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TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE
TURBINE POWER CONTROL VALVE DEVELOPMENT
AUGUST 1964

CONTRACT SNP-1

NERVA PROGRAM

MASTER

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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I. SUMMARY

The items listed below represent some TPCV development activities conducted under the NERVA program during CY 1964.

- Completed design modification of the four-inch TPCV to incorporate a valve shaft thrust bearing.
- Conducted proof and leak testing of the TPCV assembly.
- Completed fabrication of a bearing tester for use in simulating load and temperature conditions encountered by the bearings during valve operation.
- Conducted hot gas testing of the TPCV to evaluate the design integrity and to demonstrate the valve endurance capability. Completed valve modifications as required.
- Conducted bearing evaluation and endurance tests.
- Started fabrication of four TPCV assemblies.
- Prepared updated test plan and test request for hot gas testing of the Turbine Power Control Valve in the Aerojet-General Sacramento C-7 and H-4 test facilities.

A detailed discussion of each summary item follows.

II. DISCUSSION

A. SHAFT THRUST BEARING DEVELOPMENT

The early model, four inch, canted-shaft TPCV assemblies (P/N 278100-29) when subjected to moderate pressure upstream of the gate, suffered indentations on the body bore which were caused by the vertical component of the upstream pressure force shifting the gate into contact with the valve body. This problem was inherent in the basic design. A modification to existing valve bodies was initiated to install a carbon thrust bearing between the gate shaft and the shaft housing, thus transmitting the shaft end load through the thrust bearing, into the valve body. Subsequent pressure and torque tests on the modified valve (P/N 278100-39) demonstrated a satisfactory design correction. Figure 1 presents a comparison sketch of the original and improved design.

B. PROOF AND LEAK TEST

1. Proof Test

A special proof test of TPCV inconel body (P/N 281714-1, S/N 006) was required to investigate the propagation of a suspected weld crack. The unit was subjected to a ten-cycle proof pressure test using 1340 psig water. Post-test X-ray showed that the defective area had increased slightly. Based on the uncertainty of the weld integrity, this valve body will not be used in high pressure applications. A dimensional inspection indicated no apparent permanent distortion had resulted from the proof testing. The normal proof test requirement is one cycle to 1200 psig pressure.

2. Leak Test

A test to determine gas leakage through the TPCV while in the closed position was conducted in the cryogenic laboratory.

The leak-test program was divided into three basic operations; calibration of the Fisher-Porter Flowrater, correlation of Flowrater readings at various flow rates, and conducting actual leakage tests on a TPCV assembly P/N 278100-9, S/N 005.

a. Calibration of the Flowrater (S/N 740-6955) was accomplished by flowing GN_2 , He, and GH_2 through a critical flow nozzle at various upstream pressures while recording Flowrater readings. The purpose of using the GN_2 and He, in addition to hydrogen, was to gain correlation data between the three gases. If sufficient correlation did exist, the non-flammable gases could be used in the development program leakage testing, thus eliminating the hazards associated with GH_2 .

b. Correlating the Flowrater readings at various leakage rates through the TPCV was accomplished by maintaining a constant 25 psig upstream pressure while varying the TPCV gate position. Gas temperature was corrected to 60°F.

Based upon the data obtained from the flow tests, using the three gases, it was observed that a straight line would represent the resulting curve of flowrater reading vs gas flow through the valve. A straight line is estimated to be within 10% of the actual curves. Figure 2 presents the gas flow rate vs Flowrater data for the three gases.

c. TPCV leakage data were obtained for the three gases. The test sequence involved pressurizing the feed line upstream of the TPCV to 25 psig and observing the gas flow rate through the meter which was situated downstream of the TPCV.

The leak rates were as follows:

<u>Gas</u>	<u>Inlet Press</u>	<u>% Flowrater Reading</u>	<u>Leakage (CFM)</u>
N_2	25 psig	50	1.05
He	25 psig	46	2.65
H_2	25 psig	48	3.60

Further TPCV leakage testing was performed to determine the sensitivity of the TPCV gate to the zero position (gate full closed). It was determined that if the gate was misaligned $\pm 2^\circ$ from the zero position, the leakage would increase approximately 50%. Dimensional tolerance "stackup" can result in a misalignment of $\pm 1^\circ 35$ -minutes.

An attempt was made to reduce the gate rotational sensitivity by grinding a spherical seat on the TPCV body bore such that the piston ring contact with the body wall would be sustained through a longer arc during gate rotation. A spherical seat was ground on one valve body. Subsequent leakage tests revealed that rotational sensitivity was improved to $\pm 4^\circ$. However, leakage rates and torque requirements were higher because of seat surface imperfections resulting from the grind operations. No further attempts at grinding spherical seats were made because of the limited supply of valve bodies.

C. BEARING TESTER FABRICATION

The TPCV bearing tester P/N 9692-63-006 was designed and fabricated to simulate the temperature and load conditions encountered by the bearings during engine operation.

Temperature capabilities to 1400°F and bearing loads to 6,780 pounds have been demonstrated. The bearing load is representative of a 120 psi differential pressure across the valve gate.

A hydraulic actuator provides zero to 90° rotary motion of the bearing shaft. A hydraulic ram applies a load normal to the bearing shaft at a point midway between the bearings.

Gas flow ports are provided to allow purging of the bearing cavity with hydrogen gas. A resistance-type heating element provides the temperature environment to the bearing. Figure 3 shows the assembled bearing tester.

D. HOT GAS TESTS

The C-7 test facility design featured a 2-inch diameter, hot gas diversion valve, to bypass the gas generator products around the TPCV as required so that TPCV inlet pressure would be constant, regardless of gate position. The bypass valve position was controlled by a closed loop electrical servo system which sensed differential pressure across the TPCV. Due to slow response of the servo system, and the high sensitivity of the diversion valve with respect to position, the servo control system proved to be inadequate for controlling TPCV inlet pressure. The inadequacy was evidenced by extreme variations of inlet pressure to the TPCV on the first test which resulted in rupture of the gas system burst diaphragm. The rupture resulted from excessive pressure at the TPCV inlet. Subsequent tests were performed using independent position control over each valve while monitoring inlet pressure to the TPCV. The manual control system requires swift response of the test personnel operating the valve position switches to insure a constant inlet pressure to the TPCV while cycling is in progress. However, this method of valve position control has proven to be satisfactory.

The first hot gas test on the four inch TPCV (1.2-03NNV-001) assembly S/N 005 was conducted on 5 February 1964 using H_2-O_2 combustion products from a modified second stage Titan gas generator.

The test was terminated after 46-seconds due to the rupture of the hot gas system burst disc. Valve inlet pressures and temperatures were variable from 500 to 670 psig and 1050 to 1175^oF respectively. The valve butterfly, initially full open, was cycled two times between 72^o and 34^o. The burst disc ruptured midway through the third butterfly cycle due to extreme inlet pressure at the TPCV.

The high inlet pressure resulted from slow opening response of the diversion valve which would normally allow escape of the gas generator products when the TPCV is cycling toward the closed position.

Detailed analysis of the test data was inconclusive because of the variable inlet conditions to the test valve. However, the data did reveal that a

differential pressure of 350 psi across the TPCV gate existed for approximately four seconds while the valve temperature was 1100°F. Post-test visual inspection of the valve revealed no apparent damage resulting from the excessive differential pressure.

Test 1.2-03-NNV-002 was conducted 24 February 1964 for a duration of 65-seconds. Again TPCV S/N 005 was the test valve. The gas generator output was erratic in temperature and pressure due to a leaking pressure regulator in the oxidizer tank pressurization circuit.

Manipulation of the hot gas diversion valve position was not effective in maintaining constant TPCV inlet conditions due to the variable pressure output of the gas generator. Inlet pressure to the TPCV varied from 350 psig to 575 psig and temperatures recorded were 760 - 1375°F. Valve flow characteristics could not be determined because of extreme variations in test data.

Test 1.2-03-NNV-003 (valve assembly S/N 005) was terminated at 12-seconds because of a gas generator failure and subsequent test stand fire.

The test valve suffered no apparent damage from the fire but post-test inspection found the valve gate jammed on the 20° position. Jamming was apparently caused by a piston ring emerging from the ring groove during the thermal expansion, thus obstructing the freedom of gate rotation.

An investigation to determine the cause of the gas generator failure revealed the following:

1. On test run 002, the shear pin (fabricated from 0.140 diameter drill rod) between the TPCV actuator and gate shaft had sheared. Test records from run 002 show TPCV gate rotation occurring without any change in differential pressure across the valve. The valve position trace was taken from a potentiometer mounted on the hydraulic actuator output shaft; therefore, a shear pin failure went undetected, as the position trace indicated gate rotation both during and after run 002.

Data of differential hydraulic pressure used to drive the valve actuator also indicated a peak pressure 300 psi. Normal actuation pressure required to rotate the valve is 15-30 psi.

2. The exact gate position at the start of run 003 is not known. However, differential pressure across the valve was 80 psi almost immediately after FS_1 thus indicating a position other than full open, even though the position trace showed the valve to be in the full-open position.

At $FS_1 + 4$ -seconds, differential pressure across the TPCV immediately increased to 475 psi, without application of hydraulic pressure to the valve actuator.

Based on the above, it was concluded that the TPCV butterfly was free to rotate about its shaft because of shear pin failure incurred during test run 002.

3. The test stand gas generator fuel system installation did not have a properly sized orifice between the fuel supply tank and the gas generator fuel valve which resulted in the following events:

Upon closure of the TPCV butterfly, gas pressure upstream of the TPCV increased to a level which approached that of fuel tank pressure resulting in a decreased fuel flow. The resulting "oxidizer rich" condition caused the gas generator temperature to increase to approximately 2400°F. Burn-through of the gas generator followed. A signal was made to open the hot gas diversion valve but this could not be accomplished in sufficient time to prevent the sudden pressure rise in the gas generator.

4. To prevent re-occurrence of the events causing the gas generator destruction, the following corrective measures were implemented.

a. A suitably sized orifice was installed in the gas generator fuel circuit to allow a higher fuel tank operating pressure, thus eliminating the possibility of pressure equalization between the fuel tank and the gas generator combustion chamber.

b. TPCV gate rotation not to be initiated prior to $FS_1 + 30$ -seconds. This requirement is to allow temperature stabilization within the TPCV.

c. Hydraulic actuation pressure required to rotate the TPCV gate is not to exceed 150 psi. This requirement limits the valve shaft torque input to approximately 520 inch-pounds.

d. Automatic shutdown is to be activated if differential pressure across the TPCV exceeds 575 psi.

e. Prior to each test, a functional check of the TPCV gate rotation is performed consisting of actuating the TPCV to the closed position, pressurizing the line upstream of the valve with GN_2 , locking up the pressurant gas, and monitoring pressure decay rate. The decay rate is not to exceed an established normal leakage rate.

f. Test personnel were advised to observe closely the ΔP across the valve relative to gate position.

g. Manual kill parameters were established for maximum allowable valve inlet pressure and temperature.

Test run 1.2-03-NNV-004 (valve S/N 005) was conducted on 25 May 1964. Duration of the run was 44-seconds. The TPCV was actuated toward the closed position at $FS_1 + 14$ -seconds. The gate rotated approximately 10° at which time the shear pin failed.

Torque input to the valve shaft increased to approximately 1100 inch-pounds prior to shear pin failure.

Thermocouples attached to the TPCV body exterior indicated that temperature stability had not been achieved prior to gate rotation.

Visual inspection indicated that interference between the gate and the valve-body bore had been present presumably during the transient thermal conditions of start up.

A thermal analysis to determine expansion rates within the valve was prepared and submitted for computer analysis. Data points were taken at one-second intervals for a duration of 100-seconds. The initial valve temperature was assumed to be ambient. Three separate cases were analyzed as follows:

	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>
Gas	H ₂	H ₂	O ₂ -H ₂
Temperature	1140°R	1760°R	1760°R
Pressure	450 psi	450 psi	450 psi
Flow Rate	4.5 lb/sec	4.5 lb/sec	4.5 lb/sec

The analysis showed that dimensional interference between the valve gate and body could occur within the first 20-seconds of temperature application, and that thermal expansion of the valve body lagged the gate expansion rate. The analysis also indicated that transient thermal gradients are more severe when flowing O₂ - H₂ than for pure GH₂.

Test 1.2-03-NNV-005 was conducted on 28 May 1964. The test was terminated at FS₁ + 50-seconds because of test facility fire caused by a small hydrogen leak in the gas generator fuel piping system. Water deluge was actuated to prevent heat damage. Post-test inspection revealed no fire damage to the test hardware; however, the main flow line upstream and downstream of the test valve was distorted. Replacement of the pipe line was required; also, a modification to the pipe restraining system was made.

The TPCV shear pin again failed shortly after the completion of one cycle of gate rotation. Torque required to rotate the gate was not beyond the specified limit.

Post-test inspection revealed that one piston ring moved out of its mounting, the groove. See Figure 4. This valve assembly incorporated "pinned" piston rings, in which case, a notch had been machined on the inside diameter of each ring at a radial location near the ring gap. A hole was drilled through the gate to allow the installation of a pin to prevent ring rotation about the gate. This design proved faulty since the ring was still allowed unrestrained radial growth when the gate was in the open position.

The ring protrusion remained after cooldown because of slight rotation of the ring about the gate during the test which caused misalignment of the ring notch with the pin. After ring rotation the inside diameter surface of the ring was then riding on top of the pin. Figure 4 shows the piston ring protruding from the ring groove.

Prior to test run 006 the following modifications were performed on test valve S/N 00007.

- a. A 0.140 diameter Inconel shear pin was installed in the valve assembly, replacing the 0.140 diameter drill rod material. This increased the torque capability at elevated temperatures.
- b. The clearance between the gate and the body bore was increased in the area adjacent to the two gate shafts by machining the gate. Increased clearance was required to assure no contact between the gate and the valve-body bore during transient thermal expansion or contraction of valve components.
- c. The method of retaining the piston ring on the valve gate was changed from a notched piston ring to a square hole machined in the rings, thus limiting radial travel of the ring with respect to the gate ring groove.
- d. The piston ring sealing edge was machined to a convex surface to decrease ring binding on the body bore.

e. A thermocouple was installed in the actuator-to-valve-adapter cavity for the purpose of monitoring gas temperature adjacent to the actuator.

Test 1.2-03-NNV-006 was conducted 24 June 1964 on valve S/N 0007. The test duration was 241 seconds during which time the valve gate was cycled 25 times between gate positions of 54° and 72°. The nominal valve inlet temperature and pressure were 1200°F, and 520 psig respectively. The maximum temperature within the hydraulic actuator cavity was 246°F. Hydraulic pressure required to open the TPCV gate did not exceed 28 psi. Closing pressure required was 10 psi. The actuation pressure values correspond to 98 inch-pounds opening torque and 35 inch-pounds closing torque. Post-test inspection of the valve assembly showed it to be in excellent condition. Figure 6 shows the valve mounted in the test facility.

The valve remained in the test facility for additional testing, to demonstrate 10-minutes of operation.

The hot gas diversion capability was lost during this test because of insufficient hydraulic pressure to actuate the diversion valve. The valve, which is normally closed at test start-up, remained closed through the test. The degree to which the TPCV could be closed was limited by upstream pressure, since the diversion valve was incapable of bypassing the gas generator combustion products.

TPCV S/N 0007 received additional testing (1.2-03-NNV-007) on 27 June 1964. The valve had not been removed from the test stand since the previous test.

Duration time for run 007 was 119-seconds, in which time the valve was rotated from the full open position to the 34° position and then returned toward full open.

The test was terminated because of an unprogrammed closure of the gas generator fuel valve, which resulted in erosion and fire damage to the gas generator,

hot gas diversion valve, instrumentation, and line system upstream of the turbine power control valve. Repair of the test facility is scheduled for completion on 1 August 1964. Figure 5 presents a valve characteristic curve based on data obtained from the test series.

A computer program is presently being formulated to permit a more detailed analysis of test data and also to predict GH_2 flow characteristics of the valve. Computer data will provide the values for curves showing resistance coefficient versus gate position and gate forces versus gate position.

E. BEARING EVALUATION AND TESTS

Several candidate roller bearings were selected for evaluation, among those were A-286 and Inconel X bearing materials. Both bearings failed to qualify when subjected to tests simulating temperature and load. Galling of the rollers and races of the Inconel X bearing occurred within the first 10-minutes of testing at loads simulating 12.5 psi differential pressure across the gate at a temperature of 750°F. A-286 bearings also failed in qualification tests because of the rollers jamming and galling on the races.

A series of tests was completed on titanium carbide roller bearings, with a total accumulated running time of eight hours at rated temperature, up to twice design operating loads (120 psi ΔP across the gate) and cycling rates from 0.5 to 6 cycles per second. Figure 7 shows the bearing installed in the tester and operating.

Testing was terminated because a roller became jammed in the slot that was cut in the bearing end-plate for the purpose of observation and photographic documentation of the bearing in operation. The bearing was operable at the conclusion of the test. Figure 8 shows the bearing post-test condition and the test conditions to which the bearing was subjected.

F. VALVE FABRICATION

Detail drawings of the TPCV were updated to reflect the required design changes which were made evident through test experience.

Fabrication orders were placed for the procurement of four valve assemblies conforming to P/N 278100-49. Scheduled delivery is for two valve assemblies in August and two in September.

G. TEST PLAN AND TEST REQUEST FOR HOT GAS TESTING OF THE TURBINE POWER CONTROL VALVE IN C-7 AND H-4 TEST FACILITIES

The test plan (7450-001) for conducting hot gas flow tests on the TPCV was published. The test plan reflects the operational requirements of the test valve and the facility requirements for both the "C" area gas generator system and the "H" area hot hydrogen facility.

The test request (control number 2623) was updated to supersede past requirements and incorporate changes found necessary from past test experience.

III. CONCLUSIONS

Hot gas testing of the Turbine Power Control Valve, although limited, has permitted the compilation of useful data and has demonstrated operational capabilities. The majority of design problems, made apparent during the tests series, have been resolved, but additional hot gas tests are necessary to prove the present design.

It is expected that the forthcoming improved C-7 test facility will permit a substantial increase in test data acquisition.

Bearing tests performed to date indicate a promising design, but additional testing in a hydrogen environment is required.

Leakage tests, to date, have been extremely limited. However, fabrication of a leak test facility in the cryogenics laboratory is in progress. The facility will permit hydrogen leak rate measurements at design temperature.

TPCV P/N 278100

-29 ASSY.
ORIGINAL DESIGN

RETAINING BOLT

END CAP

-39 ASSY

THRUST BEARING MODIFICATION

FIGURE 1

FIGURE 2

FIGURE 3

TURBINE POWER CONTROL VALVE
INLET SIDE SHOWING RING
PROTRUDING FROM GROOVE ON GATE
POST-TEST CONDITION
TEST 1.2-03-NNV-005 S/N 007

FIGURE 4

NERVA TURBINE POWER CONTROL VALVE P/N 278100-49
 LOSS COEFFICIENT VS GATE POSITION
 DATA FROM TESTS 1.2-03-NNV-001 THRU 007

FIGURE 5

FIGURE 6

TPCV ROLLER BEARING P/N 281724
OPERATING IN BEARING TESTER.
END VIEW SHOWING TWO ROLLERS AND INNER RACE.
TEMPERATURE AT 1400°F

FIGURE 7

FIGURE 8