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REPORT NO. RN-S-0228

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

TEST RESULTS, GE TPCV ACTUATORS,
SERIES AG-21

AUGUST 1965

NERVA PROGRAM

CONTRACT SNP-1

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TEST RESULTS, GE TPCV ACTUATORS,
SERIES AG-21

ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM AUGUST 1965 CONTRACT SNP-1

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ABSTRACT

Test results of the Turbine Power Control Valve Actuator designed by the General Electric Corporation, Series AG-21 are presented. Conclusions and recommendations are also presented relative to future use of this actuator in the TPCV application.

A handwritten signature in cursive script, reading "W. D. Stinnett", positioned above a horizontal line.

W. D. Stinnett
Program Manager
REON

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I. INTRODUCTION

This report presents and discusses data taken during the evaluation testing of the General Electric AG-21 series pneumatic actuator, Serial No. 1. The AG-21 actuator was designed to the NERVA program turbine power control valve actuator requirements in Specification AGC 11850A as amended by appendix B to contract NP-12.

Included in this report are the data contained in the preliminary report (REON Report No. RN-S-0228) of the same title submitted 7 October 1964. At the time this final REON report was prepared, the General Electric final report (Contract NP-12) was not available; however, such items as computer analysis, transfer function representation, and detail design features will be reported in the G.E. final report.

The evaluation testing covered by this REON report includes performance with various load conditions imposed on the actuator and environments of maximum and minimum temperature, thermal shock conditions, vibration, and reduced supply pressure.

All testing was conducted at the Aerojet-General, Von Karman Center, Azusa, California between 20 June 1964 and 1 October 1964.

II. TECHNICAL DISCUSSION

A. MECHANICAL DESCRIPTION OF THE AG-21 ACTUATOR AND THE AGC TEST SETUP

1. Description

The General Electric AG-21 series turbine power control valve is shown, in Figure 1, fully assembled and mounted on a vibration test stand. A picture of the actuator dis-assembled to show all internal components is presented in Figure 2. This actuator is a pneumatic-operated, piston-type, servo device. The aluminum body (or main block) of the actuator is shown in Figure 3 viewed from the same angle as in Figure 2. With the actuator body in Figure 3, are the supply gas filter and the supply/exhaust gas external fittings block. The relative mounting position is indicated by its location in the picture. The supply/exhaust fitting block, with external connections is shown in Figure 4, on the actuator

body, (Ref. Figure 3), next to the supply/exhaust fitting block mounting location. On the same flat surface, is a port with four screw holes arranged around it. This is the mounting position for the actuator electrical connector. The electrical connector, wire harness, and connector hold down assembly are shown in Figure 5.

The actuator supply gas is ported through the body to the servo valve. The servo valve operation is portrayed schematically in Figure 6. Pressure on the actuator pistons is controlled by venting through the servo bullet valve. Dynamic conditions are compensated by the orifices, bellows force, and damping volumes. In the steady, or no motion, condition of the actuator, the bullet valves bleed equal amounts of gas. The maximum pressure difference generated by the servo is approximately 70% of supply pressure. A photograph of the servo valve assembly is shown in Figure 7. Ports in the base of the servo valve are shown in Figure 8. The servo valve assembly is mounted to the actuator body on the surface facing the reader in Figure 9.

Pressure controlled by the servo valve is ported through the actuator body to the piston heads. The pistons and their connecting rod are shown in Figure 10. The connecting rod is machined in the form of a rack gear. Motion of the pistons produces rotation of the actuator output shaft by engagement of the rack gear with the pinion gear on the output shaft, see Figure 11. The separation forces of the rack and pinion are taken in the output shaft bearings and the connecting rod (or rack) backup bearing assembly. (Ref. Figure 12) This bearing and guide assembly prevent the rack from rotating, and relieve the gear separation forces from the pistons.

The pistons ride in special sleeves which are ground on their external surface so the exhaust gas (bleed flow) can provide cooling. A piston and the two piston sleeves are shown in Figure 13. The piston sleeves, pistons, and connecting rod assemble into the actuator body in the large sleeve bore shown facing the reader in Figure 14. The piston sleeves protrude from the body when assembled (Ref. Figure 2). The sleeve, or cylinder, is covered with a cap shown in Figure 15. Inside the cylinder cover the ports for cylinder head pressure

and sleeve cooling may be seen. The rack backup-bearing assembly and cover are mounted to the body on the pad shown on the top of the body as viewed in Figure 2.

The output shaft is shown in Figure 16; the pinion is mounted between the shaft bearings, the larger bearing is at the top end of the shaft. Above the top bearing the rotation stops and the zero position switch activating lever may be seen. At the very top of the shaft is mounted the potentiometer clamp and its drive bellows (Ref. Figure 11). The spline on the bottom of the output shaft drives the turbine power control valve. The output shaft assembly is inserted into the actuator body with its top end deep in the body bore as shown in Figure 17. Also into this body bore, and over the top end of the output shaft, the bearing housing and gap seals are assembled as shown in Figure 18. The seals control amount of leakage cooling flow. The potentiometer mount is next installed, (Ref. Figure 19). An external view of the potentiometer mount is shown in Figure 20. The small "firing pin" arrangement for actuation of the zero position switch can be seen. The potentiometer and position switch are shown in Figure 21.

The covers for the potentiometer and for the servo valve are shown in Figures 22 and 23. The taller cover is for the servo valve. The actuator body is shown in Figure 24 viewed from the bottom through which the output shaft extends. The length of shaft is covered by the base adapter which mounts on the bottom of the actuator body. This high temperature standoff adapter is shown in Figure 25 viewed from the surface that mounts to the actuator body. The other end of the adapter, which mates with the turbine power control valve, is shown in Figure 26. Into this end of the adapter (and onto the output shaft) is mounted the output shaft dynamic seal; shown in Figure 27.

Some of the gasket seals used in the AG-21 actuator are shown in Figure 28.

2. Test Setup

The primary test equipment consisted of two test stands, the load stand and the thermal stand. The load stand was constructed to duplicate the

loading imposed on the actuator by the turbine power control valve. This load consists of three parts; (a) an inertial load of $0.004 \text{ in-lb-sec.}^2$, (b) a friction load of 50 in-lbs., and (c) a spring rate of 2.85 in-lbs. per degree from 30° to 90° rotation to simulate the aerodynamic torque of the valve. This torque load always assists closure of the valve. The load stand was enclosed to provide pressurization of the output shaft dynamic seal to 600 PSI. The friction and spring rate characteristics of the load stand are presented in Figure 29. The AG-21 actuator is shown mounted on the load stand in Figure 30.

The thermal stand was designed to simulate the 1000° F temperature of the TPCV Marman flange to which the actuator mounts. This stand does not put a shaft load on the actuator. A picture of this heater stand is presented in Figure 31. The upper heater is temperature controlled to maintain flange temperature of the valve simulator block. The lower heater was used to preheat the dynamic seal gas pressurant; this heater was manually controlled.

Ambient or 270° F hydrogen, helium, or nitrogen could be supplied to the actuator and seal pressure on either the load stand or the thermal stand. If low temperature gas was desired it was obtained by piping the gas from the tank farm through a cooler tank filled with liquid nitrogen. Temperatures, flows and pressures could be measured at desired positions.

The test area was in Aerojet-General's Azusa plant. Figure 32 shows the facility. In the foreground is the tank farm surrounded by sand bags; also sandbagged is the small octagonal steel building which contained the test stands. To the right of the picture is the small wooden shack used as a control room. The inside of the control room is shown in Figure 33. The small control console on the right of the picture contains the equipment peculiar to the AG-21 testing. From the top down the equipment is: the servoanalyzer, the General Electric AG-21 servo amplifier, the bias signal panel, the function generator, a dual power supply for + and -22 1/2 volts and a dual power supply for + and - 300 volts (both supplies used to activate the servo amplifier).

B. DESCRIPTION OF TESTS

The performance and environmental evaluation of the General Electric AG-21 actuator consisted of a series of tests as described below. Data from the tests will be discussed later in the report.

Test 1 -- An evaluation of the General Electric AG-21 servo amplifier to determine gain and response.

Test 2 -- A response test of the AG-21 actuator. Two problems occurred;

- (a) It was found that the actuator could not be operated on nitrogen gas as the amplifier gain (changed by plug-in resistors) could not be satisfactorily adjusted.
- (b) The response test was attempted with helium supply gas but instrumentation problems attenuated the flow and position data.

At this point the decision was made to alter the test plan. Helium gas would be used for performance tests to verify the system performance as being equal to that obtained at General Electric before delivery. Nitrogen gas could not be used without modification of the amplifier. Hydrogen gas would be used during testing to reduce the expense of helium, and all environmental tests, which had been planned with nitrogen would now use hydrogen supply gas. These changes were primarily a result of the discovery of the system's extreme sensitivity to the type of gas used as well as the consideration that it was designed for hydrogen use.

Test 3 -- A response test using ambient helium supply gas, no load on the actuator, no seal pressure, and ambient base temperature. The data compared well with the G.E. pre-delivery tests. No seal pressure was used as the attempt to pressurize uncovered a ruptured bellows in the actuator dynamic shaft seal. The actuator was dis-assembled, partially, at this time to inspect the seal bellows and to check the servo valve bullet assembly for Teflon tape particles. These had been found in AG-20 actuators (reactor drum actuator) at WANA and the source was found to be a G.E. servo valve test block which was also used for the AG-21 actuator servo valve at G.E. No Teflon was found. The bellows failure was such that the seal could be left installed in the actuator, to contribute its friction effect, until a new seal assembly could be delivered from G.E.

Test 4 -- A short performance to test after re-assembly to show data agreement with Test 3.

Test 5 -- A response test using ambient helium supply gas, no seal pressure, full load on the actuator, and ambient base temperature. Data agreed well with the G.E. pre-delivery tests.

Test 6 -- A response test using ambient hydrogen supply gas, no seal pressure, full load on the actuator, and ambient base temperature.

Test 7 -- A response test using ambient hydrogen supply gas, no load on the actuator, no seal pressure, and ambient base temperature.

At this point a review of helium and hydrogen loaded and unloaded performance was made, Tests 3, 5, 6, and 7. The hydrogen, loaded actuator, performance did not appear satisfactory. The trouble was traced to the occasional sticking of the aluminum friction shoe in the load stand. The shoe was replaced with the original naval bronze part and the problem was corrected. It was decided that a new set of loaded and unloaded response tests would be made after the low pressure test.

Test 8 -- Low pressure response test. Ambient helium supply gas, no seal pressure, full load, and ambient base temperature. Supply pressure was reduced from 200 to 80 psi, in steps, with 45 psi back-pressure on the actuator.

Test 9 -- Hydrogen supply gas response test, no load, ambient conditions, no seal pressure, test run at the nominal bias angle of 45° .

Test 10 -- Hydrogen supply gas response test, full load conditions, ambient environment, no seal pressure, 45° nominal bias angle.

Test 11 -- Hydrogen supply gas response test, full load at 30° bias angle, friction load only, ambient conditions, no seal gas pressure.

Test 12 -- Hydrogen supply gas response test, full load at 65° bias angle ambient conditions, no seal pressure.

Test 13 -- Hydrogen supply gas response test, springload only (no friction at 65° bias angle, ambient conditions, no seal pressure.

After these performance tests, the actuator was dis-assembled to determine the relative state of wear. The only major evidence of wear was roughness of the main shaft bearings. This state of wear did not cause the G.E. people concern for the actuators performance, and testing was continued. The roughness produced a jerking drag averaging about one-half inch-pound of torque; approximately 65 hours test time had been accumulated.

Test 14 -- Hydrogen supply gas after assembly performance check test.

Test 15 -- Hydrogen supply gas response test, inertia load only, ambient conditions, no seal pressure, nominal bias angle of 45° .

Test 16 -- Hydrogen supply gas response test, inertia load only, double the specification inertia load of Test 15, ambient conditions, nominal bias angle of 45° .

Test 17 -- Hydrogen supply gas low pressure response test, ambient conditions, no seal pressure.

Test 18 -- Three axis vibration test, actuator not operating during test.

Test 19 -- Vertical axis vibration test with 200 psi nitrogen gas supplied to the actuator, no electrical connections.

The replacement dynamic shaft seal arrived from G.E. and was installed. Environmental testing began.

Test 20 -- High base temperature test (200°F to 1000°F), ambient hydrogen supply gas, seal pressurized to 600 psi, no load on the actuator.

Near the end of Test 20, the actuator dynamic seal failed, extreme leakage was recorded and the seal pressure turned off. The seal had accumulated a total of 5 hours run time.

Test 21 -- High temperature thermal shock test, ambient hydrogen gas was supplied to the actuator while the base temperature was increased to 1000°F , then the supply gas was switched to cryogenic hydrogen gas at -270°F . No seal pressure was used.

Test 22 -- Ambient hydrogen supply gas, ambient base temperature, no load response test. No seal pressure, this test is a performance base for Tests 23 and 24.

Test 23 -- Hydrogen supply gas at -270°F , no load response test, no seal pressure nominal 45° bias angle, base heaters off.

Test 24 -- Hydrogen supply gas at -270°F , full load 45° bias angle response test, base heaters off, no seal pressure.

Test 25 -- Hydrogen supply gas, ambient conditions, computer tie-in-test, 45° load, no seal pressure. The actuator was run in the analog model engine control loop.

C. DISCUSSION OF AMBIENT AND CRYOGENIC PERFORMANCE

Ambient performance was recorded using both helium and hydrogen gas. Helium supply gas was used for initial ambient performance tests to compare the actuators "as received" performance with General Electric's acceptance test data. Later hydrogen gas was used for all evaluation testing.

Prior to operation of the actuator, the amplifier performance was evaluated. The actuator torque motor was used as a load with the gas supply off. A gas temperature compensating, 10 OHM resistor is in the actuator in series with the torque motor. When the supply gas resistor temperature is reduced from ambient to -270°F its resistance drops to 3.33 OHMS: which increases system gain to compensate for the reduced supply gas temperature. For ambient hydrogen operation the amplifier gain was measured as 50 milliamps per volt of command (open loop). A Bode plot of amplifier performance at this gain is shown in Figure 34. For helium supply gas testing, General Electric used a 5 OHM resistor in parallel with the temperature compensating resistor to obtain 3.33 OHMS; ambient helium gas constants being much the same as cold hydrogen. With this gain the amplifier response was still very nearly the same as for the hydrogen gain.

The "as received" helium supply gas performance corresponded well with the General Electric Acceptance Test data. The ambient helium supply gas no load performance data from Test 3 is presented in Figures 35 through 43. From these data traces the extreme non-linearity of the system may be seen; throughout the testing, this non-linearity is present, and prevents accurate measurement of the phase angle. Although G.E. recommended a 5 OHM resistor for use with helium testing, a 10 OHM resistor was used to obtain better performance as may be seen by comparing Figures 40 and 43.

A load stand was used to simulate TPCV loading, reference Figure 29. The 45° load is the most common load used for testing as this is expected to be the shaft position for full power operation of the engine. This load condition will be referred to as "full load".

The full load, helium supply gas performance data, Test 5, is presented in Figures 44 through 50. A large effect of loading on the actuator performance is apparent; the break frequency has dropped to approximately 10 cps from the no-load value of approximately 35 cps of Test 3. This testing concluded the comparison of performance effects with those obtained at G.E. before the actuator was shipped to AGC. Agreement was generally good and hydrogen performance evaluation was begun.

Tests 6 and 7 were run with hydrogen supply gas, at loaded and no-load conditions respectively. The data exhibited large stiction effects not seen in the helium, loaded actuator, test and the trouble was traced to the load stand friction shoe. The aluminum friction shoe had begun to wear and was replaced with a naval bronze part. Aluminum had been tried for possible future use of the load stand with radiation environment, the naval bronze part would be a throw-away item after such use.

Test 8, a low supply pressure test, was run primarily for demonstration purposes. Helium supply gas was used for this reason. This test was later repeated using hydrogen gas, Test 17, and low pressure performance from this test will be discussed later.

With the load stand repaired, a pair of loaded and unloaded actuator performance tests were run; Tests 9 and 10. The unloaded, ambient hydrogen supply gas data from Test 9 are presented in Figures 51 through 57. Reasonable performance is obtained for triangular and square wave inputs; however, a 0.9 degree deadband is shown for 0.1 cps 45° triangle (peak to peak) in Figure 52. Figures 54 and 55 show stepping in the low speed sine waves. The amplitude doubles just before response is lost; see Figure 57. The break frequency is approximately 33 cps.

The full load, ambient hydrogen supply gas performance data, Test 10 Figures 58 through 65, show much less amplitude peaking than the unloaded testing;

at 8 cps. the amplitude is down 8.5 db. This is about 3.5 db. less than the 0.1 cps data, which is down 5 db. The overshoot in the step response is within specification (15%), while the resolution, as in Test 9, exceeds the specification limit of 0.5 degrees; see Figure 65. Figures 58 (0.1 cps sine) and 65 (0.1 cps ramp) indicate the actuator steps ahead of command at times and waits for the command to catch up; this is the opposite trace-step that stiction would produce.

A Bode plot of amplitude data from Test 9 (unloaded actuator, ambient hydrogen gas) and Test 10 (loaded actuator, ambient hydrogen gas) is presented in Figure 66 together with data from Tests 23 and 24 (unloaded and loaded actuator respectively, -270°F hydrogen gas).

Before discussing Tests 23 and 24 it should be mentioned that approximately 80 hours test time separate them from Tests 9 and 10; therefore Test 22, an unloaded actuator ambient hydrogen supply gas response test, was run to compare with Test 9 for base performance changes caused by wear. Test 22 response data are presented in Figures 67 through 77. It can be seen that differences are small; the breakpoint of 33 cps in Test 9 compares well with the breakpoint of 30 cps in Test 22, the amplitude decay after break is somewhat faster than in Test 9.

Test data from Tests 23 and 24 (-270°F . hydrogen gas, no load, and -270°F . hydrogen gas loaded actuator, respectively) are plotted in Figure 66; the comparative performance between load and supply gas temperature can be seen in this figure. From Figure 66 it can be seen that the loaded actuator, cold or ambient supply gas, does not meet the 8 cps response of the specification.

Test data from Test 23 are presented in Figures 78 through 86, and from Test 24 in Figures 87 through 93. These data show performance that does not meet with specification requirements of 15% maximum overshoot, 0.50 linearity and resolution, and low frequency attenuation.

Off-design performance was tested using different actuator loadings than the 45° full load rating (Ref. Figure 29). Test 11 was a friction load only; Test 12 was a friction load with a larger spring torque, the 65° position load; and Test 13 was a spring load only test using the 65° position spring load. All three of

these tests (No's. 11, 12, 13) were run using ambient hydrogen supply gas, no seal pressure, and ambient actuator base flange. The data taken show load type sensitivity; friction load increases linearity while spring load decreases linearity, friction load decreases the amplitude break point while spring load increases it. The 65° load position, having more than the usual spring torque to go with normal friction load, shows poor linearity and considerable ability to improve the amplitude output although amplitude positive gains are present. The data for these tests, 11 through 13, are presented in Figures 94 through 120.

Following Test 13, the actuator was dis-assembled and checked for wear. The only major evidence of wear was roughness of the shaft bearings, best described as a jerking drag torque of about one half inch pounds. These bearings are a full compliment, gold plated ball type, operating at 60 RPM maximum with no lubricant. The rough operation was due to galling of the gold plate on the balls. General Electric was contacted and they recommended continued use of the bearings without concern. At this time 65 hours test time had been completed. The actuator was reassembled and testing was continued.

Test 14 was an after-assembly performance check. Data agreement with the before-disassembly tests was very good.

Tests 15 and 16 evaluated the effect of inertia load on the actuator performance. Test 15 was an inertia only, base line test to establish comparative basis for Test 16 which was double the inertia load of Test 15. For these tests a steel shaft had to be used in the load stand; thus, test 15 inertial load was $.005 \text{ in/lb. sec.}^2$ and Test 16 inertial load was $0.01 \text{ in/lb. sec.}^2$, while the normal load using the aluminum load stand shaft is $0.004 \text{ in./lb. sec.}^2$ inertia.

The data taken during Tests 15 and 16 are presented in Figures 121 through 135. In general the linearity during these tests is poor; the amplitude break frequency is almost doubled by the increased inertia load (Test 16). This performance is not surprising when one considers that double the inertia load does not half the actuators pneumatic resonance frequency because the actuator moving parts have a large inertia compared to the load inertia; pneumatic resonance is

computed using the total of actuator internal inertia and external load inertia.

Test 15 and 16 were run at ambient conditions using hydrogen supply gas.

Test 17, low pressure performance, was run at ambient conditions with hydrogen supply gas at less than the design pressure of 200 psig. The supply gas pressures used were 150, 120, and 80 spig. The test data are presented in Figures 136 through 155.

The performance at 80 psig is almost nill, at 120 psig the amplitude break point is between 6 and 8 cps., and at 150 psig the break point is between 8 and 10 cps. The step and ramp command input data for "80 psig" was run at 90 psig to obtain at least recordable and meaningful data.

The remaining test at ambient conditions, Test No. 25, was a computer tie-in test where the ability of the actuator to operate in the analog engine loop was investigated. Results and data were reported separately from this report and for purposes of record it is mentioned here that the G.E. AG-21 actuator was compatible with the analog engine, for the low temperature normal load condition run.

D. DISCUSSION OF HIGH TEMPERATURE AND THERMAL SHOCK TESTS

The Turbine Power Control Valve Actuator, while designed to operate with hydrogen supply gas from ambient to -260°F. , must operate mounted on a TPCV with a mounting flange temperature of up to 1000°F.

For this reason two types of high temperature environmental tests were performed: First, a series of performance tests at a flange temperature of 200, 400, 600, 800 and 1000°F. with ambient actuator supply gas, Test 20 and, second, a 1000°F flange temperature thermal shock test induced by changing from ambient supply gas to -260°F. supply gas to the actuator and monitoring performance as conditions stabilize thermally, Test 21. These tests were run with no load on the actuators.

The high temperature test series, Test 20, was run using a new dynamic shaft seal supplied by G.E. and installed under their supervision. The seal delivered with the actuator was found to have a bellows failure on initial pressurization. Therefore, this was the first testing with the G.E. dynamic shaft seal

The seal failed during this test at 1000°F. flange temperature after about 4 hours operating time at the reduced temperatures (200, 400, 600 and 800°F.). The failure mode was high leakage and use of seal pressure was terminated while testing continued.

The data from Test 20 are presented in Figures 156 through 187. The most important changes in performance during the test was the marked reduction of linearity with increasing temperature and the large change in break frequency with temperature. From Figure 66, the ambient, no-load, break frequency was 35 cps. at 200°F. the break frequency was 21 cps., at 400°F 16 cps., at 600°F. 15.5 cps., at 800°F. 15 cps., at 930°F. 10 cps. (Ref. Figure 179), and between 930 and 970°F below 10 cps (Ref. Figure 180), then for the 1000°F. flange temperature test the break frequency was just over 15 cps. These large changes in performance are obtained by increasing the valve-actuator interface flange temperature only; ambient hydrogen supply gas was used throughout Test 20.

Test 21, thermal shock environmental test, exhibited similar results as Test 20 but without the drastic changes in break frequency. With the interface flange temperature at 1000°F. the ambient supply gas was changed at time zero to -270°F. Figure 188 shows the actuator linearity changes with time until the stabilized condition at time +35 minutes.

Other data from Test 21 at T = +35 minutes are summarized in Figures 189 through 197. These data indicate the break frequency to be 27 cps at the stabilized condition.

E. DISCUSSION OF VIBRATION TESTS

General Electric TPCV Actuator S/N 1 was vibration tested in three mutually perpendicular axes. The axes chosen were; (1) parallel to the actuator vertical axis, (2) parallel to the pistons direction of motion (piston axis), and (3) parallel to the "Torque motor to backup bearing cover" axial orientation.

Two vertical axis non-operating vibration tests were run. Results of the first, at 1.0g input are shown in Figure 198. Resonance is present at approximately 220 and 1000 cps. The high frequency g-load amplification was large and the test

was therefore stopped and rerun at 0.5g input. This data are shown in Figure 199. The torque motor reached a peak amplitude ratio of 40 at 1000 cps in this vertical axis vibration test. This vibration amplitude is 90° to the input direction of vibration. The largest amplitude ratio reached in the vertical plane, during this test, was 25 to 1 measured on the actuator body at 1000 cps. The "Piston Axis" and "Torque Motor Backup Bearing Cover Axis" vibration tests were run at 0.5g input level; data are presented in Figures 200 and 201 respectively. The levels reached are below those of the vertical axis torque motor resonance values although amplitude ratios as high as 25 were reached during the piston axis test measured at the top of the actuator bod

For interest level a non operating, nitrogen supply gas, vertical axis vibration test was made at both 0.5 and 1.0g inputs. Figures 202 and 203 show these data and indicate that the gas loads prevent the torque motor from reaching the extremely high amplitude ratios. The maximum ratios of amplification were 7 and 10 on the activation bearing backup cover and body respectively. To check the logic of torque motor produced resonance in the actuator, the vibration table was shut down and (with N_2 supply gas on) the torque motor was allowed to oscillate, or buzz as it often does with or without electrical input, and the accelerometers were read. Five "g" were produced on the torque motor and slightly less on several actuator points; this implied that the large resonances in the actuator are at least partly introduced by torque motor resonance during the non operating (no supply gas) vibration tests.

The AG-21 actuator is shown in Figures 1 and 204 mounted on the vibration table; the location of the vibration pickups.

III. CONCLUSIONS AND RECOMMENDATIONS

The performance and environmental testing of the General Electric AG-21 actuator involved an accumulated test time of just over 100 hours. From this testing the following salient features were discovered:

A. The actuator performance is very sensitive to changes in the spring rate, inertia, and friction loading.

B. Changes in the actuator supply gas temperature have a large effect on performance.

C. The temperature of the actuator interface mounting flange radically changes the linearity and break point frequency of the actuator.

D. Thermal shock affects the actuator linearity.

E. The actuator is basically a high order, non linear servo system.

F. The servo valve has a large magnification factor (resonance) during vibration testing.

G. A "buzz" is normally present in the servo valve, during operation, and is of a reasonably high energy level.

H. The only part of the actuator to experience a clear mechanical failure was the dynamic shaft seal. This seal remains a development problem.

I. The full compliment, gold plated, ball bearings on the actuator main shaft exhibited undesirable roughness; however, this did not progress to a point where performance was affected.

The results of this evaluation of the AG-21 TPCV actuator, together with schedule hardware demand and cost reasons summarized in the annual contract review presentation of the NERVA Program on November 16, 17, and 18, 1964, resulted in the recommendation by the Aerojet-General Corporation that the AG-21 actuator not be used for the TPCV application. This recommendation was concurred with by the AEC-NASA Space Nuclear Propulsion Office. Therefore, work on the AG-21 actuator for the NERVA TPCV application was terminated.

FIGURE 1
AG-21 VIBRATION TEST
ACTUATOR MOUNTED ON SLIP TABLE FOR
PISTON AXIS VIBRATION TEST. LOCATION
OF VIBRATION PICKUPS SHOWN.

FIGURE 2
AG-21 ACTUATOR COMPONENTS

FIGURE 3
MAIN HOUSING SHOWING GAS SERVICE
PAD WITH FILTER AND MANIFOLD

FIGURE 4
GAS INLET AND EXHAUST MANIFOLD
PLATE WITH SERVICE TUBES

FIGURE 5
ELECTRICAL HARNESS AND RETAINING PLATE

FIGURE 6

FIGURE 7
SERVO VALVE ASSEMBLY

FIGURE 8
SERVO VALVE ASSEMBLY - BOTTOM
VIEW SHOWING METERING ORIFICE

FIGURE 9
MAIN HOUSING - BOTTOM VIEW

FIGURE 10
PISTON AND RACK ASSEMBLY AND
PISTON ASSEMBLY

FIGURE 11
MAIN SHAFT ASSEMBLY WITH
BEARINGS AND POTENTIOMETER COUPLING

FIGURE 12
RACK LOAD BACKUP BEARING
ASSEMBLY AND SLEEVE

FIGURE 13
CYLINDER LINERS WITH PISTON
AND PISTON RINGS

FIGURE 14
MAIN HOUSING - LEFT SIDE VIEW

FIGURE 15
CYLINDER COVERS

FIGURE 16
MAIN SHAFT ASSEMBLY WITH
BEARINGS AND POTENTIOMETER COUPLING

FIGURE 17
MAIN HOUSING VIEWED FROM
POTENTIOMETER END

FIGURE 18
BEARING HOUSINGS AND BEARING GAP SEALS

FIGURE 19
POTENTIOMETER MOUNT - INTERNAL VIEW

FIGURE 20
POTENTIOMETER MOUNT AND CLEATS

FIGURE 21
POTENTIOMETER AND POSITION SWITCH

FIGURE 22
POTENTIOMETER COVER AND
SERVO VALVE COVER - EXTERNAL VIEW

FIGURE 23
POTENTIOMETER COVER AND
SERVO VALVE COVER - INTERNAL VIEW

FIGURE 24
MAIN HOUSING AS VIEWED FROM EXHAUST SIDE

FIGURE 25
MAIN HOUSING ADAPTER AND SPLINE GUARD

FIGURE 26
MAIN HOUSING ADAPTER AND SPLINE GUARD

FIGURE 27
MAIN SHAFT, SEAL ASSEMBLY, AND
RETAINING RINGS

FIGURE 28
TYPICAL APEX SEALS

FIGURE 29

FIGURE 30
AG-21 ACTUATOR MOUNTED ON
LOAD SIMULATING STAND

FIGURE 31
THERMAL TEST STAND AND
LOAD TEST STAND USED DURING AG-21 TESTING

FIGURE 32
ACTUATOR TEST FACILITY
SHOWING TANK FARM TEST CHAMBER
AND CONTROL SHACK

FIGURE 33
ACTUATOR TEST CONTROL CONSOUL

FIGURE 34

NOTE: HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 35

TEST NUMBER 3 SHEET 2

NOTE: HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

RAMP 45°

0.1 CPS

DEADBAND=APPX. 0.9°

POSITION

2.1 °/L

COMMAND

STEP 45°

0.33 CPS

POSITION

2.1 °/L

DATE NO. RA 2901-32

TIME 0.000

COMMAND

FIGURE 36

NOTE HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 37

NOTE HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 38

TEST NUMBER 3 SHEET 4

NOTE: HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 39

NOTE: HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 40

TEST NUMBER 3 SHEET 6

NOTE: HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 41

NOTE: HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 42

TEST NUMBER 3 SHEET 8

NOTE: HELIUM SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

NOTE

5 OHM GAIN RESISTOR
RECOMMENDED BY G. E.

2 CPS

0.105 °/L

POSITION

COMMAND

4 CPS

0.105 °/L

6 CPS 0.105 °/L

POSITION

COMMAND

FIGURE 43

NOTE: HELIUM SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 44

TEST NUMBER 5 SHEET 2

NOTE HELIUM SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 45

NOTE HELIUM SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 46

TEST NUMBER 5 SHEET 3

NOTE: HELIUM SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 47

TEST NUMBER 5 SHEET 4

NOTE: HELIUM SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 48

TEST NUMBER 5 SHEET 5

NOTE: HELIUM SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS
±2° AMPLITUDE 0.21°/L UNLESS MARKED

FIGURE 49

TEST NUMBER 5 SHEET 6

NOTE: HELIUM SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 50

TEST NUMBER 9 SHEET 1

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
40° ACTUATOR BIAS

FIGURE 51

TEST NUMBER 9 SHEET 2

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 52

TEST NUMBER 9 SHEET 3

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 53

TEST NUMBER 9 SHEET 4

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 54

TEST NUMBER 9 SHEET 5

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 55

TEST NUMBER 9 SHEET 6

NOTE HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 56

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 57

TEST NUMBER 10 SHEET 1

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 58

TEST NUMBER 10 SHEET 2

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
40° ACTUATOR BIAS

FIGURE 59

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 60

TEST NUMBER 10 SHEET 4

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 61

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 62

TEST NUMBER 10 SHEET 6

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 63

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 64

TEST NUMBER 10 SHEET 8

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 65

FIGURE 66

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 67

TEST NUMBER 22 SHEET 2

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 68

TEST NUMBER 22 SHEET 3

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 69

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 70

TEST NUMBER 22 SHEET 5

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 71

TEST NUMBER 22 SHEET 6

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 72

TEST NUMBER 22 SHEET 7

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 73

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 74

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 75

TEST NUMBER 22 SHEET 9

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 76

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 77

TEST NUMBER 23 SHEET 1

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 78

TEST NUMBER 23 SHEET 2

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 79

7

TEST NUMBER 23 SHEET 3

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 80

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 81

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 82

TEST NUMBER 23 SHEET 6

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 83

TEST NUMBER 23 SHEET 7

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 84

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 85

TEST NUMBER 23 SHEET 9

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 86

TEST NUMBER 24 SHEET 1

NOTE: 270° F HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BLAS

FIGURE 87

TEST NUMBER 24 SHEET 2

NOTE: 270° F HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 88

TEST NUMBER 24 SHEET 3

NOTE: 270° F HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 89

TEST NUMBER 24 SHEET 4

NOTE: 270° F HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 90

TEST NUMBER 24 SHEET 5

NOTE: 270° F HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 91

TEST NUMBER 24 SHEET 6

NOTE: 270° F HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 92

NOTE 270° F HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 93

TEST NUMBER 11 SHEET 1

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 94

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 95

TEST NUMBER 11 SHEET 3

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 96

TEST NUMBER 11 SHEET 4

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 97

TEST NUMBER 11 SHEET 5

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 98

TEST NUMBER 11 SHEET 6

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 99

TEST NUMBER 11 SHEET 7

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 100

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 101

NOTE: HYDROGEN SUPPLY GAS
FRICTION LOAD ONLY
30° ACTUATOR BIAS

FIGURE 102

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
65° ACTUATOR BIAS

FIGURE 103

TEST NUMBER 12 SHEET 2

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
65° ACTUATOR BIAS

FIGURE 104

TEST NUMBER 12 SHEET 3

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
65° ACTUATOR BIAS

FIGURE 105

TEST NUMBER 12 SHEET 4

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITIONS
65° ACTUATOR BIAS

FIGURE 106

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITIONS
65° ACTUATOR BIAS

FIGURE 107

TEST NUMBER 12 SHEET 6

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITIONS
65° ACTUATOR BIAS

FIGURE 108

TEST NUMBER 12 SHEET 7

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITIONS
65° ACTUATOR BIAS

FIGURE 109

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITIONS
65° ACTUATOR BIAS

FIGURE 110

TEST NUMBER 12 SHEET 9

NOTE: HYDROGEN SUPPLY GAS
FULL LOAD CONDITIONS
65° ACTUATOR BIAS

FIGURE 111

TEST NUMBER 13 SHEET 1

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 112

TEST NUMBER 13 SHEET 2

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 113

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 114

TEST NUMBER 13 SHEET 4

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 115

TEST NUMBER 13 SHEET 5

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 116

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 117

TEST NUMBER 13 SHEET 7

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD CONDITION
65° ACTUATOR BIAS

FIGURE 118

TEST NUMBER 13 SHEET 8

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 119

TEST NUMBER 13 SHEET 9

NOTE: HYDROGEN SUPPLY GAS
SPRING LOAD ONLY
65° ACTUATOR BIAS

FIGURE 120

NOTE: HYDROGEN SUPPLY GAS
0.005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 121

TEST NUMBER 15 SHEET 2

NOTE: HYDROGEN SUPPLY GAS
0,005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 122

TEST NUMBER 15 SHEET 3

NOTE: HYDROGEN SUPPLY GAS
0.005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 123

TEST NUMBER 15 SHEET 4

NOTE: HYDROGEN SUPPLY GAS
0.005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 124

TEST NUMBER 15 SHEET 5

NOTE: HYDROGEN SUPPLY GAS
0.005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 125

TEST NUMBER 15 SHEET 6

NOTE: HYDROGEN SUPPLY GAS
0.005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 126

NOTE: HYDROGEN SUPPLY GAS
0.005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 127

NOTE: HYDROGEN SUPPLY GAS
0.005 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 128

TEST NUMBER 16 SHEET 1

NOTE: HYDROGEN SUPPLY GAS
0.01 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 129

TEST NUMBER 16 SHEET 2

NOTE: HYDROGEN SUPPLY GAS
0.01 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 130

TEST NUMBER 16 SHEET 3

NOTE: HYDROGEN SUPPLY GAS
0.01 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 131

NOTE: HYDROGEN SUPPLY GAS
0.01 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 132

TEST NUMBER 16 SHEET 5

NOTE: HYDROGEN SUPPLY GAS
0.01 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 133

TEST NUMBER 16

NOTE: HYDROGEN SUPPLY GAS
0.01 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 134

TEST NUMBER 16 SHEET 7

NOTE: HYDROGEN SUPPLY GAS
0.01 IN. LB. SEC² INERTIA LOAD ONLY
45° ACTUATOR BIAS

FIGURE 135

TEST NUMBER 17 SHEET 1

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 136

TEST NUMBER 17 SHEET 2

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 137

TEST NUMBER 17 SHEET 3

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 138

TEST NUMBER 17 SHEET 4

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 139

TEST NUMBER 17 SHEET 5

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 140

TEST NUMBER 17 SHEET 6

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 141

TEST NUMBER 17 SHEET 7

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 142

TEST NUMBER 17 SHEET 8

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 143

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 144

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 145

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 146

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 147

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 148

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 149

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 150

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 151

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 152

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 153

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 154

NOTE: LOW PRESSURE HYDROGEN SUPPLY GAS
FULL LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 155

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
200° F FLANGE TEMPERATURE

FIGURE 156

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
200° F FLANGE TEMPERATURE

FIGURE 157

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
200° F FLANGE TEMPERATURE

FIGURE 158

TEST NUMBER 20 SHEET 4

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
200° F FLANGE TEMPERATURE

FIGURE 159

TEST NUMBER 20 SHEET 5

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
200° F FLANGE TEMPERATURE

FIGURE 160

TEST NUMBER 20 SHEET 6

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
400° F FLANGE TEMPERATURE

FIGURE 161

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
400° F FLANGE TEMPERATURE

FIGURE 162

TEST NUMBER 20 SHEET 8

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
400° F FLANGE TEMPERATURE

FIGURE 163

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
400° F FLANGE TEMPERATURE

FIGURE 164

TEST NUMBER 20 SHEET 10

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
400° F FLANGE TEMPERATURE

FIGURE 165

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
400° F FLANGE TEMPERATURE

FIGURE 166

TEST NUMBER 20 SHEET 12

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
600° F FLANGE TEMPERATURE

FIGURE 167

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
600° F FLANGE TEMPERATURE

FIGURE 168

TEST NUMBER 20 SHEET 14

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
600° F FLANGE TEMPERATURE

FIGURE 169

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
600° F FLANGE TEMPERATURE

FIGURE 170

TEST NUMBER 20 SHEET 16

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
600° F FLANGE TEMPERATURE

FIGURE 171

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
800° F FLANGE TEMPERATURE

FIGURE 172

TEST NUMBER 20 SHEET 18

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
800° F FLANGE TEMPERATURE

FIGURE 173

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
800° F FLANGE TEMPERATURE

FIGURE 174

TEST NUMBER 20 SHEET 20

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
800° F FLANGE TEMPERATURE

FIGURE 175

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
800° F FLANGE TEMPERATURE

FIGURE 176

TEST NUMBER 20 SHEET 22

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
800° F FLANGE TEMPERATURE

FIGURE 177

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
800° F FLANGE TEMPERATURE

FIGURE 178

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS

FIGURE 179

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
970° F FLANGE TEMPERATURE

FIGURE 180

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 181

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 182

TEST NUMBER 20 SHEET 28

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 183

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 184

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 185

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 186

TEST NUMBER 20 SHEET 32

NOTE: HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 187

THERMAL GRADIENT EFFECT TPCV ACTUATOR THERMAL SHOCK TEST
TEST 21

- NOTES: 1. 4 CPS $\pm$ 2° AT 45°
2. 1000°F FLANGE TEMPERATURE
3. AT T = 0, SUPPLY GAS FROM AMBIENT TO -270°F
4. AT T = +35, TEMPERATURES STABILIZE

FIGURE 188

TEST NUMBER 21 SHEET 1

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 189

TEST NUMBER 21 SHEET 2

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 190

TEST NUMBER 21 SHEET 3

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 191

TEST NUMBER 21 SHEET 4

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 192

TEST NUMBER 21 SHEET 5

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 193

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 194

TEST NUMBER 21 SHEET 7

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 195

NOTE. -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 196

TEST NUMBER 21 SHEET 9

NOTE: -270° F HYDROGEN SUPPLY GAS
NO LOAD CONDITION
45° ACTUATOR BIAS
1000° F FLANGE TEMPERATURE

FIGURE 197

FIGURE 198

FIGURE 199

FIGURE 200

FIGURE 201

FIGURE 202

FIGURE 203

FIGURE 204
AG-21 ACTUATOR VIBRATION TEST
WITH VIBRATION PICKUP LOCATION SHOWN