly from the base line data. The extended life test was terminated and the actuator removed to the Clean Room for disassembly.

9.8 Upon disassembly, it was noted that the lock pin was jammed in the lock pin cylinder. The lock pin and cylinder showed score marks and signs of galling. The tip of the pin was also worn and chipped. The lock pin and cylinder had been coated with molybdenum diselenide at assembly but this had worn off due to the high stresses imposed during the scram operations. The lock pin is shown in Figure 9.2 and the lock pin cylinder is shown in Figure 9.3. The worn tip of the lock pin was caused by the lock pin falling on the lock pin cam during the scram operations. The lock pin cam also showed signs of wear as can be seen in Figure 9.4. The pre-test condition of the lock pin and

Figure 9.2. Lock Pin

Figure 9.3. Lock Pin Cylinder

Figure 9.4. Lock Pin Cam

cam can be seen in Figures 8.6, 8.7 and 8.8 in the preceding section of this report.

9.9 The drive shaft pinion gear is shown in Figure 9.5. There appears to be more wear in the area of rack contact in comparison with Figure 8.1, but there is no sign of chipped gear teeth. The upper end of the drive shaft is shown in Figure 9.6 and the corresponding contact area of the soft stop spring is shown in Figure 9.7. The contact areas appear to be worn but this wear occurs only when the actuator is locked and has no effect on actuator performance. The actuator rack and piston is shown in Figure 9.8. As on the pinion, the rack gear teeth show a wearing away of the oxide coating. On the rack, however, there are signs of flaking of the gear teeth. The flaking is a small percentage of the gear teeth and not enough to cause disengagement of the rack and pinion. An accumulation of residue was noted in the space between the two piston rings. This residue was a combination of dust from piston ring wear, rack and pinion oxide, and dry film lubricant. The space between the piston rings is not washed by either the coolant or drive gas and any particles in this area accumulate to form a residue. Figure 9.9 is of the rack back-up bearing. A spalling of the gold-plate can be seen. Performance of the bearing was not affected by this spalling of the gold-plate. In Figure 9.10, the piston coupling yoke is shown in good condition. There are no signs of bending, fracture or wear.

9.10 The cylinder liner and piston of the P_1 side is shown in Figure 9.11 and the corresponding cylinder cover is in Figure 9.12. Figure 9.13 shows the P_2 liner and piston and Figure 9.14 is the cylinder cover for the P_2 side. The cylinder liners show very little wear but an accumulation of dust can be seen at the limit of the piston stroke. Metallic chips from the lock pin and cam can be seen inside the cylinder covers. These chips were trapped in the seal areas of the coolant flow passages and did not enter the piston areas. The dry film lubricant appears to have adhered to the internal surfaces of the actuator as a black coating and is shown in Figure 9.15.

Figure 9.5. Drive Shaft and Pinion Gear

Figure 9.6. Drive Shaft - Upper End

Figure 9.7. Soft Stop Spring

Figure 9.8. Rack and Piston

Figure 9.9. Rack Back Up Bearing

Figure 9.10. Piston Coupling Yoke

Figure 9.11. Piston and Cylinder No. 1

Figure 9. 12. Cylinder Cover No. 1

Figure 9.13. Piston and Cylinder No. 2

Figure 9.14. Cylinder Cover No. 2

Figure 9.15. Actuator Housing - Internal Walls

9.11 The lower drive shaft bearing is shown in Figure 9.16. The gold-plate is gone from the balls and metallic chips can be seen in the recesses of the bearing holder. The bearing rotation appeared to be rough and uneven. Before disassembly, the breakaway friction of the drive train was measured. The maximum breakaway friction was 6 in-lbs. Maximum specified friction for the XE actuator is 1.875 in-lbs. The increase in friction is attributed to bearing wear caused by metallic chips from the lock pin and cam and a loss of the gold-plate on the bearings. The increased friction, however, did not appear to seriously affect actuator performance.

9.12 The servovalve was removed as a unit and placed on the servovalve test stand. The bias current remained at 20 ma as it had throughout the test. The frequency response of the valve did not change from its initial setpoint. It appears that the change in bias current from the setpoint value of 30 ma to 20 ma was the result of a shift in the bellows on the valve at the onset of the test.

9.13 Figure 9.17 lists the results of the transient response, scram turnaround, and resolution tests obtained during the performance checks. The most noticeable change was in the resolution. This deviation occurred as a shift of the entire resolution curve which was caused by a difference in shift between the +10 VDC and the -15 VDC power supplies. In conjunction with the change in resolution was also the maximum change in outward rise and settling times. The frequency response curves are shown in Figures 9.18, 9.19, 9.20 and 9.21. The change in frequency response from the base line data appears as a low frequency peaking and a more rapid roll-off which is indicative of increased actuator friction.

9.14 The following table lists the total operating time of the XE test actuator No. 58608:

Figure 9.16. Lower Drive Shaft Bearing

	<u>BLD</u>	<u>1990 hr</u>	<u>2491 hr</u>	<u>3211 hr</u>
Scram Turnaround				
Closed Loop (sec)	0.019	0.021	0.021	0.018
% of BLD	--	+10.5	+10.5	-5.3
Open Loop (sec)	0.057	0.040	0.048	0.062
% of BLD	--	-30.0	-16.0	+8.8
Rise Time (in)				
Time (sec)	0.259	0.277	0.250	0.246
$\Delta\%$ BLD	--	+7.0	-3.5	-5.0
Rise Time (out)				
Time (sec)	0.294	0.333	0.327	0.332
$\Delta\%$ BLD	--	+13.3	+11.3	+12.9
Settling Time (in)				
Time (sec)	0.460	0.460	0.494	0.455
$\Delta\%$ BLD	--	0	+7.4	-1.1
Settling Time (out)				
Time (sec)	0.507	0.623	0.546	0.545
$\Delta\%$ BLD	--	+23.0	+7.7	+7.5
Maximum Resolution	--	1.07	0.7	0.99
Deviation (degrees)				

Figure 9.17. Table of Test Data

Figure 9.18. Extended Life Test Base Line Data

Figure 9.19. Extended Life Test 1990 Hours

Figure 9.20. Extended Life Test 2491 Hours

Figure 9.21. Extended Life Test 3211 Hours End of Test

Acceptance Test	8.35 hr
Subsystems Test	21.50 hr
Vibration Test	17.75 hr
Mechanical Shock Test	17.78 hr
Thermal Test	4.95 hr
Life Test	157.00 hr
Combined Environment Test	15.00 hr
Extended Life Test	3211.00 hr
TOTAL	3453.30 hr

During the above total accumulated hours of operation, the actuator performed the following number of scram operations.

Open Loop Scrams	3985
Closed Loop Scrams	3215
Total Full Load Scrams	7200

10.0 NRX-A6 PNEUMATIC ACTUATOR SIDE-BY-SIDE EXPERIMENT

The side-by-side actuator test was performed to obtain data on the effects of a radiation environment on the components and on the operation of the pneumatic control drum actuator.

One objective of the test was to determine component, subassembly and/or assembly degradation due to the integrated neutron flux and gamma radiation. A second objective was to determine the effectiveness of the coolant gas flow and its ability to remove radiation induced heating.

10.1 DESCRIPTION OF TEST SETUP

A block diagram of the test setup is shown in Figure 10.1. The drive supply gas was regulated to a constant pressure of 215 psia and maintained at this constant pressure throughout the test. Coolant was supplied to the actuator through a regulating valve controllable from the control room. Both the He drive and coolant passed through an LN₂ heat exchanger. The temperature at the exit of this heat exchanger was about 140°R. The coolant gas pressure and the electrical input and output signals to the actuator originated in the control room and were varied during the test by the side-by-side Test Operator. The actuator experiment was mounted on the test car inside the 360 degree shield next to the reactor at the 180 degree θ position. The position of the pneumatic actuator side-by-side experiment with respect to the NRX-A6 reactor is shown in Figure 10.2. Figure 10.3 is a drawing of the actuator, pedestal and a simulated drum load enclosed in its housing. This drawing shows external details of the actuator, pedestal and simulated drum load as well as showing instrumentation impulse lines, instruments and thermocouples. A photograph of the instrumented actuator system is shown in Figure 10.4 prior to installation of the enclosure. In this photograph, the actuator, pedestal, electrical control wires and many of the instrumentation cables and impulse lines are visible. The marmon clamp, one pressure transducer and several accelerometers are also visible. This photograph is oriented approximately the same as the drawing of Figure 10.3 and can be used for comparative purposes. The completely assembled pneumatic actuator side-by-side test fixture is shown in Figure 10.5. The clamp that mounts the side-by-side experiment to the test car adapter can be seen in this picture. Also, the electrical leads, thermocouples and plumbing lines are shown. In Figure 10.6 the test fixture is shown mounted on the test car. The dosimeter packets

Figure 10.1. Block Diagram of Test Setup

Figure 10.2. Side-by-Side Actuator Test Actuator Position Diagram

Figure 10.3. Actuator, Pedestal and Load

Figure 10.4. Test Fixture Assembly

Figure 10.5. NRX-A6 Side-by-Side Actuator Test Fixture

Figure 10.6. Test Fixture Mounted on Test Car

SSA-3 and SSA-5 can be seen in the photograph while dosimeter packets SSA-2 and SSA-4 are hidden because they are mounted diametrically opposite to SSA-3 and SSA-5. SSA-1 cannot be seen in the photograph because it was located on the top of the test experiment near the lifting handle.

The actuator used for this test was an AG-20 type actuator which is a prototype of the XE series actuators. This actuator was upgraded with XE-1 parts that were sensitive in nature and to make the component as nearly like an XE-1 actuator as possible without actually testing an XE-1. The XE-1 parts installed were:

- 1) Servovalve
- 2) Potentiometer
- 3) Piston Rings
- 4) Solenoid Shut-Off Valve

The Shut-Off Valve was a new design retrofitted into all the XE-1 actuators. The actuator was lubricated using molybdenum diselenide as used in the XE-1 units. One of the major difficulties experienced with the preparation of this test was to adequately instrument the actuator so that the test would provide useful information. Installing thermocouples for this purpose was difficult. Pressure transducers and impulse lines were installed to measure and provide signals for recording the following pressures.

- 1) Coolant Pressure
- 2) Drive Pressure
- 3) Cylinder No. 1 Pressure
- 4) Cylinder No. 2 Pressure
- 5) Exhaust Pressure

Thermocouples were installed to give temperatures of critical components as well as give temperature distribution information across the actuator. Thermocouples were installed to measure the following temperatures.

- 1) Coolant Temperature
- 2) Drive Temperature

- 3) Potentiometer Temperature
- 4) Exhaust Temperature
- 5) Torquemotor Temperature
- 6) Cylinder No. 1 and No. 2 Temperature
- 7) Lock Housing Temperature
- 8) Marmon Clamp Temperature

In some cases, more than one thermocouple was installed to measure temperatures at different points on a component. For example, four thermocouples were installed at different θ locations to measure the marmon clamp temperature. Also, temperature at various locations within the load were recorded to assure safe operation. In addition to pressure and temperature measurements, three accelerometers were used to record levels of shock and vibration during testing. Dosimeter packets were mounted on the final assembly. The dosimeters, SSA-1 to SSA-5, were used to measure.

Slow neutron integrated flux ($E < 0.4 \text{ eV}$)

Fast neutron integrated flux ($E > 2.9 \text{ MeV}$)

Gamma dose

In addition to pressure, temperature, acceleration, and radiation, the actuator performance parameters measured and recorded were:

Position command signal

Actuator position signal

Torquemotor current

10.2 DESCRIPTION OF THE TEST

Prior to operation of the reactor, a closed loop frequency response was performed. A four degree peak to peak input command was given to the actuator at various frequencies and the feedback position was compared to this input. The frequency response was repeated while the reactor was at full power and again after the reactor was shut down. In addition to the frequency response, the following test sequence was initiated approximately 15 minutes prior to reactor startup.

- 3.5 min. Sinusoidal input of 4° p-p at 3 HZ while actuator was positioned at 90°
- 0.5 min. Scram, lock and reset
- 5.0 min. Sinusoidal input of 40° p-p at 0.5 HZ while actuator was positioned at 90°
- 0.5 min. Scram, lock and reset
- 9.0 min. Ramp input at $3^{\circ}/\text{sec}$; 20° to 160°
- 0.5 min. Scram, lock and reset
- 5.0 min. Step between 81° and 99° at 0.1 HZ
- 0.5 min. Scram, lock and reset
- 5.0 min. Dwell at static position of 90°
- 0.5 min. Scram, lock and reset

This test sequence was repeated until approximately 15 minutes after reactor shutdown.

10.3 TEST RESULTS

The plot in Figure 10.7 shows the three closed loop frequency responses taken before, during, and after the test. Very little change in performance occurred between the pre-run test and the full power test. The test performed after the reactor run exhibits an increased bandwidth which is indicative of reduced piston rings friction.

Although the data were adequate to provide accurate attenuation information, a malfunctioning speed control on the Sanborn recorders made it impossible to separate the adjacent cycles sufficiently to obtain phase shift information. Evaluation of the performance data shows that the actuator can be safely used to drive the control drums on the XE reactors and that the radiation levels experienced were at about the levels predicted for the R and E reactors.

A summary plot of actuator temperatures and coolant pressure during the reactor full power run is shown in Figure 10.8. In general, the coolant pressure was reduced in controlled increments during reactor full power operation to obtain internal temperature distribution as a function of the cooling pressure. One significant difference between this test and XE and R type tests (where the actuators will be mounted on the pressure vessel or external shield) is the coolant temperature as it enters the actuators. Coolant temperatures on XE and R tests are

Figure 10.7. NRX-A6 Side-by-Side Actuator Test Closed Loop Frequency Response

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Figure 10.8. NRX-A6 Side-by-Side Actuator Test Full Power Run

expected to be very near dome temperature or about 212°R at full power. The actuator side-by-side coolant temperature was about 400 to 450°R . This warm up of coolant in the side-by-side test is due to the relatively long run between the LN_2 heat exchanger and the inlet to the actuator. The closely coupled XE and R tests will eliminate this warm-up. Even with the relatively warm coolant gas temperature (450°R) and the experimentally low coolant pressures (550 psi) none of the component temperatures exceeded allowable limits. This gives strong evidence of the adequacy of the actuator coolant flow.

A plot of the gamma dose received by the side-by-side experiment is shown in Figure 10.9. These curves were plotted using data obtained from the dosimeter pockets mounted directly on the experiment container. From the figure, it can be seen that the actuator experienced a heating rate of about 93 to 116 watts/lb. This exceeds the expected XE gamma dose by a factor of about 250 and is approximately equal to the gamma dose predicted for the R & E reactors. A plot of the fast neutron flux obtained by using dosimeter data is shown in Figure 10.10. The flux field in the vicinity of the actuator was between 0.1 and 0.2×10^{16} n/cm² which is about 100 greater than predicted field for the XE actuators located above the shield. A similar plot showing slow neutron flux is presented in Figure 10.11. The slow neutron flux levels were between 3 and 5×10^{16} n/cm² at the actuator.

Following the test, the side-by-side pneumatic actuator was completely disassembled and photographed in search of any radiation caused damage. No malfunctions were observed during performance and no unusual wear or damage to internal components were detected upon disassembly. Although many photographs were taken, only a few are presented here. The views selected are of those components felt to be of the most critical nature. Figure 10.12 shows the torquemotor, solder joints, lead wire and miscellaneous servovalve components. Figure 10.13 shows the lock indication switches, solder connections, wires and the lock and lock shut off valve in the background. A view of the three deck potentiometer again showing the solder points, wire and insulating sleeves is shown in Figure 10.14. Figure 10.15 shows the P_1 piston and rack assembly, the P_2 piston and all the piston rings.

Figure 10.9. Gamma Dose

Figure 10.10. Fast Neutron Flux

Figure 10.11. Slow Neutron Flux

Figure 10.12. Site Photo, Torque Motor

Figure 10.13. Site Photo, Lock Indication Switches

Figure 10. 14. Three Deck Potentiometer

Figure 10.15. Site Photo, Pistons and Rack

10.4 CONCLUSIONS

The pneumatic control drum actuator will perform as designed while under the influence of a radiation field (and after being subjected to an integrated radiation field) well in excess of the XE predicted field and about equivalent to that expected on the R reactor and E engine tests. The coolant flow to the actuator was designed with the NR heating rates of 350 watts/lb as a parameter; these rates are higher than required for heating rates expected on the XE, R and E programs which are predicted to be on the order of 125 watts/lb maximum. Coolant flow could probably be reduced, and as more experience is obtained this modification will be considered.

APPENDIX A

Subcontract NP-1

WANL-TME- 1040 , Rev. A
30 November 1967

Westinghouse Astronuclear Laboratory

**QUALIFICATION SPECIFICATIONS FOR CONTROL DRUM
PNEUMATIC ACTUATORS FOR XE-1 APPLICATION**

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1. INTRODUCTION

This document specifies the environmental tests and expected performance of the XE-1 Control Drum Pneumatic Actuator. The actuator is to be subjected to the various environments that are expected in the XE Test Series while its performance as a control system component is evaluated. Among the tests to be performed are vibration and shock which shall qualify the actuator for both ground handling and anticipated ground firing conditions. The actuator shall also be tested for operation at low temperatures. The low temperature tests shall consist of both uniform temperature throughout the actuator and localized cooling at various points on the actuator housing. To determine the life expectancy of the actuator, a continuous operation for 150 hours followed by one hour operation at low temperature and under expected ground firing vibration is to be performed. The results of the NRX-A6 Side-by-Side Test and the NASA Lewis AG-20 and XE-1 irradiating tests will serve to qualify the actuator for use in a radiation environment.

2. VIBRATION QUALIFICATION TESTS FOR CONTROL DRUM PNEUMATIC ACTUATORS

2.1 PURPOSE

The purpose of this test is to determine the acceptability of the pneumatic drum actuator for use in the NERVA X-Engine Test XE-1. This investigation is limited to qualification in a vibration environment consisting of a sinusoidal forcing function varying in frequency at a logarithmic rate.

2.2 GUIDING SPECIFICATIONS

The following specifications shall serve as guidelines in completing the requirements of this specification:

- 1) MIL-STD-810 - "Environment Test Methods for Aerospace and Ground Equipment" (Equipment Class 4, and Equipment Class 6, Mounting Method "a")
- 2) AGC Report Number RN-DR-0020 - "Preliminary Specification, NERVA X-Engine, NERVA Program, Contract SNP-1"
- 3) WANL Specification E-675560 - "Actuator Mechanisms, Pneumatic - XE Series Control Drum"

2.3 PROCEDURE

2.3.1 Pre-Test Installation and Test

Prior to the initiation of the vibration test, measure and record the load stand spring gradient and friction. Apply low level vibration to a dummy actuator of dimensions similar to an actual XE-1 actuator to determine the resonances of the load stand.

Mount the actuator on the load stand and tune the amplifier for optimum transient response of the system and establish the 100 degree per second velocity limits.

2.3.2 Pre-Test Performance Record

A complete set of performance data shall be recorded with the actuator operated under ambient conditions and no applied vibration. This data shall be used as a reference

throughout the subsequent test and shall be referred to as the "Base Line Data". The "Base Line Data" shall include:

- 1) Linearity and resolution check
- 2) Transient response check
- 3) Scram turnaround check
- 4) Frequency response check between frequencies of 0.1 to 20 cps (Hz)

The definition and conditions for these tests shall be as outlined in the appropriate paragraphs of WANL Specification E-675560 except as modified herein. The method of obtaining data shall be as outlined in TS 711892-A.

2.3.3 Vibration Tests

2.3.3.1 Test Plan

The tests described in the table below shall be conducted to determine the performance of the actuator when subjected to these vibratory environments. TS 711892-A outlines the procedure to be followed in performing these tests.

2.3.3.2 Planes of Vibration

The actuator shall be vibrated according to the test schedule of Table 2-1 in each of the following planes:

Vertical:	Applied vibration force in a plane parallel to the actuator output shaft.
Horizontal Number 1:	Applied vibration force in a plane parallel to the direction of piston travel.
Horizontal Number 2:	Applied vibration force in a plane normal to the direction of piston travel.

TABLE 2-1
TEST SEQUENCE AND SPECIFICATIONS

Phase	Actuator Condition	Vibration Plane	Performance Tests					Resonance Dwell		
			Test No.	Sweep Frequency (cps)	No. of Sweeps	Time/Sweep	Applied Force (g)	Test No.	Dwell Time at Resonance	Applied Force (g) Vector
Low Level Vibration Search	Non-Operational	All 3	1	5-2000-5	2	3 min	1.0	--	--	--
Shipment and Storage	Non-Operational	All 3	2	10-30-10	3	2 min	4.0	5	30 min	4.0
Ground Firing	Operating	Vertical	3	5-2000-5	1	30 min	See Figure 2-1	6	10 min	See Figure 2-1
Ground Firing	Operating	Horizontal	4	5-500-5	2	15 min	See Figure 2-2	7	10 min	See Figure 2-2

Figure 2-1. Anticipated Vibration Environment, NERVA XE-1; Ground Firing Test, Longitudinal Plane

Figure 2-2. Anticipated Vibration Environment, NERVA XE-1; Ground Firing Test; Lateral Plane

2.3.3.3 Test Sequence

The tests listed in Table 2-1 shall be conducted in the following sequence:

Vertical: 1, 2, 3, 5, 6

Horizontal

Number 1: 1, 2, 4, 5, 7

Horizontal

Number 2: 1, 2, 4, 5, 7

In addition, a dynamic resolution check and a transient response check shall be performed after tests 3 and 4, whenever they occur in the test sequence, while a complete set of performance data shall be taken after tests 6 and 7.

2.3.3.4 Actuator Conditions

1) Non-operating

In those tests where the actuator is non-operating, the following conditions shall prevail:

- a) The drive and coolant gas supplies to the actuator shall be turned off.
- b) The actuator shall be locked at the 15 degree shaft position.
- c) The electrical supplies to the torque motor shall be turned off.

2) Operating

In those tests where the actuator is operating, the following conditions shall prevail:

- a) Drive gas pressure at 200 ± 10 psig.
- b) Coolant gas pressure at 675 ± 25 psig.
- c) Drive and coolant gas temperature at ambient conditions.
- d) External friction load shall be as measured.
- e) Simulated inertia load at $0.24 \text{ inch/pound/second}^2$.
- f) Actuator velocity limit set at 100 ± 10 degrees per second.
- g) The actuator set at a nominal drum position of 90 degrees, with various command signals superimposed on the nominal position.

2.3.3.5 Data Requirements

The following data shall be recorded during the tests:

- 1) Vibration control accelerometer.
- 2) Three accelerometers recording motion along the three axes of the actuator.
- 3) Drive gas pressure and temperature.
- 4) Coolant gas pressure and temperature.
- 5) Two cylinder pressures.
- 6) Actuator shaft position.
- 7) Actuator command.
- 8) Torquemotor current.
- 9) Position error.

2.4 PERFORMANCE REQUIREMENTS FOR QUALIFICATIONS

To successfully demonstrate the qualification of the actuator in the XE-1 vibration environment, performance within the deviations specified should be satisfied during and after the vibration tests described in Table 2-1. Isolated departures that vary beyond the allowable limits shall be evaluated individually in light of the control system requirements.

2.4.1 Scram Operation

Maximum allowable turnaround time - ± 10 percent of base line data.

2.4.2 Transient Response to 18 Degree Peak-to-Peak Square Wave

Rise Time	-	± 10 percent of base line data
Settling Time	-	± 10 percent of base line data
Overshoot	-	± 10 percent of base line data

2.4.3 Frequency Response to 4 Degree Peak-to-Peak Sine Wave

- 1) Amplitude ratio shall not exceed ± 2 db of base line.
- 2) Phase lag at 1 cps (Hz) not to exceed ± 5 degrees of base line data.

- 3) Phase lag at 2 cps (Hz) not to exceed ± 5 degrees of base line data.
- 4) Phase lag at 6 cps (Hz) not to exceed ± 7.5 degrees of base line data.
- 5) Phase lag at 12 cps (Hz) not to exceed ± 10 degrees of base line data.

2.4.4 Dynamic Resolution to a 3 Degree per Second Ramp Command

Maximum error from base line data shall be ± 0.5 degree (0.0055 volt).

2.4.5 Static Resolution

Static position resolution at the output shaft shall not exceed ± 0.5 degree (0.0275 volt) of base line data.

2.5 POST VIBRATION INSPECTION

Upon completion of all the scheduled tests, if there is an unexplainable discrepancy in the performance requirements (detailed in Section 2.4) the actuator shall be disassembled and inspected for physical damage or changes. A careful record shall be maintained of each step in the disassembly process. Pictures shall be taken wherever it is deemed necessary.

2.6 REPORT REQUIRED

2.6.1 Final Report

A final report covering the entire environmental testing of the XE-1 actuator shall be written which shall include the results of the vibration qualification test. It should include but not be limited to:

- 1) Introduction
- 2) Description of Test Setup
- 3) Description of Test Procedure
- 4) Presentation of Discussion of Test Data
- 5) Conclusions and Recommendations

3. MECHANICAL SHOCK QUALIFICATION SPECIFICATION FOR DRUM PNEUMATIC ACTUATORS FOR XE-1 APPLICATION

3.1 PURPOSE

The purpose of this test is to qualify the pneumatic drum actuators for use in the NERVA X-Engine Test XE-1. This investigation will be limited to observing the actuator closed loop performance while it is subjected to mechanical shock loads, which are considered typical of the XE-1 environment.

3.2 GUIDING SPECIFICATIONS

The following specifications will serve as guidelines in completing the requirements of this specification:

- 1) MIL-STD-810 - "Environmental Test Methods for Aerospace and Ground Equipment" (Test Method Number 516, Procedure 1)
- 2) AGC Report Number RN-DR-0020 (Revised) - "Preliminary Specification, NERVA Program, Contract SNP-1", September 1964
- 3) WANL Specification E-675560 - "Actuator Mechanisms, Pneumatic - XE Series Control Drum"

3.3 PROCEDURE

3.3.1 Pre-Shock Test Performance Record

Prior to the initiation of the shock tests, the actuator shall be mounted on the test stand and a complete set of performance data shall be recorded. This data will be used as a reference throughout the subsequent test and will be referred to as "the base line data". The base line data shall include the following items:

- 1) Linearity and Resolution Check
- 2) Transient Response Check
- 3) Scram Turnaround Check
- 4) Frequency Response Check between 0.5 and 20 cps(Hz)

The definition and test conditions for these tests shall be as outlined in the appropriate paragraphs of WANL Specification E-675560, except as modified herein.

3.3.2 Shock Test

3.3.2.1 Test Plan

The following tests shall be conducted to determine the actuator performance when subjected to shock loads. TS 711892-B outlines the procedure to be followed in performing these tests.

3.3.2.2 Direction of Applied Loads

The shock loads shall be applied in the following planes as described in

Table 3-1:

Vertical:	Applied force parallel to the actuator output shaft.
Horizontal Number 1:	Applied force parallel to the direction of the piston travel.
Horizontal Number 2:	Applied force normal to the direction of the piston travel.

TABLE 3-1

SHOCK SCHEDULE

Plane	Actuator Condition	Load (g's)	Dwell Time (sec)	Shocks in Each Direction	Shocks in Each Plane
Vertical	Operating	± 2.0	0.01	3	6
Horizontal No. 1	Operating	± 1.0	0.01	3	6
Horizontal No. 2	Operating	± 1.0	0.01	3	6

3.3.2.3 Actuator Conditions

During all of the tests described in Table 3-1, the conditions to be imposed on the actuator shall be as follows:

- 1) Drive gas pressure at 200 ± 10 psig
- 2) Coolant gas pressure at 675 ± 25 psig
- 3) Drive and coolant gas temperatures at ambient conditions
- 4) Simulated inertia load at $0.24 \text{ in} / \text{lb}/\text{sec}^2$
- 5) Actuator velocity limit set at 100 ± 10 degrees/second
- 6) The actuator set at a nominal drum position of 90 degrees and a 3 degree/second triangular wave of 100 degrees peak-to-peak amplitude applied.

3.3.2.4 Data Requirements

The following data shall be recorded during the tests:

- 1) Applied shock pulse
- 2) Shock pulse as recorded at two places on the actuator housing
- 3) Drive gas pressure and temperature
- 4) Coolant gas pressure and temperature
- 5) Actuator shaft position
- 6) Actuator command
- 7) Torquemotor current
- 8) Position error

3.3.3 Post Shock Test Performance Record

Upon completion of the tests described in Section 3.3.2, a complete set of performance data shall be recorded to compare with the base line data recorded in Section 3.3.1. These data shall include the same requirements as specified in Section 3.3.1.

3.4 PERFORMANCE REQUIREMENTS FOR QUALIFICATION

To successfully demonstrate qualification of the actuator in the XE-1 environment, the following performance parameters should be satisfied after the shock tests described in Table 3-1. In addition, the physical structure of the actuator should remain intact. There should be no damage to the individual components such that they would be unable to perform their intended functions. Isolated cases that vary beyond the allowable limits shall be evaluated individually in light of the control system requirements.

3.4.1 Scram Operation

Maximum allowable turnaround time - ± 10 percent of base line data.

3.4.2 Transient Response to 18 Degree Peak-to-Peak Square Wave

Rise Time	-	± 10 percent of base line data
Settling Time	-	± 10 percent of base line data
Overshoot	-	± 10 percent of base line data

3.4.3 Frequency Response to 4 Degree Peak-to-Peak Sine Wave

- 1) Amplitude ratio shall not exceed ± 2 db of base line data
- 2) Phase lag at 1 cps (Hz) not to exceed ± 5 degrees of base line data
- 3) Phase lag below 2 cps (Hz) not to exceed ± 5 degrees of base line data
- 4) Phase lag at 6 cps (Hz) not to exceed ± 2.5 degrees of base line data
- 5) Phase lag at 12 cps (Hz) not to exceed ± 10 degrees of base line data

3.4.4 Dynamic Resolution to a 3 Degree per Second Ramp Command

Maximum error from base line data shall be ± 0.1 degree (0.0055 volt)

3.4.5 Static Resolution

Static position resolution at the output shaft shall not exceed ± 0.1 degree (0.005 volt) of the base line data.

3.5 POST SHOCK TEST INSPECTION

Upon completion of all scheduled tests, if there is an unexplainable discrepancy in the performance requirements (detailed in Section 3.4), the actuator shall be disassembled and visually inspected for physical damage or changes. A careful record shall be maintained of each step in the disassembly process. In the event that any part(s) shows evidence of material failure or excessive wear, a dimensional check with suitable photographs of the failure will be made.

3.6 REPORT REQUIRED

3.6.1 Final Report

A final report covering the entire environmental testing of the XE-1 actuator shall be written which shall include the results of the mechanical shock qualification test. It should include but not be limited to:

- 1) Introduction
- 2) Description of Test Setup
- 3) Description of Test Procedure
- 4) Presentation and Discussion of the Test Data
- 5) Conclusions and Recommendations

4. LOW TEMPERATURE QUALIFICATION SPECIFICATIONS FOR CONTROL DRUM PNEUMATIC ACTUATORS FOR XE-1 APPLICATION

4.1 SCOPE

The XE-Engine control drum pneumatic actuators, herein called actuators, must be capable of operating satisfactorily when using low temperature gas as supplied by the XE-Engine. Specific operating requirements and conditions required to qualify actuators for XE-1 Engine use are defined and specified by this document.

4.2 OBJECTIVE

It is the primary objective of this document to demonstrate by tests that the actuators are qualified for XE-1 during low temperature operation. This qualification will be considered for both mechanical integrity of the actuator and components as well as functional operation of the actuator sub-system.

4.3 REFERENCE SPECIFICATIONS

The following sources shall serve as specification guidelines in interpretation of the actuator requirements for low temperature qualification:

AGC Report RN-DR-0020	"Preliminary Specification, NERVA X-Engine, NERVA Program Contract SNP-1"; Section 5 (September 1964)
WANL Specification E-675560	"Actuator Mechanisms, Pneumatic - XE Series Control Drum"

4.4 TEST PARAMETERS

Test parameters, as specified herein, must be controlled and recorded during all phases of test qualifications. The only exception being the inertia load value which should be constant, but need not be measured.

4.4.1 Actuator Drive Gas Parameters

Fluid	He or H ₂
Pressure	200 ± 10 psig
Temperature	150 ± 25°R and 50 + 25°R (H ₂ only)

4.4.2 Actuator Coolant Gas Parameters

Fluid	He or H ₂
Pressure	675 ± 25 psig
Temperature	150 ± 25°R and 50 + 25°R (H ₂ only)

4.4.3 Actuator Return Gas Parameters

Fluid	Mixture of coolant and drive
Pressure	Back pressure of vent (not to exceed 35 psig)
Temperature	Result of mixture

4.4.4 Friction Load

Friction Value 0 to 32 in /lb (not controlled)

4.4.5 Actuator Temperature

Metal Temperature - regulated by gas temperature

4.4.6 Inertia Load

Inertia Value - 0.24 in /lb/sec²

4.4.7 Test Duration

Number of Cycles - 4 at each specified temperature

Length of Cycles - 300 seconds minimum with steady state actuator temperatures

4.4.8 Actuator Subsystem Gain Controls

Gain control values shall remain constant for the entire test. Actual settings will be adjusted prior to testing.

4.5 TEST PLAN

4.5.1 Test Description

It will be required to provide all of the test parameters as specified above for each test cycle. A test cycle will be performed to attain the gas temperatures specified for a minimum of 300 seconds. The actuator should be allowed to "warm up" to room temperature after each cycle prior to beginning another cycle. During each cycle the actuator must be operated in such a manner as to demonstrate the actuator qualification requirements as outlined in Section 4.6 of this document. TS 711892-C outlines the procedures to be followed in performing these tests.

4.5.2 Data Required

The following data shall be measured and recorded.

4.5.2.1 Pressures

- a) Drive gas
- b) Coolant gas
- c) Cylinder gas (P_1 and P_2)

4.5.2.2 Temperatures

- a) Drive gas
- b) Coolant gas
- c) Actuator Housing

4.5.2.3 Actuator Data

- a) Shaft position
- b) Position command
- c) Position error
- d) Torquemotor current

4.6 QUALIFICATION REQUIREMENTS

Prior to low temperature operation, an ambient "base Line" operation shall be accomplished and the values of the following "Qualification Performance Requirements" shall be measured and recorded. These values shall be referred to as "Base Line Data" for evaluation of actuator performance at low temperature.

4.6.1 Scram Operation

Maximum allowable turnaround time - ± 10 percent of base line data

4.6.2 Transient Response to 18 Degree Peak-to-Peak Square Wave

Rise Time - ± 10 percent of base line data

Settling Time - ± 10 percent of base line data

Overshoot - ± 10 percent of base line data

4.6.3 Frequency Response to 4 Degree Peak-to-Peak Sine Wave

- 1) Amplitude ratio shall not exceed ± 2 db of base line data.
- 2) Phase lag at 1 cps (Hz) not to exceed ± 5 degrees of base line data.
- 3) Phase lag at 2 cps (Hz) not to exceed ± 5 degrees of base line data.
- 4) Phase lag at 6 cps (Hz) not to exceed ± 7.5 degrees of base line data.
- 5) Phase lag at 12 cps (Hz) not to exceed ± 10 degrees of base line data.

4.6.4 Dynamic Resolution to a 3 Degree per Second Ramp Command

Maximum error from base line data shall be ± 0.1 degree (0.0055 volt).

4.6.5 Static Resolution

Static resolution at the output shaft shall not exceed ± 0.1 degree (0.0055 volt) of base line data.

4.7 POST MORTEM INSPECTION

Upon completion of low temperature testing, if there is an unexplainable discrepancy in the performance requirement (detailed in Section 4.6), the actuators shall be disassembled and a visual inspection performed on all parts. In the event that any part(s) shows evidence of material failure or excessive wear, a dimensional check with suitable photographs of the failure shall be made.

4.8 REPORTS

A final report covering the entire environment testing of the XE-1 actuator shall be written which shall include the results of the low temperature. The report shall include all performance data and an evaluation of the results of the test.

5. LIFE QUALIFICATION TESTS FOR CONTROL DRUM PNEUMATIC ACTUATORS

5.1 SCOPE

This memorandum defines the life test requirements for the XE-1 Engine Control Drum Actuators. The test conditions as specified herein represent the design life requirements as specified in WANL-Specification E-675560 but modified to what is currently known of the XE-1 Engine test environment. TS-711892-D outlines the procedure to be followed in performing these tests.

5.2 OBJECTIVE OF TEST

The objective of the life test defined herein is to qualify the control drum actuators for the XE-1 Engine Test by demonstrating satisfactory performance over an extended operating period.

The life test shall consist of a 150 hour room temperature test followed by a one hour combined low temperature and vibration test.

5.3 ENVIRONMENTAL CONDITIONS

5.3.1 Room Temperature Test

The room temperature test shall consist of 150 hours of operation in accordance with the duty cycle specified in paragraph 5.4.1. Helium shall be used as the drive gas whenever data are to be taken, but to conserve helium, the actuator shall be operated on nitrogen drive gas for the remaining time. The coolant shall be nitrogen gas. The test shall be conducted continuously in so far as possible with any necessary shutdowns held to a minimum. Any breakdowns shall be repaired and the test continued to completion.

5.3.2 Combined Low Temperature and Vibration Test

The combined low temperature and vibration test shall consist of one hour of operation in accordance with the duty cycle defined in paragraph 5.4.2 while subjected to the vibratory conditions defined by Figure 2-1. Vibration shall be in the vertical plane, i. e., along the

the axis of the output shaft. The drive gas, coolant gas and the actuator housing temperature shall be maintained at $140 \pm 25^{\circ}\text{R}$. Sufficient time shall be allowed prior to running the one hour test to allow the housing temperature to stabilize.

5.4 DUTY CYCLE

The actuator shall be subjected to the following duty cycle during the test. During the room temperature test the cycling sequence shall be such that the actuator will be cycled through each of the six steps at least once per hour.

5.4.1 Room Temperature Test

1) Sinusoidally at 6 cps and 4 degrees peak-to-peak amplitude	12.5 hours
2) Sinusoidally at 0.5 cps and 40 degrees peak-to-peak amplitude	20.0 hours
3) Ramp at 3 degrees per second over full stroke	45.0 hours
4) Scram, lock, and reset	22.5 hours
5) Step at 0.1 cps (Hz) between 81 degrees and 99 degrees	25.0 hours
6) Dwell at static position of 90 degrees	<u>25.0 hours</u>
TOTAL	150.0 hours

5.4.2 Combined Low Temperature and Vibration Test

1) Ramp at 3 degrees per second over full stroke	15.0 minutes
2) Step at 0.1 cps (Hz) between 81 degrees and 99 degrees	15.0 minutes
3) Dwell at static position of 90 degrees	15.0 minutes
4) Sinusoidally at 6 cps (Hz) and 4 degrees peak-to-peak amplitude	<u>15.0 minutes</u>
TOTAL	60.0 minutes

5.5 TEST PARAMETERS

The various test parameters shall be controlled as specified in the following table.

5.5.1 Pressures

<u>Parameter</u>	<u>Room Temperature Test</u>	<u>Combined Environment Test</u>
a) drive gas	200 ± 10 psig	200 ± 10 psig
b) coolant gas	675 ± 25 psig	675 ± 25 psig
c) exhaust	not regulated	not regulated

5.5.2 Temperatures

a) drive gas	530 to 540°R	140 ± 25°R
b) coolant gas	530 to 540°R	140 ± 25°R
c) actuator housing	530 to 540°R	140 ± 25°R

5.5.3 Load

a) inertia	0.24 in /lb/sec ²	0.24 in /lb/sec ²
b) friction	0 to 32 in /lb	0 to 32 in /lb

5.6 DATA

Prior to the start of the test, a complete set of data, as defined in paragraph 5.7, shall be taken and shall be referred to as the base line data. A complete set of data shall also be taken at the completion of the 150 hour room temperature test and upon completion of the one hour combined low temperature and vibration test.

During the room temperature test, a frequency response test shall be made every 25 hours.

The following data shall be recorded continuously (except gas flow) throughout the test except during the dwell period defined in paragraph 5.4.1, item (6).

5.6.1 Temperatures

- 1) Drive gas
- 2) Coolant gas
- 3) Structural temperature (to be taken only during cold test of paragraph 5.3.2).

5.6.2 Pressures

- 1) Drive gas
- 2) Coolant gas
- 3) Piston chamber, P_1
- 4) Piston chamber, P_2

5.6.3 Electrical Measurements

- 1) Manual Command
- 2) Dynamic Command
- 3) Actuator position
- 4) Torquemotor current
- 5) Error

5.6.4 Gas Flow

The drive gas and coolant flow shall be read during the dwell period of paragraph 5.4.1, item (6), approximately every 8 hours.

5.6.5 Test Time

A running time meter shall be used to record the actual operating time. The time meter shall be operated when the actuator is unlocked.

5.7 PERFORMANCE REQUIREMENTS FOR QUALIFICATION

The actuator shall be considered to have passed the life qualification test provided the following performance requirements are met. Isolated cases that vary beyond the allowable limits shall be evaluated individually in light of the control system requirements.

5.7.1 Scram Operation

Maximum allowable turnaround time - ± 10 percent of base line data.

5.7.2 Transient Response to 18 Degree Peak-to-Peak Square Wave

1) Rise time	-	± 10 percent of base line data
2) Settling time	-	± 10 percent of base line data
3) Overshoot	-	± 10 percent of base line data

5.7.3 Frequency Response to 4 Degree Peak-to-Peak Sine Wave

- 1) Amplitude ratio shall not exceed ± 2 db of base line data.
- 2) Phase lag at 1 cps (Hz) shall not exceed ± 5 degrees of base line data.
- 3) Phase lag at 2 cps (Hz) shall not exceed ± 5 degrees of base line data.
- 4) Phase lag at 6 cps (Hz) shall not exceed ± 7.5 degrees of base line data.
- 5) Phase lag at 12 cps (Hz) shall not exceed ± 10 degrees of base line data.

5.7.4 Dynamic Resolution to a 3 Degree per Second Ramp Command

Maximum error from base line data shall be ± 0.5 degree (0.0275 volt).

5.7.5 Static Resolution

Maximum static position resolution at the output shaft shall not exceed ± 0.5 degree (0.0275 volt) of base line data.

5.8 INSPECTION

Upon completion of the test if there is an unexplainable discrepancy in the performance requirements (detailed in Section 5.7), the actuator shall be disassembled and a visual inspection made of all parts. A dimensional inspection shall be made and photographs taken of any parts exhibiting significant wear.

5.9 REPORT REQUIRED

A final report covering the entire environmental testing of the XE-1 actuator will be written which will include the results of the life qualification test. The report should include the performance data and an evaluation of the results of the test.

6. RADIATION QUALIFICATION SPECIFICATIONS FOR CONTROL DRUM PNEUMATIC ACTUATORS FOR XE-1 APPLICATION

6.1 SCOPE

The installation requirements imposed by XE-1 place the Control Drum Pneumatic Actuators above the external shield in the vicinity of Station 130.0. At this location estimates have been made of the radiation level expected in the fully shielded condition. The dose rates are defined by Aerojet Letter 7425:009, dated July 28, 1964. The integrated dose and environmental conditions are based on information contained in the NERVA X-Engine Specification RN-DR-0020 dated September 1964. It is expected that the results of the NRX-A6 side-by-side test, and the Lewis AG-20 and XE-1 irradiation tests will serve to qualify the actuators for use in a radiation environment.

6.2 OBJECTIVE

The purpose of this specification is to define the necessary conditions for qualification of the Control Drum Pneumatic Actuator in the XE-1 radiation environment.

6.3 ENVIRONMENTAL CONDITIONS

Since the functional operation of the pneumatic actuator is dependent upon the material properties of the components, it is necessary that the materials be qualified under the most severe conditions expected. The combined environments of radiation and low temperature represent the most severe environmental condition because the low temperature tends to accelerate or intensify the material degradations due to radiation.

6.3.1 Radiation Field

The radiation field in and near the pneumatic actuator in the XE-1 shielded condition can be characterized by the following values:

<u>Item</u>	<u>Dose Rate</u>
Gamma	2.8×10^5 rad/hr
Fast Neutron (E 1 Mev)	4×10^{10} N/cm ² /sec
Thermal Neutron (E 0.48 ev)	Not reported

Neglecting the heating effect due to neutrons, the heating value due to X rays is calculated at 0.35 watt /lb.

6.3.2 Temperature Field

Accurate information is not presently available with regard to the temperature distribution within the actuator mechanism. It is sufficient to consider the lowest value expected, and the temperature is based on the actuator coolant flow obtained from the reactor plenum volume. The estimated value for the actuator mechanism on XE-1 is 50 to 60°R.

6.4 QUALIFICATION REQUIREMENTS

6.4.1 Unconditional Qualification

In this sense the entire actuator mechanism must be tested under the conditions of Section 6.3 with the following results:

- 1) The actuator mechanism must retain its mechanical and electrical integrity.
- 2) The actuator mechanism must perform satisfactorily when operated in the sub-system. Satisfactory performance exists when the requirements of WANL Specification E-675378, Section 6.5 are met.

6.4.2 Conditional Qualification (XE-1 Application)

In this context, the actuator mechanism components (as opposed to the actuator mechanism) must be tested under conditions of Section 6.3 with equivalent input/output characteristics, including loading, yielding the following results:

- 1) The components must retain their mechanical and electrical integrity.
- 2) The components must perform satisfactorily when operated under the sub-system conditions encountered in the closed loop; i.e., a dynamically similar and equivalent test.

6.4.3 Exceptions

Minor departures from the required performance may occur in either case (Sections 6.4.1 or 6.4.2). These will be analyzed with regard to the control system requirements,

and if no adverse effects result, they will become a part of the final XE-1 qualification conditions.

6.4.4 Equivalence

Either Section 6.4.1 or 6.4.2 is sufficient to show qualification for XE-1.

6.5 REPORT

A summary report will be issued indicating the actuator qualification for the XE-1 radiation environment. The report must include:

- 1) Abstract
- 2) Description of Test(s)
- 3) Results
- 4) Conclusions and Recommendations

APPENDIX B

T-711892 A, B, C & D

QUALIFICATION TEST, ENVIRONMENTAL

XE-1 CONTROL DRUM ACTUATOR

PREPARED BY:

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QUALIFICATION TEST, VIBRATION

TS-711892-A

1.0 Introduction

In this procedure the methods for testing the XE-1 Pneumatic Control Drum Actuator in a controlled vibration environment shall be outlined. Prior to vibrating the actuator a series of tests shall be run to determine the performance of the actuator. The results of these tests shall establish the "Base Line Data" for the actuator under test.

The actuator shall then be vibrated to simulate the shipment, storage, and ground firing conditions which are expected to be placed on the actuator. Both during and after the vibrations the actuator's performances shall be tested. The results of these tests shall be compared with the Base Line Data and any change shall be noted. Though small changes are to be expected, any gross or critical deviation not logically explained in the actuator's performance shall necessitate the complete disassembly of the actuator to determine the cause of the deviation.

2.0 Material and Equipment Requirements

- 2.1 Vibration Test Load Stand
- 2.2 Vibration Driver and Control System
- 2.3 Actuator Amplifier XE-1
- 2.4 Visicorder Honeywell, Model 1508
- 2.5 Frequency Response Analyzer, IMC, Model 101
- 2.6 Function Generator, Hewlett Packard, Model 202
- 2.7 D.C. Power Supply, +10V, $\pm 15V$, $\pm 24V$, +28V Trygon Model PS32-2.5

- 2.8 X,Y,Y' Recorder, Honeywell Model 480
- 2.9 Pressure Transducers, C.E.C., Model 4-354
- 2.10 Gage Balance Unit, Honeywell
- 2.11 Accelerometers, Endevco
- 2.12 Data Amplifiers, C.E.C., Type 155
- 2.13 Digital Voltmeter, Honeywell Model 6305
- 2.14 Helium Drive Gas (ambient temperature, 200 ± 5 psig)
- 2.15 Nitrogen Coolant Gas (ambient temperature, 650 ± 25 psig)

3.0 Parameters

- 3.1 The parameters to be measured in this test are:

- 3.1.1 a_c - control acceleration
- 3.1.2 P_c - coolant gas pressure
- 3.1.3 P_d - drive gas pressure
- 3.1.4 P_e - exhaust gas pressure
- 3.1.5 P_1 - pressure in cylinder #1
- 3.1.6 P_2 - pressure in cylinder #2
- 3.1.7 ΔP - pressure differential ($P_1 - P_2$)
- 3.1.8 θ_d - d.c. demand voltage (angle)
- 3.1.9 $\Delta \theta_d$ - a.c. demand voltage (angle)
- 3.1.10 θ_o - actuator position voltage (angle)
- 3.1.11 $\Delta \theta_o$ - a.c. value of actuator position centered about θ_o ($\theta_o - \theta_d$)
- 3.1.12 θ_e - error voltage (angle) ($\theta_o - \theta_d - \Delta \theta_d$)
- 3.1.13 I_1 - torque motor current
- 3.1.14 a_x - acceleration perpendicular to piston travel
- 3.1.15 a_z - acceleration parallel to piston travel
- 3.1.16 a_z - acceleration parallel to output shaft

4.0 Load Stand Friction and Spring Gradient Test

4.1 Place torque wrench in Load Stand Spline and measure:

4.1.1 Breakaway torque of increasing angle at spring rest position.

Breakaway torque of increasing angle at 15°.

Breakaway torque of increasing angle at 90°.

4.1.2 Relaxation torque of decreasing angle at 90°.

Relaxation torque of decreasing angle at 15°.

Relaxation torque of decreasing angle at spring rest position.

5.0 Transient Response for Amplifier Tuning

5.1 Place actuator in vibration load stand and secure marman clamp.

5.2 Turn on drive gas, coolant gas, and actuator amplifier.

5.3 Move actuator to 90° (-5 volt) drum position and apply a 100° (5.55 volt) p-p square wave to $\Delta \theta_d$.

5.4 Adjust velocity limits to 100°/sec $\pm$ 20°/sec as measured by the output voltage of the amplifier rate stage (1 volt $\pm$ 0.2 volts).

5.5 Using an 18° (1.0 volt) p-p square wave set the gain and lead controls to give optimum performance with an overshoot of less than 5°.

5.6 Re-check velocity limits and repeat procedure if velocity limits need to be changed.

5.7 Record gain and lead settings and velocity.

6.0 Determination of Base Line Data

6.1 Linearity and Static Resolution Check

6.1.1 Apply a 90° (-5 $\pm$.001 volt) command (θ_d) and adjust amplifier offset pot for a position (θ_o) of 90° (-5 $\pm$.001 volt).

- 6.1.2 Record command (θ_d) on X-axis of plotter (1 volt/in) and static error (θ_e) on Y-axis (.01 volt/in).
- 6.1.3 Move actuator command (θ_d) in 9° (0.5 volt) increments from 9° to 171° (0.5 volt to 9.5 volt) and record points when actuator assumes its rest position.
- 6.2 Dynamic Resolution Check
 - 6.2.1 Return to 90° (-5 volt) position and apply a $3^\circ/\text{sec}$ (7.8 volt p-p @ 0.01 HZ) ramp to the dynamic command ($\Delta \theta_d$) input.
 - 6.2.2 Record $\Delta \theta_d$ on X-axis of plotter (1.0 volt/in) and error voltage (θ_e) on Y-axis (.01 volt/in).
- 6.3 Transient Response Check
 - 6.3.1 Return to 90° position (-5 volt) and apply an 18° (1 volt p-p) square wave to $\Delta \theta_d$.
 - 6.3.2. Record $\Delta \theta_d$ and $\Delta \theta_o$ on the visicorder.
- 6.4 Scram Turnaround Check
 - 6.4.1 Return to 90° (-5 volt) position and set auto-scam control to scam the actuator when $\theta_o \geq 120^\circ$ (-6.666 volt) and apply a 100° (5.55 volt) square wave to $\Delta \theta_d$.
 - 6.4.2 Allow actuator to scam and record θ_o , I_1 , P_1 , P_2 , ΔP , lock light, and unlock light on visicorder.
- 6.5 Frequency Response Check
 - 6.5.1 Turn off auto-scam and reset scam relay.
 - 6.5.2 Return actuator to 90° (-5 volt) position.
 - 6.5.3 Apply the IMC Osc. output to $\Delta \theta_d$ and set for 4° (.222 volt) p-p sine wave.

- 6.5.4 Connect ΔQ_d to the e_1 input of the IMC and ΔQ_o to the e_2 input to the IMC.
- 6.5.5 Record frequency on the X-axis of the plotter, amplitude on the Y-axis, and phase on the Y'-axis.
- 6.5.6 Run the frequency from 0.1 HZ to 20 HZ and obtain the closed loop frequency response of the actuator.

7.0 Vibration Schedule

Vertical Direction (actuator mounted on vibration stand so that the direction of acceleration (A_z) is parallel to the actuator drive shaft).

7.1 Test No. 1

- 7.1.1 Mount actuator and secure marman clamp.
- 7.1.2 Make two (2) sweeps from 5 HZ to 2000 HZ to 5 HZ at 1.0g acceleration.
- 7.1.3 Each sweep shall be 3 minutes in duration.
- 7.1.4 Record all accelerometer voltages and frequency of vibration on the visicorder.

7.2 Test No. 2

- 7.2.1 With drive gas, coolant gas, and actuator amplifier still off make three (3) sweeps from 10 HZ to 30 HZ to 10 HZ.
- 7.2.2 Each sweep shall be 2 minutes in duration at 4.0g acceleration.
- 7.2.3 Record all accelerometer voltages and frequency of vibration on the visicorder.

7.3 Test No. 3

- 7.3.1 Turn on drive gas, coolant gas, and actuator amplifier.
- 7.3.2 Move actuator to the 90° (-5 volt) position.

- 7.3.3 Make one (1) sweep of 30 minute duration using the frequency and acceleration shown on Curve 1.
- 7.3.4 While sweep is in progress repeat Section 6.2.
- 7.3.5 After the sweep is finished, turn off vibration and repeat Sections 6.2 and 6.3

7.4 Test No. 5

- 7.4.1 Turn off drive gas, coolant gas, and actuator amplifier.
- 7.4.2 Vibrate actuator at the resonant frequency or frequencies for 30 minutes each at 4.0g acceleration.

7.5 Test No. 6

- 7.5.1 Turn on drive gas, coolant gas, and actuator amplifier.
- 7.5.2 Move actuator to 90° (-5 volt) position.
- 7.5.3 Vibrate actuator at its resonant frequency or frequencies for 10 minutes at the acceleration shown in Curve 1.
- 7.5.4 While vibrating the actuator repeat Section 6.2.
- 7.5.5 After vibrating the actuator repeat Section 6.0.
- 7.5.6 Turn off drive gas, coolant gas, and actuator amplifier.

8.0 Horizontal #1 Direction (actuator mounted on vibration stand so that the direction of acceleration (A_y) is parallel to the direction of piston travel).

8.1 Test No. 1

- 8.1.1 Mount actuator and secure marman clamp.
- 8.1.2 Make two (2) sweeps from 5 HZ to 2000 HZ to 5 HZ at 1.0g acceleration.
- 8.1.3 Each sweep shall be 3 minutes in duration.

8.1.4 Record all accelerometer voltages and frequency of vibration on the visicorder.

8.2 Test No. 2

8.2.1 With drive gas, coolant gas, and actuator amplifier still off make three (3) sweeps from 10 HZ to 30 HZ to 10 HZ.

8.2.2 Each sweep shall be 2 minutes in duration at 4.0g acceleration.

8.2.3 Record all accelerometer voltages and frequency of vibration on the visicorder.

8.3 Test No. 4

8.3.1 Turn on drive gas, coolant gas, and actuator amplifier.

8.3.2 Move actuator to the 90° (-5 volt) position.

8.3.3 Make two (2) sweeps of 15 minute duration using the frequency and acceleration shown on Curve 2.

8.3.4 While sweep is in progress repeat Section 6.2.

8.3.5 After the sweep is finished turn off vibration and repeat Section 6.2 and 6.3.

8.4 Test No. 5

8.4.1 Turn off drive gas, coolant gas, and actuator amplifier.

8.4.2 Vibrate the actuator at the resonant frequency or frequencies for 30 minutes at 4.0g acceleration.

8.5 Test No. 7

8.5.1 Turn on drive gas, coolant gas, and actuator amplifier.

8.5.2 Move actuator to 90° (-5 volt) position.

- 8.5.3 Vibrate actuator at its resonant frequency or frequencies for 10 minutes at the acceleration shown in Curve 2.
 - 8.5.4 While vibrating the actuator repeat Section 6.2.
 - 8.5.5 After vibrating the actuator repeat Section 6.0.
 - 8.5.6 Turn off drive gas, coolant gas, and actuator amplifier.
- 9.0 Horizontal #2 Direction (actuator mounted on vibration stand so that the direction of acceleration (A_x) is perpendicular to the direction of piston travel).
- 9.1 Test No. 1
 - 9.1.1 Mount actuator and secure marman clamp.
 - 9.1.2 Make two (2) sweeps from 5 HZ to 2000 HZ to 5 HZ at 1.0g acceleration.
 - 9.1.3 Each sweep shall be 3 minutes in duration.
 - 9.1.4 Record all accelerometer voltages and frequency of vibration on the visicorder.
 - 9.2 Test No. 2
 - 9.2.1 With drive gas, coolant gas, and actuator amplifier still off make three (3) sweeps from 10 HZ to 30 HZ to 10 HZ.
 - 9.2.2 Each sweep shall be 2 minutes in duration and at 4.0g acceleration.
 - 9.2.3 Record all accelerometer voltages and frequency of vibration on the visicorder.
 - 9.3 Test No. 4
 - 9.3.1 Turn on drive gas, coolant gas, and actuator amplifier.

- 9.3.2 Move actuator to the 90° (-5 volt) position.
- 9.3.3 Make two (2) sweeps of 15 minutes duration using the frequency and acceleration shown on Curve 2.
- 9.3.4 While sweep is in progress repeat Section 6.2
- 9.3.5 After the sweep is finished turn off vibration and repeat Sections 6.2 and 6.3.

9.4 Test No. 5

- 9.4.1 Turn off drive gas, coolant gas, and actuator amplifier.
- 9.4.2 Vibrate the actuator at the resonant frequency or frequencies for 30 minutes at 4.0g acceleration.

9.5 Test No. 7

- 9.5.1 Turn on drive gas, coolant gas, and actuator amplifier.
- 9.5.2 Move actuator to 90° (-5 volt) position.
- 9.5.3 Vibrate actuator at its resonant frequency or frequencies for 10 minutes at the acceleration shown in Curve 2.
- 9.5.4 While vibrating the actuator repeat Section 6.2.
- 9.5.5 After vibrating the actuator repeat Section 6.0.
- 9.5.6 Turn off drive gas, coolant gas, and actuator amplifier.

CURVE NO. 1 ANTICIPATED VIBRATION ENVIRONMENT, NERVA XE-1;
GROUND FIRING TEST, LONGITUDINAL PLANE.

NOTE: D. A. = DOUBLE AMPLITUDE

ANTICIPATED VIBRATION ENVIRONMENT NERVA XE-1;
GROUND FIRING TEST; LATERAL PLANE

Note: D.A. = Double Amplitude

QUALIFICATION TEST, MECHANICAL SHOCK

TS-711892-B

1.0 Introduction

In this procedure the XE-1 Pneumatic Control Drum Actuator shall be tested to determine its qualification for mechanical shock as specified in WANL-TME-1040, Rev. A.

Before the application of any mechanical shock, the actuator shall be given a series of tests to establish the original performance of the actuator. The results of these tests shall be called the "Base Line Data".

The actuator shall then be given controlled shocks. After the shocks the actuator shall again be tested. The results of these tests shall be compared with the Base Line Data. If any gross deviation occurs between the pre-shock and the post-shock tests, the actuator shall be completely disassembled to determine the cause of the deviation.

2.0 Material and Equipment Requirements

- 2.1 Shock Test Load Stand
- 2.2 Shock Driver and Control System
- 2.3 Actuator Amplifier, XE-1
- 2.4 Visicorder, Honeywell, Model 1508
- 2.5 Frequency Response Analyzer, I.M.C., Model 101
- 2.6 Function Generator, Hewlett Packard, Model 202
- 2.7 D.C. Power Supply, +10V, $\pm 15V$, $\pm 24V$, +28V, Trygon, Model PS32-2.5
- 2.8 X,Y,Y' Recorder, Honeywell, Model 4-354
- 2.9 Gage Balance Unit, Honeywell

- 2.10 Accelerometers, Endevco
- 2.11 Data Amplifier, CEC, Type 155
- 2.12 Digital Voltmeter, Honeywell, Model 6305
- 2.13 Helium Drive Gas (ambient temperature, 200 ± 5 psig)
- 2.14 Nitrogen Coolant Gas (ambient temperature, 650 ± 25 psig)

3.0 Parameters

- 3.1 The parameters to be measured in this test are:
 - 3.1.1 P_c - coolant pressure
 - 3.1.2 P_d - drive pressure
 - 3.1.3 P_e - exhaust pressure
 - 3.1.4 P_1 - pressure in cylinder #1
 - 3.1.5 P_2 - pressure in cylinder #2
 - 3.1.6 ΔP - differential pressure ($P_1 - P_2$)
 - 3.1.7 θ_d - d.c. demand voltage (angle)
 - 3.1.8 $\Delta \theta_d$ - a.c. demand voltage (angle)
 - 3.1.9 θ_o - d.c. actuator drum position voltage (angle)
 - 3.1.10 $\Delta \theta_o$ - a.c. actuator drum position voltage (angle)
 - 3.1.11 θ_e - error voltage
 - 3.1.12 I_1 - torque motor current
 - 3.1.13 a_c - applied shock pulse
 - 3.1.14 a_x - acceleration perpendicular to piston travel
 - 3.1.15 a_y - acceleration parallel to piston travel
 - 3.1.16 a_z - acceleration parallel to output shaft

4.0 Transient Response for Amplifier Tuning

- 4.1 Place actuator on shock load stand and secure marman clamp.
- 4.2 Turn on drive gas, coolant gas, and actuator amplifier.
- 4.3 Move actuator to 90° (-5 volt) position and apply a 100° (5.55 volt p-p) square wave to the a.c. command (ΔQ_d).
- 4.4 Adjust the velocity limits if necessary to $100^\circ/\text{sec}$ (± 1 volt at the rate output test point).
- 4.5 Change command input (ΔQ_d) to an 18° (1.0 volt p-p) square wave.
- 4.6 Adjust gain and lead controls if required to give a rise time of less than .055 sec, a settling time of less than 0.15 sec, and an overshoot of less than 6° (.333 volts).
- 4.7 Recheck velocity limits and repeat procedure if velocity limits must be changed.
- 4.8 Record gain and lead settings and velocity.

5.0 Determination of Base Line Data

5.1 Linearity and Static Resolution Check

- 5.1.1 Apply a 90° ($-5 \pm .001$ volt) command (Q_d) and adjust amplifier offset pot for a position (Q_o) at 90° ($-5 \pm .001$ volt).
- 5.1.2 Record command (Q_d) on X-axis of plotter (1 volt/in) and static error (Q_e) on Y-axis (.01 volt/in).
- 5.1.3 Move actuator command (Q_d) in 9° (0.50 volt) increments from 9° to 171° (0.50 volt to 9.50 volt) and record points when actuator assumes its rest position.

5.2 Dynamic Resolution Check

- 5.2.1 Return to 90° position and apply a $3^\circ/\text{sec}$ ramp (7.8 volt at 0.01 HZ) to the dynamic command (ΔQ_d) input.

5.2.2 Record $\Delta \theta_d$ on X-axis of plotter (1.0 volt/in) and error (θ_o) on Y'-axis (.01 volt/inch).

5.3 Transient Response Check

5.3.1 Return to 90° position and apply an 18° (1 volt p-p) square wave to θ_d .

5.3.2 Record $\Delta \theta_d$ and $\Delta \theta_o$ on the visicorder.

5.4 Scram Turnaround Check

5.4.1 Return to 90° position and set the auto-scam control to scam the actuator when $\theta_o \geq 120^\circ$ (-6.66 volt) and apply a 100° (5.55 volt) square wave to $\Delta \theta_d$.

5.4.2 Allow actuator to scam and record θ_o , I, P₁, P₂, ΔP , lock light, and unlock light on the visicorder

5.5 Frequency Response Check

5.5.1 Turn off auto-scam and reset scam relay.

5.5.2 Return actuator to 90° position.

5.5.3 Apply the I.M.C. oscillator output to $\Delta \theta_d$ and set for 4° (.222 volt) p-p sine wave.

5.5.4 Connect $\Delta \theta_d$ to the e₁ input of the I.M.C. and $\Delta \theta_o$ to the e₂ input of the I.M.C.

5.5.5 Record frequency on the X-axis of the plotter, amplitude on the Y-axis, and phase on the Y' axis.

5.5.6 Run the frequency from 0.1 HZ to 20 HZ and obtain a plot of the closed loop frequency response of the actuator.

6.0 Shock Schedule

6.1 Vertical direction (actuator mounted so that the direction of shock is parallel to the actuator drive shaft).

- 6.1.1 Mount actuator on load stand and secure marman clamp.
- 6.1.2 Turn on drive gas, coolant gas, and actuator amplifier.
- 6.1.3 Move actuator to 90° drum position.
- 6.1.4 Apply a 3°/sec ramp (7.8 volt p-p @ 0.01 HZ) to the dynamic command ($\Delta \theta_d$).
- 6.1.5 Apply 3 shocks at +2.0g with a 0.01 sec shock duration.
- 6.1.6 Apply 3 shocks at -2.0g with a 0.01 sec shock duration.
- 6.1.7 During all 6 shocks record $\Delta \theta_d$, $\Delta \theta_o$, I_1 , P_1 , P_2 , ΔP , applied shock, pulse, a_x , a_y , and a_z .
- 6.1.8 Remove 3°/sec ramp and repeat Section 5.0. (Determination of Base Line Data).
- 6.1.9 Turn off drive gas, coolant gas, and actuator amplifier.

6.2 Horizontal #1 Direction (actuator mounted so that the direction of shock is parallel to the direction of piston travel.

- 6.2.1 Mount actuator on load stand and secure the marman clamp.
- 6.2.2 Turn on drive gas, coolant gas, and actuator amplifier.
- 6.2.3 Move actuator to 90° drum position.
- 6.2.4 Apply a 3°/sec ramp (7.8 volt p-p @ 0.01 HZ) to the dynamic command ($\Delta \theta_d$).
- 6.2.5 Apply 3 shocks at +1.0g with a 0.01 sec shock duration.
- 6.2.6 Apply 3 shocks at -1.0g with a 0.01 sec shock duration.
- 6.2.7 During all 6 shocks record $\Delta \theta_d$, $\Delta \theta_o$, I , P_1 , P_2 , ΔP , applied shock, pulse, a_x , a_y , and a_z .

6.2.8 Remove 3°/sec ramp and repeat Section 5.0 (Determination of Base Line Data).

6.2.9 Turn off drive gas, coolant gas, and actuator amplifier.

6.3 Horizontal #2 Direction (actuator mounted so that the direction of shock is perpendicular to the direction of piston travel.

6.3.1 Mount actuator on load stand and secure the marman clamp.

6.3.2 Turn on drive gas, coolant gas, and actuator amplifier.

6.3.3 Move actuator to 90° drum position.

6.3.4 Apply a 3°/sec ramp (7.8 volt p-p @ 0.01 HZ) to the dynamic command ($\Delta \theta_d$).

6.3.5 Apply 3 shocks at +1.0g with a 0.01 sec shock duration.

6.3.6 Apply 3 shocks at -1.0g with a 0.01 sec shock duration.

6.3.7 During all 6 shocks record $\Delta \theta_d$, $\Delta \theta_o$, I_1 , P_1 , P_2 , ΔP , applied shock pulse, a_x , a_z , and a_y .

6.3.8 Remove 3°/sec ramp and repeat Section 5.0 (Determination of Base Line Data).

6.3.9 Turn off drive gas, coolant gas, and actuator amplifier.

QUALIFICATION TEST, THERMAL

TS-711892-C

1.0 Introduction

In this procedure the methods for testing the XE-1 Pneumatic Control Drum Actuator in a controlled thermal environment shall be outlined. The actuator, with its amplifier shall first be tuned at ambient temperatures. A series of tests shall then be run to determine the performance of the actuator. The results of these tests shall determine the Base Line Data for the actuator under test.

The actuator shall then be cooled to the specified temperatures using cold drive and coolant gas and the tests shall be repeated. By comparing the results of the cold tests with the Base Line Data the qualification shall be determined as specified in WANL-TME-1040, Rev. A.

Should the actuator fail to qualify in any way which grossly affects its performance the actuator shall be disassembled to determine the cause of the failure.

2.0 Material and Equipment Requirements

- 2.1 Actuator Amplifier, XE-1
- 2.2 Visicorder, Honeywell, Model 1508
- 2.3 Frequency Response Analyzer, I.M.C., Model 101
- 2.4 Function Generator, Hewlett Packard, Model 202
- 2.5 D.C. Power Supply (+10V, $\pm 15V$, $\pm 24V$, +28V), Trygon Model PS32-2.5
- 2.6 X,Y,Y' Recorder, Honeywell, Model 480
- 2.7 Pressure Transducers, C.E.C., Model 4-354

- 2.8 Gage Balance Unit, Honeywell
- 2.9 Data Amplifiers, C.E.C., Type 155
- 2.10 Digital Voltmeter, Honeywell, Model 6305
- 2.11 Thermocouples, Copper/Constantan
- 2.12 Thermocouple Reference Junction, Pace Model BRJ14-18TP-1182
- 2.13 Helium Drive Gas (200 ± 5 psig, controlled temperature)
- 2.14 Hydrogen Drive Gas (200 ± 5 psig, controlled temperature)
- 2.15 Hydrogen Coolant Gas (650 ± 25 psig, controlled temperature)
- 2.16 Nitrogen Coolant Gas (650 ± 25 psig, controlled temperature)
- 2.17 Heat Exchangers

3.0 Parameters

- 3.1 The parameters to be measured in this test are:
 - 3.1.1 P_c - coolant pressure
 - 3.1.2 P_d - drive pressure
 - 3.1.3 P_e - exhaust pressure
 - 3.1.4 P_1 - cylinder #1 pressure
 - 3.1.5 P_2 - cylinder #2 pressure
 - 3.1.6 ΔP - differential pressure ($P_1 - P_2$)
 - 3.1.7 T_c - coolant temperature
 - 3.1.8 T_d - drive temperature
 - 3.1.9 T_e - exhaust temperature
 - 3.1.10 T_1 - potentiometer case temperature
 - 3.1.11 T_2 - actuator housing temperature
 - 3.1.12 θ_d - d.c. demand voltage (angle)
 - 3.1.13 $\Delta \theta_d$ - a.c. demand voltage (angle)

- 3.1.14 θ_d - actuator position voltage (angle)
- 3.1.15 $\Delta\theta_o$ - a.c. actuator position centered about θ_o ($\theta_o - \theta_d$)
- 3.1.16 θ_e - error voltage (angle) ($\theta_o - \theta_d - \theta_d$)
- 3.1.17 I_1 - torque motor current
- 3.1.18 V_r - rate stage output
- 3.1.19 Lock Light Voltage
- 3.1.20 Unlock Light Voltage

4.0 Determination of Base Line Data

4.1 Linearity and Static Resolution Check

- 4.1.1 Apply a 90° ($-5 \pm .001$ volt) command (θ_d) and adjust the amplifier offset pot for a position (θ_o) of 90° ($-5 \pm .001$ volt).
- 4.1.2 Record command (θ_d) on X-axis of plotter (1 volt/in) and static error (θ_e) on Y-axis (.1 volt/in).
- 4.1.3 Move actuator command (θ_d) in 9° (.5 volt) increments from 9° to 171° (.5 volt to 9.5 volt) and record points when actuator assumes its rest position.

4.2 Dynamic Resolution Check

- 4.2.1 Return to 90° position and apply a $3^\circ/\text{sec}$ ramp (7.8 volt @ .01 HZ) to the dynamic command ($\Delta\theta_d$) input.
- 4.2.2. Record $\Delta\theta_d$ on X-axis of plotter (1.0 volt/in) and error (θ_e) on Y'-axis (.01 volt/in).

4.3 Transient Response Check

- 4.3.1 Return to 90° position and apply an 18° (1 volt p-p) square wave to $\Delta\theta_d$.

4.3.2 Record $\Delta\theta_d$ and $\Delta\theta_o$ on the visicorder.

4.4 Scram Turnaround Check

4.4.1 Return to 90° position and set the auto-scam control to scam the actuator when $\theta_o \geq 120^\circ$ (-6.66 volt) and apply a 100° (5.55 volt) square wave to $\Delta\theta_d$.

4.4.2 Allow actuator to scam and record θ_o , I, P_1 , P_2 , ΔP , lock light, and unlock light on the visicorder.

4.5 Frequency Response Check

4.5.1 Turn off auto scam and reset scam relay.

4.5.2 Return actuator to 90° position.

4.5.3 Apply the I.M.C. oscillator output to dynamic command ($\Delta\theta_d$) and set for 4° (.222 volt) p-p sine wave.

4.5.4 Connect $\Delta\theta_d$ to the e_1 input of the I.M.C. and $\Delta\theta_o$ to the e_2 input of the I.M.C.

4.5.5 Record frequency on the X-axis, amplitude on the Y-axis, and phase on the Y^1 -axis of the plotter.

4.5.6 Run the frequency from 0.1 HZ to 20 HZ and obtain a plot at the closed loop frequency response of the actuator.

5.0 Thermal Cycle Schedule

5.1 Run #1 (150°R)

5.1.1 Supply the actuator with ambient drive and coolant gas.

5.1.2 Unlock the drum and set manual command (θ_d) to $-5 \pm .001$ volt (90°)

5.1.3 Adjust the amplifier trim to obtain $-5 \pm .001$ volt on position (θ_o) buffer amplifier.

- 5.1.4 Set velocity limits to $100^\circ/\text{sec}$ (± 1 volt on output of rate stage) with a 100° step command on $\Delta \theta_d$.
- 5.1.5 Set gain and lead controls for optimum step response.
- 5.1.6 Perform Section 4.0 to determine the Base Line Data
- 5.1.7 Start thermal cycles
 - 5.1.7.1 For the first and third cycle the actuator shall be operated with a 100° ramp input ($\Delta \theta_d$) during cooldown.
 - 5.1.7.2 Allow drive and coolant gas to cool to $150 \pm 25^\circ\text{R}$.
 - 5.1.7.3 Record temperatures and pressures on visicorder and perform Section 4.2 during cooldown.
 - 5.1.7.4 When actuator temperatures have stabilized perform Section 4.0.
 - 5.1.7.5 After completion of Section 4.0 warm drive and coolant gas to ambient and record warm up while performing Section 4.2.
 - 5.1.7.6 For the second the fourth cycle the actuator shall be locked at the 15° position with the amplifier turned off.
 - 5.1.7.7 Allow drive and coolant gas to cool to $150 \pm 25^\circ\text{R}$.
 - 5.1.7.8 Record temperatures and pressures on visicorder.
 - 5.1.7.9 When actuator temperatures have stabilized perform Section 4.0.
 - 5.1.7.10 After completion of Section 4.0 warm drive and coolant gas to ambient and record warm up with actuator locked at 15° position.

5.1.7.11 Four cycles will be completed by performing all of Section 5.1.7 twice.

5.2 Run #2 (50°R)

5.2.1 Supply the actuator with ambient drive and coolant gas.

5.2.2 Unlock the drum and set manual command (θ_d) to $-5 \pm .001$ volt (90°).

5.2.3 Adjust the amplifier trim to obtain $-5 \pm .001$ volt on position (θ_o) buffer amplifier.

5.2.4 Set velocity limits to 100°/sec (± 1 volt on output of rate stage) with a 100° step command on $\Delta \theta_d$.

5.2.5 Set gain and lead controls for optimum step response.

5.2.6 Perform Section 4.0 to determine the Base Line Data.

5.2.7 Start thermal cycles.

5.2.7.1 For the first and third cycle the actuator shall be operated with a 100° ramp input ($\Delta \theta_d$) during cooldown.

5.2.7.2 Allow drive and coolant gas to cool to $50 \pm 25^\circ\text{R}$.

5.2.7.3 Record temperatures and pressures on visicorder and perform Section 4.2 during cooldown.

5.2.7.4 When actuator temperatures have stabilized perform Section 4.0.

5.2.7.5 After completion of Section 4.0 warm drive and coolant gas to ambient and record warm up while performing Section 4.2.

5.2.7.6 For the second and fourth cycle the actuator shall be locked at the 15° position with the amplifier turned off.

5.2.7.7 Allow drive and coolant gas to cool to $50 \pm 25^{\circ}\text{R}$.

5.2.7.8 Record temperatures and pressures on visicorder.

5.2.7.9 When actuator temperatures have stabilized
perform Section 4.0.

5.2.7.10 After completion of Section 4.0 warm drive and
coolant gas to ambient and record warm up with
actuator locked at 15° position.

5.2.7.11 Four cycles will be completed by performing all
of Section 5.2.7 twice.

QUALIFICATION TEST, LIFE

TS-711892-D

1.0 Introduction

This procedure outlines the methods to be used to test the XE-1 Pneumatic Control Drum Actuator for its life qualification as specified in WANL-TME-1040, Rev. A. The actuator shall be mounted on its load stand and a set of "Base Line Data" shall be recorded to determine the performance of the actuator. The actuator shall then be cycled with various input signals for 150 hours continuous. After 150 hours of operation the actuator shall again be tested for performance and the results compared with the "Base Line Data" to determine its qualification.

In the second phase of the test the actuator shall be operated at a low temperature, vibrated in the vertical plane, and given various inputs for one hour. After this test the performance of the actuator shall again be tested to determine its qualification.

2.0 Material and Equipment Requirements

- 2.1 Actuator Amplifier, XE-1
- 2.2 Visicorder, Honeywell, Model 1508
- 2.3 Frequency Response Analyzer, I.M.C., Model 101
- 2.4 Function Generator, Hewlett Packard, Model 202
- 2.5 D.C. Power Supply (+10V, $\pm 15V$, $\pm 24V$, +28V), Trygon Model PS32-2.5
- 2.6 X,Y,Y' Recorder, Honeywell Model 480
- 2.7 Pressure Transducers, C.E.C. Model 4-354
- 2.8 Gage Balance Unit, Honeywell
- 2.9 Data Amplifiers, C.E.C. 155
- 2.10 Digital Voltmeter, Honeywell, Model 6305

- 2.11 Thermocouples, Copper/Constantan
- 2.12 Thermocoupe1 Reference Junction, Pace Model BRJ14-18TP-1182
- 2.13 Drive Gas, Helium, 200 ± 5 psig, controlled temperature
- 2.14 Coolant Gas, Nitrogen, 650 ± 25 psig, controlled temperature
- 2.15 Vibration Controller and Driver
- 2.16 Accelerometers, Endevco
- 2.17 Heat Exchangers
- 2.18 Elapsed Time Meter

3.0 Parameters

3.1 The parameters to be measured in this test are:

- 3.1.1 P_c - coolant pressure
- 3.1.2 P_d - drive pressure
- 3.1.3 P_e - exhaust pressure
- 3.1.4 P_1 - cylinder #1 pressure
- 3.1.5 P_2 - cylinder #2 pressure
- 3.1.6 ΔP - differential pressure ($P_1 - P_2$)
- 3.1.7 T_c - coolant temperature
- 3.1.8 T_d - drive temperature
- 3.1.9 T_e - exhaust temperature
- 3.1.10 T_1 - potentiometer case temperature
- 3.1.11 T_2 - actuator housing temperature
- 3.1.12 θ_d - d.c. demand voltage (angle)
- 3.1.13 $\Delta \theta_d$ - a.c. demand voltage (angle)
- 3.1.14 θ_d - actuator position voltage (angle)
- 3.1.15 $\Delta \theta_o$ - a.c. actuator position centered about θ_o ($\theta_o - \theta_d$)

- 3.1.16 θ_e - error voltage (angle) ($\theta_o - \theta_d - \Delta\theta_d$)
- 3.1.17 I_1 - torque motor current
- 3.1.18 V_R - rate stage output
- 3.1.19 Lock light voltage
- 3.1.20 Unlock light voltage
- 3.1.21 Elapsed Time

4.0 Determination of Base Line Data

4.1 Linearity and Static Resolution Check

- 4.1.1 Apply a 90° ($-5 \pm .001$ volt) command (θ_d) and adjust the amplifier offset pot for a position (θ_o) of 90° ($-5 \pm .001$ volt).
- 4.1.2 Record command (θ_d) on X-axis of plotter (1 volt/inch) and static error (θ_e) on Y-axis (.01 volt/inch).
- 4.1.3 Move actuator command (θ_d) in 9° (0.5 volt) increments from 9° to 171° (.5 volt to 9.5 volt) and record points when actuator assumes its rest position.

4.2 Dynamic Resolution Check

- 4.2.1 Return to 90° position and apply a $3^\circ/\text{sec}$ ramp (7.8 volt p-p at .01 HZ) to the dynamic command ($\Delta\theta_d$) input.
- 4.2.2 Record $\Delta\theta_d$ on X-axis of plotter (1.0 volt/inch) and error (θ_e) on Y-axis (.01 volt/inch).

4.3 Transient Response Check

- 4.3.1 Return to 90° position and apply an 18° (1 volt p-p) square wave to $\Delta\theta_d$.

4.3.2 Record $\Delta \theta_d$ and $\Delta \theta_o$ on the visicorder.

4.4 Scram Turnaround Check

4.4.1 Return to 90° position and set the auto-scam control to scam the actuator when $\theta_o \geq 120^\circ$ (-6.66 volt) and apply a 100° (5.55 volt) square wave to $\Delta \theta_d$.

4.4.2 Allow actuator to scam and record θ_o , I_1 , P_1 , P_2 , ΔP , lock light, and unlock light on the visicorder.

4.5 Frequency Response Check

4.5.1 Turn off auto-scam and reset scam relay.

4.5.2 Apply the I.M.C. oscillator output to dynamic command ($\Delta \theta_d$) and set for 4° (.222 volt) peak to peak sine wave.

4.5.3 Connect $\Delta \theta_d$ to the e_1 input of the I.M.C. and $\Delta \theta_o$ to the e_2 input of the I.M.C.

4.5.4 Record frequency on the X-axis, amplitude on the Y-axis, and phase on the Y^1 -axis of the plotter.

4.5.5 Run the frequency from 0.1 HZ to 20 HZ and obtain a plot of the closed loop frequency response of the actuator.

5.0 Life Test Schedule

5.1 Mount actuator on load stand and secure marman clamp.

5.2 Turn on helium drive and nitrogen coolant gas and the actuator amplifier.

5.3 Position the actuator at 90° ($-5 \pm .001$ volt) and set velocity limits to $100^\circ/\text{second}$ using a 100° (5.55 volt) step input.

5.4 Set gain and lead dials of amplifier for best transient response to an 18° (1 volt) step input.

- 5.5 Perform Section 4.0 to obtain the "Base Line Data".
- 5.6 Change helium drive gas to nitrogen and operate the actuator with the following inputs for the time periods given.
 - 5.6.1 Sine Wave - 6 HZ - 4° p-p (.222 volt) - 5 min.
 - 5.6.2 Sine Wave - 0.5 HZ - 40° p-p (2.22 volt) - 6 min.
 - 5.6.3 Ramp - 0.01 HZ - 3°/sec (7.80 volt p-p) - 20 min.
 - 5.6.4 Step - 0.1 HZ - 18° p-p (1.00 volt) - 10 min.
 - 5.6.5 Dwell at 90° 10 min.
 - 5.6.6 After the each of the five periods (5.6.1 to 5.6.5) mentioned above scram, lock, and reset the actuator to the 90° position.
- 5.7 After each 25 hour period change the drive gas from nitrogen to helium and obtain a frequency response as detailed in Section 4.5.
- 5.8 After 150 hours repeat Section 4.0 to determine the performance of the actuator.

6.0 Combined Low Temperature and Vibration Test Schedule

- 6.1 Mount actuator on load stand and secure marman clamp.
- 6.2 Turn on ambient drive and coolant gas and the actuator amplifier.
- 6.3 Position the actuator to 90° and set velocity limits to 100°/sec using a 100° (5.55 volt) step input.
- 6.4 Set gain and lead dials of amplifier for best transient response to an 18° (1 volt) step input.
- 6.5 Perform Section 4.0 to obtain the "Base Line Data".
- 6.6 Lower temperature of drive and coolant gas to 140°R ± 10°R and allow the actuator housing to stabilize.

- 6.7 After a constant temperature is achieved start the vibration of the actuator as detailed in Curve I.
- 6.8 A complete cycle, both up and down in frequency shall last fifteen minutes.
- 6.9 During each successive cycle the actuator input shall be:
 - 6.9.1 Ramp, .01 HZ, 3°/sec (7.8 volt) for first vibration cycle.
 - 6.9.2 Step, .1 HZ, 18° p-p (1 volt) for second vibration cycle.
 - 6.9.3 Dwell at 90° position for third vibration cycle.
 - 6.9.4 Sine wave, 6 HZ, 4° p-p (.222 volt) for fourth vibration cycle.
- 6.10 After vibration and while the actuator is still at $395^{\circ} \pm 10^{\circ}\text{R}$ repeat Section 4.0 to determine the performance of the actuator.

CURVE NO. 1 ANTICIPATED VIBRATION ENVIRONMENT, NERVA XE-1;
GROUND FIRING TEST, LONGITUDINAL PLANE.

NOTE: D. A. = DOUBLE AMPLITUDE