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VIBRATION TEST OF AN ELECTRO-PNEUMATIC ACTUATOR
BENDIX MODEL ND-D1

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VIBRATION TEST OF AN ELECTRO-PNEUMATIC ACTUATOR
BENDIX MODEL ND-D1

WANL-TNR-112
(CD-1683)

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I. ABSTRACT

TITLE: Vibration Test of an Electro-Pneumatic Actuator - Bendix Model ND-D1

ABSTRACT: A Bendix Actuator was vibrated so that the effects of limited vibration on the actuator performance could be studied.

SUMMARY: The test results show that the actuator has significant resonant frequencies of 220 cps, 580 cps, and 1700 cps in the horizontal plane and 1800 cps in the vertical plane. Actuator performance under vibration loads was not seriously affected, however, failure of a torque motor electrical connection caused a loss of control and random oscillations of the output shaft. A careful study of the torque motor problem in general is needed to improve the design and reliability of the component in the operating environment.

II. INTRODUCTION

The purpose of this test was to study the effects of limited vibrations on the performance of the ND-D1 Actuator. The levels of excitation and the methods of testing were so chosen that some valuable data would be obtained before the unit might be damaged due to excessive vibration. These levels are shown in Figure 10 and are a combination of the vibration environments described in a letter from SNPO and the capabilities of the vibration equipment available.

III. DESCRIPTION OF ACTUATOR

The Bendix Actuator (Figure 1) used for these tests was purchased by WANL under P. O. No. 59-YA-07195 dated February 1962. The governing procurement specification was WANL-CD-147, and Bendix drawing No. 2150750 describes the actuator.

The actuator was delivered to WANL in September 1962 and its performance has been evaluated under both ambient and low temperature conditions. Approximately 31 hours of running time had been logged on it during those tests. Prior to this test, the unit was completely disassembled, inspected, repaired and reassembled by Bendix personnel under the constant surveillance of members of the actuator control group at Westinghouse.

MODEL ND-D1 ACTUATOR
FIGURE 1

I V. DESCRIPTION OF TEST SET UP

The vibration tests were conducted in the Actuator Control Development Laboratory located at Large, Pennsylvania. The equipment includes a MB Electronic Model C-10E Vibration Exciter powered by a MB Electronic Model T251Y Amplifier and controlled by a Bruel and Kjaer Model 1014 Beat Frequency Oscillator as shown in Figure 2.

FIGURE 2 - Vibration Table and Associated Controls

Three Endevco Model 2213C and 2226 accelerometers fed into Endevco Model 2702B Dyno Monitor gauge readouts were used to monitor acceleration on the actuator (see Figure 3). Records were produced by a Minneapolis Honeywell Model 1508 Visicorder.

Three Special vibration fixtures were used to mount the actuator on the vibration table and they are shown in Figure 4. The actuator was held in the vertical position (non-operating) by fixture A, the horizontal position (non-operating) by fixture B, and the vertical position (operating) by fixture C.

FIGURE 3 - Vibration Monitoring Equipment

FIGURE 4 - Vibration Test Mounting Fixtures

The ambient gas test stand shown in Figure 5 was used to determine the performance of the actuator before and after the vibration test. With the actuator mounted on the test stand, the drive and coolant gas were supplied along with the necessary electrical power.

FIGURE 5 - Ambient Gas Test Stand

V. PROCEDURE

The vibration testing was divided into two major categories:

- A. Non-operating vibration tests
- B. Operating vibration tests
- A. Non-operating vibration tests

These tests were conducted to determine major resonant frequencies and to insure that the actuator would remain intact at low "g" level vibrations during which period the actuator would not be pressurized. Performance data was taken on the actuator both before and after the vibration tests.

After establishing the performance characteristics on the warm gas test stand, the actuator was mounted on test fixture "A" and placed on the vibration table in the vertical position (Figure 6).

FIGURE 6 - Actuator Mounted in Vertical Plane for Non-Operating Vibration Test

An accelerometer on the pressure vessel adapter was used to control the motion of the test item. The excitation was advanced to 1g and the frequency was increased from 20 to 2000 cps at a logarithmic rate in 104 seconds. Five seconds was allowed to stop the sweep and start in the reverse direction. The frequency was decreased from 2000 to 20 cps at a logarithmic rate in 104 seconds and then the 1g excitation was removed. The output from the three accelerometers was observed on gauges and recorded on the visicorder. The No. 1 accelerometer recorded the motion of the base (control accelerometer), No. 2 recorded the cross-talk (vibration normal to the direction of excitation) and No. 3 recorded the motion of the top of the unit.

The actuator was then placed on test fixture "B" and mounted on the vibration table in the horizontal position with the line of force in the direction parallel to the motion of the slide valve (Figure 7).

FIGURE 7 - Actuator Mounted in Horizontal Plane For Non-Operation Vibration Test. (force parallel to slide valve axis)

The accelerometer placed on the pressure vessel adapter between the fixture and the actuator was used to control the motion of the test item. The 1g excitation was applied and the frequency spectrum was scanned at the logarithmic rate described in the preceding paragraph. The output from the three accelerometers was observed on the gauges and recorded on the visicorder. The No. 1 accelerometer recorded the motion of the base, No. 2 recorder the crosstalk, and No. 3 the motion of the top of the unit.

The actuator was then rotated 90° on test fixture "B" so that the line of force was perpendicular to the slide valve axis (Figure 8). The vibration procedure described above was repeated.

FIGURE 8 - Actuator Mounted in Horizontal Plane for Non-Operating Vibration Test. (force normal to slide valve axis).

FIGURE 9 - Actuator Mounted in Vertical Plane for "Operating" Vibration Test.

Next the actuator was returned to the ambient gas test stand and performance data was taken to compare with that taken prior to the vibration tests.

Following the post vibration testing connected with Phase "A" the actuator was remounted on the vibration table using test fixture "C". The actuator was connected to the gas supply and control system as shown in Figure 9.

With the actuator mounted in the vertical plane, spot checks were made to record typical output waveshapes prior to the vibration test. Phase "B" of the test plan was then completed.

B. Operation Vibration Tests

An accelerometer mounted on the base of the pressure vessel adapter was used to control the power to the vibration exciter. An accelerometer, mounted near the top of the actuator, recorded the crosstalk and the velocity pickup, built into the vibration table, recorded the motion of the table.

The actuator was positioned at 90° shaft position, and a 18° step input was applied to the command circuit of the actuator. The actuator and load were vibrated in accordance with curve 2 on Figure 10. The excitation was held at 1.33 g from 20 to 90 cps at which point the logarithmic sweep was stopped, the excitation readjusted to 5 g, and the sweep continued up to 2000 cps. The sweep was stopped and reversed downward to 90 cps. The excitation was reduced to 1.33 g and the sweep resumed down to 20 cps.

The 18° step input to the actuator was replaced with a 3°/sec ramp. The actuator was vibrated a second time according to curve 2 of Figure 10.

Having completed this test, the 3°/sec ramp was replaced with a $\pm 2^\circ$ sine wave at 2.0 cps. The actuator was then vibrated a third time according to curve 2 of Figure 10

Curve No. 1 - Anticipated Vibration Environments for NERVA Engine Assembly
 Curve No. 2 - Vibration Curve Followed in Phase "B" of Testing.

FIGURE 10

VI. TEST RESULTS AND OBSERVATIONS

Results of the non-operating vibration tests show that the performance of the actuator was unaffected by 1 g vibration forces. Table 1 is a comparison of typical performance parameters recorded before and after the vibration tests associated with phase "A" of the testing. Figures 15 through 20 are typical waveshapes of the performance before and after these tests.

The non-operating vibration tests showed significant resonant frequencies of 220 cps, 580 cps, and 1700 cps in the horizontal plane. A resonant condition at 1800 cps in the vertical direction was also recorded. Peak forces of 16.5 g's (0.5 g input) at 220 cps and 29.5 g's (1.0 g input) at 1800 cps were recorded in the horizontal and vertical directions respectively.

Figures 11 through 14 are plots of amplitude ratio (output G divided by input G) versus frequency. Figures 12 and 13 show a large number of resonant frequencies. For these tests the accelerometer recording the forces on the actuator was mounted on the cover of the actuator. On the premise that a number of these resonances were caused by the cover vibration rather than components inside the cover, a horizontal test was made with the cover removed. For this test an accelerometer was mounted on the cross-over piece connecting the slide valve to the gearmotor. The excitation force for this test was 0.5 g's applied in the direction perpendicular to the slide valve axis. The results showed a lesser number of resonances and are plotted in Figure 14.

The 5 g vibration tests, conducted with the actuator pressurized, had slight effects on the actuator performance. With the actuator following a $\pm 2^\circ$ sine wave and the vibration input set at 5 g's, a small change in the bias level of the shaft position was noticed during the sweep of the frequency spectrum. The waveshape, however, remained unchanged throughout this period.

During the vibration test in which the actuator was following the sine wave an internal connection in the torque motor was broken thereby causing the actuator to lose control. This occurred at about 700 cps with an excitation force of 5 g's. Figures 21 through 28 show typical waveshapes of the actuator performance during vibration, and prior to the failure of the torque motor. Figure 29 shows the performance where the torque motor failed.

VII. CONCLUSIONS

Results of the non-operating tests revealed a large buildup of "g" forces at some of the resonant frequencies. In one instance, a force of 16.5 g's was recorded at the crossover piece connecting the slide valve to the gear motor. This occurred with an excitation force of 0.5 g's. Performance checks, made after this test, showed that the actuator was unaffected by this test; however, similar vibration tests which call for 20 g's excitation could cause damage to the physical structure of the actuator.

Actuator performance during vibration was not seriously affected by the vibration forces although failure of a torque motor electrical connection caused a loss of control and random oscillations of the output shaft. Failure of the torque motor in this manner, although different in nature, is part of a continuing series of problems with this component. In view of the problems incurred with this component, it is recommended that further development work be done to improve its design and reliability in the operating environment.

TABLE 1 - ACTUATOR PERFORMANCE COMPARISON

<u>Test</u>	<u>Pre-Vibration Tests</u>		<u>Post Vibration Tests</u>	
18° Step Response	Toward 0°	Toward 180°	Toward 0°	Toward 180°
a) Rise Time to 62.5%	0.12 sec.	0.12 sec.	0.11 sec.	0.11 sec.
b) Settling Time to $\pm 1^\circ$	0.21 sec.	0.30 sec.	0.22 sec.	0.26 sec.
c) Overshoot	1.02°	2.50°	3.34°	2.51°
Dynamic Resolution	0.63°		1.29°	
Static Resolution	.07° P-P		.07° P-P	
Maximum Velocity	Toward 0°	Toward 180°	Toward 0°	Toward 180°
	281°/sec.	225°/sec.	268°/sec.	234.5°/sec.
Frequency Response				
a) Phase Lag at 8 cps	115°		131°	
b) Phase Lag at 11 cps	186°		180°	
Scram Turnaround Time	.07 sec.		.075 sec.

EXCITATION: 1G IN THE VERTICAL PLANE
FORCE PARALLEL TO AXIS OF OUTPUT SHAFT.

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FIGURE 11

EXCITATION: 1G IN THE HORIZONTAL PLANE
FORCE PARALLEL TO SLIDE VALVE AXIS.

FIGURE 12

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EXCITATION: 1G IN THE HORIZONTAL PLANE.
FORCE NORMAL TO THE SLIDE VALVE AXIS.

FIGURE 13

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EXCITATION: 0.5G IN THE HORIZONTAL PLANE. FORCE
NORMAL TO THE SLIDE VALVE AXIS. COVER REMOVED AND ACCELEROMETER
MOUNTED ON CROSSOVER PIECE FOR THIS TEST.

FIGURE 14

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PRE-VIBRATION TEST (PHASE A)

DRIVE GAS: Helium at 200 psig and 530°R

COOLANT GAS: Nitrogen at 605 psig and 530°R

RETURN GAS: 35 psig

QUIESENT POSITION: 90°

FRICTION: 33 1/2 in-lbs.

FIGURE 15 - COMMAND SIGNAL: 18° Step
CHART SPEED: 4.0 in/sec.

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FIGURE 16 - COMMAND SIGNAL: $3^\circ/\text{sec.}$ Ramp
CHART SPEED: 0.4 in/sec.

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FIGURE 17 - COMMAND SIGNAL: $+2^\circ$ Sine at 8 cps
CHART SPEED: 8 in/sec.

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POST VIBRATION TEST (PHASE A)

DRIVE GAS: Helium at 200 psig and 530°R

COOLANT GAS: Nitrogen at 641 psig and 530°R

RETURN GAS: 34 psig

QUIESENT POSITION: 90°

FRICITION: 33 1/2 in-lbs.

FIGURE 18 - COMMAND SIGNAL: 18° Step
CHART SPEED: 4.0 in/sec.

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FIGURE 19 - COMMAND SIGNAL: $3^\circ/\text{sec.}$ Ramp
CHART SPEED: 0.4 in/sec.

FIGURE 20 - COMMAND SIGNAL: $+2^\circ$ Sine at 8.0 cps
CHART SPEED: 8.0 in/sec.

VIBRATION TEST (PHASE B)

DRIVE GAS: Helium at 200 psig and 530°R

COOLANT GAS: Nitrogen at 650 psig and 530°R

RETURN GAS: 33 psig

FIGURE 21 - COMMAND SIGNAL: 18° Step
VIBRATION EXCITATION: None
CHART SPEED: 4.0 in./sec.

FIGURE 22 - COMMAND SIGNAL: 18° Step
VIBRATION EXCITATION: 5 g's at 1800 cps
CHART SPEED: 1.0 in./sec.

FIGURE 23 - COMMAND SIGNAL: 18° Step
VIBRATION EXCITATION 5 g's at 600 cps
CHART SPEED: 1.0 in./sec.

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FIGURE 24 - COMMAND SIGNAL: $3^\circ/\text{sec.}$ Ramp
VIBRATION EXCITATION: None
CHART SPEED: 0.4 in/sec.

FIGURE 25 - COMMAND SIGNAL: $3^\circ/\text{sec.}$ Ramp
VIBRATION EXCITATION: 5 g's at 1800 cps
CHART SPEED: 0.4 in/sec.

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FIGURE 26 - COMMAND SIGNAL: $3^\circ/\text{sec.}$ Ramp
VIBRATION EXCITATION: 5 g's at 300 cps
CHART SPEED: 0.4 in/sec.

FIGURE 27 - COMMAND SIGNAL: $+2^\circ$ Sine at 2.0 cps
 VIBRATION EXCITATION: None
 CHART SPEED: 1.0 in/sec.

FIGURE 28 - COMMAND SIGNAL: $+2^\circ$ Sine at 2.0 cps
 VIBRATION EXCITATION: 5 g's at 1800 cps
 CHART SPEED: 0.4 in/sec.

FIGURE 29 - COMMAND SIGNAL: $+2^\circ$ Sine at 2.0 cps
VIBRATION EXCITATION: 5 g's at 600 cps
CHART SPEED: 0.4 in/sec.