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REON

ROCKET ENGINE OPERATIONS - NUCLEAR

REPORT NO. RN-S-0073

to

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

BENDIX TPCV ACTUATOR PRESENTATION

A Presentation to SNPO-C

NERVA PROGRAM

CONTRACT SNP-1

19 MARCH 1964

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AZUSA, CALIFORNIA

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Atomic Energy Act of 1954

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SECTION A

BENDIX TPCV ACTUATOR
DESIGN AND DEVELOPMENT HISTORY

Figure 1 is a functional block diagram representing the Bendix Turbine Power Control Valve Actuator. This control loop consists of a magnetic amplifier, a mechanical actuator, and a turbine power control valve. A feedback potentiometer is used to close the servo loop at the input of the magnetic amplifier. The position-indicating potentiometer is supplied for instrumentation readout. The actuator is pneumatic, operating on low-temperature hydrogen gas.

TPCV FUNCTIONAL BLOCK DIAGRAM

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Figure 2 is a schematic of the turbine power control valve actuator. It consists of a torque motor, a two-stage spool valve, a gear motor, and a nutating transmission. The transmission output shaft drives the turbine power control valve. Also noted in this figure are the two potentiometers, the two zero-position-indicating switches, and a dynamic seal which prevents hot gas from entering the actuator. The turbine power control valve has no shaft seal to protect the actuator.

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SCHEMATIC TPCV ACTUATOR

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Figure 3 shows a Bendix NTB series TPCV actuator mounted on a turbine power control valve. The general configuration of the assembly is shown. The valve flanges are only partially machined.

NTB SERIES, TPCV ACTUATOR AND VALVE

Side View

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Figure 4 is identical to Figure 3, except that the actuator and valve assembly is viewed from an angle which allows the inside of the TPCV to be shown. The valve is a butterfly configuration, and is currently designed to use a metal piston ring seal.

NTB SERIES, TPCV ACTUATOR AND VALVE

View Through Valve

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GENERAL INFORMATION

Figure 5 shows the turbine power control valve assembled with an NTC series TPCV actuator. The NTC series of actuators are the first built to withstand the high temperatures of the turbine power control valve.

NTC SERIES TPCV ACTUATOR AND VALVE

NTC SERIES TPCV ACTUATOR AND VALVE

NTC SERIES, TPCV ACTUATOR AND VALVE

Side View

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SECTION B

HIGH TEMPERATURE AND THERMAL SHOCK
TESTING

NTC-2 actuator S/N 11 actuator completed 70 hours of testing
at high temperature and with thermal shock.

Figure 6 shows an NTC series TPCV actuator mounted on the thermal test stand. The purpose of this stand is to electrically heat a valve simulator to allow high temperature testing of the actuator. Below the actuator and valve simulator heater is another heater which pre-heats the seal gas before it is applied to the base of the actuator.

NTC SERIES, TPCV ACTUATOR ON THERMAL TEST STAND

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Figure 7 presents data taken during the thermal tests run on Bendix Actuator NTC-2 Serial Number 11. Temperatures were stabilized five times, and data were recorded, as indicated by the five test numbers on the graph. The graph shows the increasing spread of thermal gradients in the actuator as higher valve temperatures are simulated. During these tests, minimum actuator flow was used to give minimum cooling, and, no limiting temperatures were reached.

NTC SERIES, TPCV ACTUATOR THERMAL TESTS

ACTUATOR SUPPLY GAS - AMBIENT NITROGEN
BENDIX NTC-2 ACTUATOR SERIAL NUMBER 11

TEST DATE: 8 NOVEMBER 1963

Supply Gas Pressure	150 PSIG
Exhaust Gas Pressure	15 PSIA
Seal Gas Pressure	595 PSIG
Position	30 to 65 DEG.
Frequency	0.1 CPS
Amplitude	± 2 DEG.

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Figure 8 presents data taken from a thermal shock test. The flange of the valve simulator was brought to 800°F and the actuator supply gas was switched from ambient to cold. Actuator performance was quite acceptable during this test. The test was concluded when temperature throughout the actuator stabilized.

NTC SERIES, TPCV ACTUATOR THERMAL SHOCK TEST

800°F Valve Flange Temperature

800°F VALVE FLANGE TEMPERATURE

ACTUATOR SUPPLY GAS-CRYOGENIC NITROGEN

BENDIX NTC-2 TPCV ACTUATOR - SERIAL NUMBER 11

TEST DATE: 25 NOVEMBER 1963

Supply Gas Pressure	150 PSIG
Exhaust Gas Pressure	15 PSIA
Seal Gas Pressure	595 PSIG
Position	45 DEG.
Frequency	8 CPS
Amplitude	± 2 DEG.

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Figure 9. Data taken from a thermal shock test similar to that shown in Figure 8. The valve simulator was brought to 1000°F and the actuator was switched to cold supply gas. After temperature stabilization, the valve-simulator and seal-gas electric heaters were turned off, permitting the actuator to cool further. After approximately an hour, some warpage of the actuator's dynamic seal occurred, increasing its leakage flow rate. At about this time the actuator had cooled to a point where droplets of liquid nitrogen appeared in the exhaust gas.

NTC SERIES, TPCV ACTUATOR THERMAL SHOCK TEST

1000°F Valve Flange Temperature

1000°F VALVE FLANGE TEMPERATURE

ACTUATOR SUPPLY GAS-CRYOGENIC NITROGEN

BENDIX NTC-2 TPCV ACTUATOR - SERIAL NUMBER 11

TEST DATE: 25 NOVEMBER 1963

Supply Gas Pressure 150 PSIG
Exhaust Gas Pressure 15 PSIA
Seal GPS Pressure 595 PSIG
Position 45 Deg
Frequency 8 CPS
Amplitude ± 2 Deg.

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Figure 10. The increased seal leakage which occurred during the 1000°F thermal shock test of Figure 9 is shown in Figure 10. Flow rate is plotted as a function of identical time scale. The monitoring of the leakage continued until the valve seal cavity pressure could no longer be held above 500 psi. Additional flow could not be supplied to the cavity due to the small size of the seal leakage flow measuring orifice.

NTC SERIES, TPCV ACTUATOR SEAL LEAKAGE

DURING THE 1000°F VALVE FLANGE TEMPERATURE
THERMAL SHOCK TEST

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SECTION C

CRYOGENIC ENDURANCE TESTING WITH SIMULATED LOAD

NTC-2 actuator S/N 13 actuator completed 100 hours of operation at low temperatures and with a simulated load. The dynamic shaft seal failed after 45 hours and was removed from the actuator.

Figure 11 portrays TPCV actuator NTC-2 Serial 13 on a load stand for cryogenic endurance tests. Four pictures are arranged vertically to show two views of the actuator. The upper pictures were taken during the test when the actuator was cold, while the lower ones show the same views at ambient temperature. Low temperature did not warp this actuator's shaft seal enough to change its leakage rate.

NTC SERIES, TPCV ACTUATOR ON CRYOGENIC ENDURANCE TEST STAND

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Figure 12 presents the load stand schedule which was used to simulate the turbine power control valve during the cryogenic endurance testing.

TPCV ACTUATOR CRYOGENIC ENDURANCE LOAD SCHEDULE

BENDIX NTC-2 ACTUATOR SERIAL NUMBER 13

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Figure 13. After 45 hours of cryogenic testing the actuators output shaft seal failed. The failure was noted when the output position became jerky and irregular. The actuator was restored to satisfactory operation when seal pressure was removed. Figure 13 shows the seal and its rubbing surface on the output shaft potentiometer drive gear. Note that the flame plateing is worn from the seal. This seal did not change its low leakage flow rate when it failed. The test was continued with the seal removed and the potentiometer gear replaced, although seal-gas pressure was not used for the remainder of the test. After 90 hours cryogenic test time the actuator was disassembled to note its condition.

FAILED SHAFT SEAL

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Figure 14 shows the actuator servo valve at the end of cryogenic testing. No special wear marks were visible on the valve spool.

SERVO VALVE AFTER CRYOGENIC ENDURANCE TEST

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Figure 15 shows parts of the TPCV actuator air motor after cryogenic endurance testing. Wear marks may be seen on the air motor gear teeth, on the air motor spline teeth, and on the inside walls of the air motor case.

AIR MOTOR AFTER CRYOGENIC ENDURANCE TEST

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Figure 16 shows the transmission nutating gears and diaphragm at the end of cryogenic testing. Very minor marks may be seen on the nutating gears. A piece of safety wire from the shaft assembly is shown resting on the diaphragm. Marks made by the safety wire may also be seen on the diaphragm, although it is not measurably damaged.

TRANSMISSION GEARS AFTER CRYOGENIC ENDURANCE TEST

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SECTION D

VIBRATION TESTING

NTB actuator S/N 6 was test vibrated to peak "G" levels successfully.

NTC actuator S/N 11 was test vibrated to peak "G" levels, but experienced torque motor failure. Apparently the failure was due to loose mounting of the air motor to the transmission; thus transmitting a high "G" load gain factor to the air motor.

NTC series actuator vibration testing will continue.

Figure 17. Bendix Model NTB-3, TPCV actuator S/N 6, was vibration-tested at their facility. Figure 17 presents the vibration levels scheduled for test as compared with those levels actually attained. It should be noted that the obtained vibration levels are rms values and would have to be multiplied by the square root of 2, in order to obtain peak values. This vibration test met the requirements of AGC NDC-51.

NTB SERIES, ACTUATOR VIBRATION LEVELS

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G - LEVELS FOR TESTS B - C - D AND E

ACTUAL G LEVELS (RMS) MAINTAINED DURING VIBRATION SCHEDULE III

ACTUAL G LEVELS (RMS) MAINTAINED DURING VIBRATION SCHEDULES I AND II

Vibration Levels

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Figure 18 presents a table listing the test-run performance before and after the vibration test, to the schedule in Figure 17. No malfunction of the actuator occurred.

COMPARISON OF INITIAL AND FINAL VIBRATION TEST DATA **CONFIDENTIAL**

Test Run	Specification Requirement	Before Vibration (Test A)	After Vibration (Test G)
Dynamic Resolution	± 0.5 degree with a triangular input signal of $\pm 5^\circ$ at a 1 degree per second ramp	± 0.13 degree	± 0.18 degree
Transient Response	15% overshoot 0.3 second(maximum) to $\pm 5\%$ of ordered stop	21% overshoot 0.14 sec. settling time	18.7% overshoot 0.12 sec. settling time
Frequency Response 90 degree phase shift 180 degree phase shift	With input of ± 2 degree Sine wave, 90-degree phase shift and should occur @ 8 cps (minimum)	90 degree @ 12 cps 180 degree @ 21 cps	90 degree @ 12 cps 180 degree @ 21 cps

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NTC SERIES, TPCV ACTUATOR AFTER VIBRATION TEST

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Figure 20. TPCV actuator S/N 11, torque motor, which failed during vibration testing, is shown disassembled in Figure 20. One permanent magnet is broken. All permanent magnets had become unsoldered and were loose. The torque motor armature came loose from its "Torsion Spring and Torque Tube" mounting and continued to vibrate, breaking the flapper and damaging the torque motor cover.

TORQUE MOTOR DISASSEMBLED AFTER VIBRATION TEST

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Figure 21 indicates the location of the torque motor armature, torsion springs, torque tube, and flapper with respect to a completely assembled torque motor.

ASSEMBLED TORQUE MOTOR WITH PARTS FROM VIBRATION TEST MOTOR

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SECTION E

RADIATION TESTING

NTB actuator S/N 10 actuator successfully completed a 50-hour and a 100-hour radiation test. This actuator has accumulated over 200 hours test time.

Figure 22 shows breadboard actuator S/N 10 mounted on the test stand in preparation for radiation testing at the Nuclear Aerospace Research Facility operated by General Dynamics, Fort Worth, Texas. This unit underwent a 50-hour radiation test, followed by a 100-hour radiation test. The actuator operated without difficulty.

NTB SERIES SET UP FOR RADIATION TEST

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Figure 23 is a Bodie plot of performance for Actuator S/N 10 before and during the 100-hour radiation test. Note that the performance is above specification, not greatly affected by radiation, and that the actuator has now reached a total operating life of 128 hours.

CLOSED LOOP FREQUENCY RESPONSE

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Pre-Test and Early Test

CLOSED LOOP FREQUENCY RESPONSE

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Figure 24 is a Bodie plot showing performance of actuator X/N 10 during the 100-hour radiation test (but at a later time than Figure 23) and the operation of the actuator after the 100-hour radiation test. Total time on the actuator is now 217 hours. It is still operating quite well but is slightly below specification performance. This is considered good performance for this extreme duration of test time, even when it is noted the unit was operated without external load. The load sensitivity of the actuator is not great; actuator performance is slightly better when operated on hydrogen, instead of the helium, as used in this test.

CLOSED LOOP FREQUENCY RESPONSE

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Late Test and Post-Test

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SECTION F

REMAINING PROBLEM AREAS
AND SOLUTIONS OFFERED BY THE
NTD SERIES ACTUATOR DESIGN

Figure 25. TPCV actuator, NTC-2, S/N 12, began to operate erratically not long after it was received at Aerojet-General. On disassembly it was noted that a micro-switch actuating lever had broken and caught in the potentiometer gearing. The actuating lever was serrated by the gearing and one pot shaft was bent approximately 10° . The repaired actuator and the pieces of the micro-switch actuating lever are shown in Figure 25. Because of its subsequent behavior, Actuator 12 was again disassembled, and at that time found to have a dragging air motor and rough spots in the transmission. It will be returned to Bendix for overhaul.

TPCV ACTUATOR NTC-2, SERIAL 12, WITH BROKEN MICROSWITCH PARTS

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Figure 26 is a cross-sectional diagram of the Bendix NTD-1 actuator design. This is the newest actuator design and should help us with several problem areas:

1. The actuator dynamic seal is a two-piece unit giving the seal vendor control of both seal surfaces, each of which will be flame-plated. This replaces the old design in which warpage of the seal was possible.
2. There are no micro-switches. Micro-switches are purchased parts, and have caused several failures. They are therefore eliminated until a more definite need is established.
3. The potentiometers are placed in the top of the actuator to ease the temperature problem inherent in this type of equipment. The new method of mounting does not require potentiometer drive gears; thus, these parts are eliminated.
4. The torque motor and servo valve are mounted directly on the transmission beside the air motor. This shortens the actuator and eases the torque motor vibration problem.
5. The nutating gear diaphragm, in the transmission, is replaced by a multi-leaf spring to lower the stress level in this part.
6. There are still 6 bearings in the transmission. However, the small bearings have been removed. The new transmission has four large bearings and two extremely large diameter bearings; it is not expected that the large diameter bearing will present any problem as the speed will be 60 rpm maximum.

NTD-1 TPCV ACTUATOR DESIGN

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