NUCLEAR DIVISION

RN-TD-0058

FINAL REPORT
PUMP DISCHARGE SHUTOFF VALVE RANDOM
VIBRATION TESTING

NERVA PROGRAM

CONTRACT SNP-1

JUNE 1969

NUCLEAR ROCKET OPERATIONS

TECHNICAL DOCUMENT CENTER
Nuclear Rocket Operations

DOC. NO. N-1770

AGCS 0120-48

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

**AEROJET
GENERAL**

RN-TD-0058

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**FINAL REPORT
PUMP DISCHARGE SHUTOFF VALVE RANDOM
VIBRATION TESTING**

NERVA PROGRAM

CONTRACT SNP-1

NUCLEAR ROCKET OPERATIONS

JUNE 1969

CLASSIFICATION CATEGORY

UNCLASSIFIED

CR Snyder
CLASSIFYING OFFICER

5-26-69
DATE

AEROJET - GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

5

RN-TD-0058

FINAL REPORT

PUMP DISCHARGE SHUTOFF VALVE RANDOM
VIBRATION TESTING

A. V. Lundback

C. R. Snyder, Manager
Engine Component Section
Engineering Department
Nuclear Rocket Operations

G. S. Kaveney, Manager
Structures
Engineering Department
Nuclear Rocket Operations

I. L. Odgers, Manager
Engineering Department
Nuclear Rocket Operations

CONTENTS

	<u>Page</u>
I. Introduction	1
II. Test Component	2
III. Test Equipment, Instrumentation, Setup and Fixtures	2
IV. Test Procedures	2
V. Test Results	3
VI. Discussion	16
VII. Conclusions	29
VIII. References	31

TABLES

<u>No.</u>		<u>Page</u>
1	Phase II Post Vibration Functional Cycle Tests	6
2	Phase III Post Vibration Functional Cycle Tests	12
3	PDSV Equivalent Run Time Data	17

FIGURES

<u>No.</u>		<u>Page</u>
1	Phase II Longitudinal Endurance Test Responses	4
2	Phase II Radial Endurance Test Responses	7
3	Phase II Tangential Endurance Test Responses	9
4	Phase III Tangential 40-Minute Endurance Test Responses	11
5	Phase III Longitudinal 40-Minute Endurance Test Responses	13
6	Phase III Radial 40-Minute Endurance Test Responses	14
7	Crack in Weld Joint of Liquid Nitrogen Drip-Shield	21
8	Lipseal Wear Contact Points (Arrow)	23
9	Butterfly-Gate Contact Points (Arrows)	24
10	Potentiometer Assembly Cross-Section	25
11	Potentiometer End Cover	27
12	Potentiometer Assembly, End Cover Removed	28

I. INTRODUCTION

Vibration tests of the pump discharge shutoff valve (PDSV, P/N 1114342-9, S/N 880005) have been completed.^{(1)*} The tests (Series 1187-A01-OV-031 through -044) were conducted at the Aerojet Sacramento Facility Test Area G Vibration Laboratory during the period 12 December 1968 through 1 January 1969 according to the requirements of Test Plan RN-TP-0101. The primary test objective was to demonstrate the ability of the PDSV to withstand the vibration environment and to operate satisfactorily after being subjected to random vibration loading (equivalent to 70 minutes of XE-engine operation) in each of three mutually perpendicular axes corresponding to the engine radial, longitudinal, and tangential axes. An additional objective of 70 minutes of "real" time testing was also included.

Data from transmissibility tests conducted at the Nuclear Rocket Development Station were combined with NRX/EST turbopump power spectral density (PSD) data to obtain engine-test predicted response curves for the PDSV in each of the three mutually perpendicular axes. The PDSV was mounted in a rigid fixture and excited by a Model C-70, M.B. shaker at input levels which would provide responses at the PDSV actuator that were in agreement with the test-plan envelope and engine-test predicted responses.

Interim Report 7770:M:6008 on the random vibration test results (issued 31 January 1969) is superseded by this report.

*Superscript number refers to references listed in Section VIII.

II. TEST COMPONENT

The valve tested was a five-inch, normally open, butterfly-type shutoff valve. Actuation to the closed position is accomplished by pressurizing the piston-type, integrally mounted, linear actuator using gaseous helium at 500 psig. During the opening cycle, pneumatic pressure and actuator springs return the valve to the open position. The valve tested was similar in configuration to the XE-Engine PDSV designed for a liquid hydrogen operating environment at 1200 psig nominal fluid pressure. Assembly of the valve was performed according to the requirements of Drawing No. 1114342-9 and Report 7770:AP:4096, Assembly Procedure, NERVA Five-Inch Butterfly Valve.⁽²⁾

III. TEST EQUIPMENT, INSTRUMENTATION, SETUP AND FIXTURES

The test equipment, instrumentation, setup, and fixtures used during the tests are of the same basic configuration as used during the pump discharge vent valve (PDVV) tests.⁽³⁾

IV. TEST PROCEDURES

The tests were conducted according to Plan RN-TP-0101⁽¹⁾ The test plan outlines the input requirements for the Phase I low-level sinusoidal and random tests and describes the general procedure for conducting Phases II and III.

The tests were performed using the same basic step-by-step procedure as outlined for the PDVV tests except that vibration damper tests were not conducted.⁽³⁾

V. TEST RESULTS

The initial Phase I sinusoidal vibration tests were conducted 12 December 1968. The valve was subjected to a sinusoidal frequency search over a frequency range of 20-1000 Hz using a constant 2g input. Sinusoidal sweep tests were performed in each of the three mutually perpendicular axes and response sweep plots were obtained for each response accelerometer for a given input. The response plot for radial input revealed a predominant resonant frequency at 160 Hz with a magnitude of 46g. The predominant resonant frequency for the longitudinal response with longitudinal input occurred at 180 Hz with a magnitude of 44g and the maximum tangential resonance occurred at 610 Hz with an amplitude of 52g.

Random vibration tests, using a $0.01 \text{ g}^2/\text{Hz}$ flat-spectrum input over a 100 - 1000 Hz frequency range, were also conducted as part of the Phase I tests. The PDSV was subjected to random vibration for approximately three minutes in each of the three mutually perpendicular axes. Some correlation between the maximum response points on the random vibration test results and the resonant points on the sweep test plots was evident. The maximum radial response for radial input was $0.6 \text{ g}^2/\text{Hz}$ and occurred at 125 Hz. The maximum longitudinal response for longitudinal input was observed at 170 Hz and was approximately $2.2 \text{ g}^2/\text{Hz}$. Maximum tangential response was recorded at 600 Hz and was approximately $0.7 \text{ g}^2/\text{Hz}$.*

The Phase II 30-minute longitudinal endurance test was conducted 20 December 1968. Test results are shown in Figure 1. Prior to the endurance test, two confirmation tests (a low-level test at approximately $0.003 \text{ g}^2/\text{Hz}$ and a high-level run at approximately $0.05 \text{ g}^2/\text{Hz}$ over a frequency range of approximately 200 to 750 Hz) were conducted to shape the input spectrum and to obtain the response that would best simulate the test-plan envelope and predicted

*To reduce the volume of enclosures required for this report and to provide a reference source for low-level test data, all data sheets for the Phase I tests and the Phases II and III test confirmation runs are presented in a data report issued 26 February.(4)

Figure 1 - Phase II Longitudinal Endurance Test Responses

engine-response plots. The longitudinal endurance test results disclosed some peak shifting between the engine-predicted and the test-result response plots at certain frequencies. Three predominant peak frequencies, based on predicted engine response, occurred at 165, 240 to 255, and 440 Hz. The corresponding predominant peak frequencies (based on longitudinal response for longitudinal input, L/L) occurred at 180 and 225 Hz. A predominant peak frequency (based on longitudinal response for radial input, L/R) occurred at 470 Hz.

During the tests it was noted that there was a "well" or dead spot" at approximately 425 Hz. Attempts to increase the longitudinal response by raising the input level in this range were not successful. Based on the test results, the longitudinal response (L/L) grms level was 6.55 resulting in a total equivalent run time of seventy minutes at the 5.9 grms level. Following the longitudinal test, the valve was subjected to a functional test using 500-psig gaseous helium actuation pressure. No abnormalities were noted. A summary of the Phase II functional-test operating times is shown in Table 1.

The Phase II radial endurance tests were conducted 26 December 1968. Test results are shown in Figure 2. Two high-level confirmation runs (at an input spectrum level of approximately $0.2 \text{ g}^2/\text{Hz}$ over a frequency range of approximately 250 to 750 Hz) were performed prior to the radial endurance test. Both confirmation tests were run with a relatively high-input spectrum level because there was almost a one-to-one ratio between the input and output response grms level in the radial direction. The input spectrum level was increased at 450 Hz during the second confirmation run in an attempt to increase the low response or "well" noted at 450 Hz during the first confirmation run. However, the input increase had very little effect on the response at 450 Hz and a decision was made to perform the endurance test without changing the input spectrum setting.

The endurance test results disclosed peak shifting between the engine-predicted and test-result response data at certain frequencies. Three predominant peak frequencies, based on the predicted engine response, occurred

TABLE 1

PHASE II POST VIBRATION FUNCTIONAL CYCLE TESTS

Phase II Vibration Test Run Number	Vibration Axis	GHe Actuation Pressure (psig)	Functional Times		Remarks
			Cycle Number	Total Cycle Time (sec)	
1187-A01-OV-037 & 038	Longitudinal	500	1	Open - 0.22 Close- 0.48	0.056-in. diameter orifices were used on both the opening and closing ports in place of the 0.028-in. opening and 0.056-in. closing orifice, resulting in the faster response times compared to the PDVV.
			2	Open - 0.22 Close- 0.50	
			3	Open - 0.22 Close- 0.48	
1187-A01-OV-040 & 041	Radial	500	1	Open - 0.28 Close- 0.58	
			2	Open - 0.26 Close- 0.60	
			3	Open - 0.26 Close- 0.58	
1187-A01-OV-042, 043	Tangential	475	1	Open - 0.18 Close- 0.46	
			2	Open - 0.18 Close- 0.48	
			3	Open - 0.18 Close- 0.48

Figure 2 - Phase II Radial Endurance Test Responses

at 175, 440 to 460, and 540 Hz. The predominant peak frequencies (based on radial response for radial input, R/R) occurred at 170, 340, and 625 Hz. A "well" or "dead spot" was noted in the 400 to 500 Hz range during the endurance test. The response recorded in the radial direction (R/R) was 10.8 grms, resulting in a total equivalent run time at the 10.3 grms level of 144 minutes. Functional cycle tests at 500-psig gaseous helium actuation pressure following the radial endurance tests were satisfactorily conducted and no anomalies were noted.

The Phase II tangential endurance tests were conducted 27 December 1968. Test results are shown in Figure 3. Prior to the endurance test, two high-level confirmation runs were conducted at an input spectrum level of approximately $0.04 \text{ g}^2/\text{Hz}$ over a frequency range of approximately 150 to 400 Hz. It was noted that there was almost a one-to-one ratio between the input and output response level in the tangential direction also. During the second confirmation run, the input level was increased in the 100 to 200 Hz range, resulting in a notable increase in response in the same range and providing improved simulation between test response and predicted engine response.

Peak shifting between the engine-predicted and test-result response plots was also noted during the tangential endurance tests. The predominant predicted engine response peak frequencies occurred at 100, 165, 395, and 540 Hz. Predominant tangential response for tangential input peak frequencies occurred at 115, 430, and 525 Hz. A predominant peak frequency (based on tangential response for radial input, T/R) was also noted at 165 Hz which corresponded to the engine-predicted response at 165 Hz. The tangential response (T/T) grms level was 11.4, based on the true rms meter reading used which is lower than the Honeywell plot grms level of 12.8.

The "on-line" response visually observed during the test was approximately 8 grms. The Honeywell data was rechecked in an effort to determine the reason for the observed difference. No discrepancies were found, however. It is possible that an instrumentation problem could have existed during the test,

Figure 3 - Phase II Tangential Endurance Test Responses

resulting in the low observed "on-line" response. During the test, a significant radial response (T/R) of 8.6 grms was also recorded. Based on the 11.4 grms (T/T) response, the equivalent run time at the 5.9 grms level was 2331 minutes.

A functional cycle test was conducted following the tangential vibration test and the position traces and cycle times were normal. Photographs of the PDSV for the longitudinal, radial, and tangential endurance tests are identical to those shown in Report RN-TD-0050, except that the PDVV radial and tangential axes correspond to the PDSV tangential and radial axes, respectively.⁽³⁾

The Phase III 40-minute tangential endurance test was conducted 16 January 1969. Results are shown in Figure 4. Three confirmation runs were performed to obtain a response that would correspond to the test-plan envelope and predicted engine response plots. The endurance test was then conducted for a total of 40 minutes "real" time. Peak shifting as noted during the tangential 30-minute tests was evident during Phase III testing. The (T/T) test result grms level was 9.3, resulting in a cumulative equivalent run time of 3178 minutes from all Phase II and Phase III tests. The corresponding "real" run time was 91 minutes. Following the tangential tests, three functional cycles were successfully completed at 500 psig actuation pressure. A summary of the Phase III functional test operating times is shown in Table 2.

The Phase III longitudinal 40-minute endurance tests were conducted 16 January 1969. Test results are shown in Figure 5. Two test-confirmation runs were conducted prior to the endurance test. Peak shifting was also evident during this test and the test-result grms level in the longitudinal direction (L/L) was 7.7. The cumulative equivalent run time was 395 minutes with a corresponding "real" run time of 82 minutes. Functional cycle tests following the longitudinal endurance tests were satisfactorily conducted and no anomalies were noted.

The Phase III 40-minute radial endurance test was conducted 17 January 1969. Test results are shown in Figure 6. One confirmation run

Figure 4 - Phase III Tangential 40-Minute Endurance Test Responses

TABLE 2

PHASE III POST VIBRATION FUNCTIONAL CYCLE TESTS

Phase III Vibration Test Run Number	Vibration Axis	GHe Actuation Pressure (psig)	Functional Times		<u>Remarks</u>
			Cycle Number	Total Cycle Time (sec)	
1187-A01-OV-045, 046 047 & 048	Tangential	500	1	Open - 0.26 Close- 0.56	
			2	Open - 0.26 Close- 0.6	
			3	Open - 0.26 Close- 0.56	
1187-A01-OV-049, 050 & 051	Longitudinal	500	1	Open - 0.26 Close- 0.58	
			2	Open - 0.28 Close- 0.58	
			3	Open - 0.28 Close- 0.56	
1187-A01-OV-052 & 053	Radial	500	1	Open - 0.28 Close- 0.58	
			2	Open - 0.26 Close- 0.6	
			3	Open - 0.26 Close- 0.58

Figure 5 - Phase III Longitudinal 40-Minute Endurance Test Responses

Figure 6 - Phase III Radial 40-Minute Endurance Test Responses

was conducted prior to the test. The radial Phase III endurance test results disclosed peak shifting similar to the Phase II tests. The radial response (R/R) grms level was 11.9. The cumulative equivalent run time for all Phase II and Phase III testing was 481 minutes with a corresponding "real" run time of 90 minutes. The PDSV was subjected to a functional cycle test following the longitudinal tests and no abnormalities were noted.

VI. DISCUSSION

The primary purpose of the Phase I sinusoidal sweep tests was to determine the fundamental resonance points and corresponding transmissibilities of the PDSV assembly in each axis. The results of the Phase I random vibration tests were used to predict the required input spectrum levels for Phase II tests. A review of Phase I sinusoidal and random data disclosed that there was correlation between the maximum random response points and the sinusoidal resonance points as noted in Section V.

The derivation of the Phase II test-predicted engine 30-minute response PSD's shown in Figures 1, 2, and 3 is outlined in Reference 5. The corresponding predicted 70-minute grms levels are: radial, 8.9; tangential, 5.9; and longitudinal, 5.9. Since Phase II endurance tests were to be run for 30 minutes to reduce testing time, an exaggeration factor of 1.15 was used to obtain the test plan 30-minute grms run levels of 10.3 radial, and 6.8 tangential and longitudinal. The exaggeration factor was intended to provide in a 30-minute test damage equivalent to a 70-minute test at the predicted engine response levels. A discussion concerning the validity of using the exaggeration factor for reducing the vibration test time of multi-degree-of-freedom systems is presented in Reference 6. The total equivalent run-time derivation is shown in Table 3. Figures 24 through 26 of Volume 2 of the Shock and Vibration Handbook was used to compute the equivalent 70-minute engine level run times based on the measured grms levels of the test runs.⁽⁷⁾

The test-plan response envelopes shown in Figures 4, 5, and 6 represent a general indication of the required level of response as determined from the engine predictions. The areas under the test-plan curves were established to provide a test plan grms level. As expected, component resonances appear as peaks of varying magnitudes at different frequencies. Depending upon the relative magnitudes, these peaks may or may not exceed the test-plan envelope curve. Between the peaks may be "wells" or "dead spots" where little response is obtained regardless of the energy input.

TABLE 3

Page 1 of 3

PDSV EQUIVALENT RUN TIME DATA

<u>Date</u>	<u>Run No.</u>	<u>Run Description</u>	<u>grms* Level</u>	<u>grms Ratio α</u>	<u>λ</u>	<u>Actual Run Time (min)</u>	<u>Equivalent Run Time (min)</u>		
							<u>Rad.</u>	<u>Tang.</u>	<u>Long.</u>
12/20/68	037	Long. Test Confirmation	6.42	1.10	0.55	4			7.3
	038	Long. Endurance	6.55	1.12	0.48	30			62.5
12/26/68	039	Rad. - Test Confirmation	11.36	1.27	0.21	3	14.3		
	040	Rad. - Test Confirmation	12.16	1.36	0.135	3	22.2		
	041	Rad. - Endurance	10.79	1.21	0.28	30	107.0		
12/27/68	042	Tang. - Test Confirmation	9.61	1.63	0.042	4		95.3	
	043	Tang. - Test Confirmation	9.56	1.62	0.042	4		95.3	
	044	Tang. - Endurance	11.4**	1.93	0.014	30		2140.0	
Totals Phase II (Minutes)							143.5	2330.6	69.8

*Based on either the Honeywell or hybrid analyzer PSD plot.

**This is the true RMS meter reading. The Honeywell grms level was 12.8.

The Seventy Minute Reference Levels are: Radial - 8.92 grms
Tangential - 5.90 grms
Longitudinal - 5.85 grms

TABLE 3 (cont.)

Page 2 of 3

<u>Date</u>	<u>Run No.</u>	<u>Run Description</u>	<u>grms* Level</u>	<u>grms Ratio α</u>	<u>λ</u>	<u>Actual Run Time (min)</u>	<u>Equivalent Run Time (min)</u>		
							<u>Rad.</u>	<u>Tang.</u>	<u>Long.</u>
1/12/69	045	Tang. Test Confirmation (T/T)	6.8	1.15	0.42	4		9.5	
	046	Tang. Test Confirmation (T/T)	8.5	1.44	0.098	5		34.7	
1/16/69	047	Tang. Test Confirmation (T/T)	9.0	1.52	0.066	4		32.9	
	048	Tang. Endurance (T/T)	9.3	1.57	0.052	40		770.0	
	049	Long. Test Confirmation (L/L)	8.7	1.49	0.076	4			52.6
	050	Long. Test Confirmation (L/L)	8.0	1.37	0.13	4			30.8
	051	Long. Endurance (L/L)	7.7	1.32	0.165	40			242.0
1/17/69	052	Radial-Test Confirmation (R/R)	11.9	1.33	0.16	4	25.0		
	053	Radial Endurance (R/R)	11.9	1.33	0.16	50	<u>312.0</u>		
Totals (Min)							337.0	847.1	325.4
Totals from Phase II Tests (Min)							<u>143.5</u>	<u>2330.6</u>	<u>69.8</u>
Cumulative Phase II & Phase III (Min)							480.5	3177.7	395.2
*Based on either the Honeywell or hybrid analyzer PSD plot							90.0	91.0	82.0
Cumulative Phase II & Phase III "Real" run time (Min)									

Example:

Derivation of equivalent run time in longitudinal direction:

1. Total equivalent run time = Equivalent test confirmation run time + equivalent endurance run time.

2. Equivalent test configuration run time:

a. The test amplitude exaggeration factor (α) = $\frac{\text{Test Level grms (6.42)}}{\text{Required 70 Min. grms (5.85) Run Level}} = 1.10$

b. From Figure 24-26 (Reference (c)) the test duration factor (λ) = 0.55

c. Therefore, the equivalent test configuration run time = Test Duration (Min) = $\frac{4}{0.55} = 7.3$

3. Equivalent endurance run time:

a. $\alpha = \frac{6.55}{5.85} = 1.12$

b. $\lambda = 0.48$

c. Run Time = $\frac{30}{0.48} = 62.5$ min

4. Therefore, total equivalent run time = $7.3 + 62.5 = 69.8$ Min.

During the testing of the valve, a flat spectrum was generally applied over the frequency range of 150 to 600 cps with roll-off on either end. Thus, the valve as set up was permitted to respond at its own natural frequencies, with the frequencies and magnitudes according to its frequency response function. It is estimated that the difference between the engine and valve vibration test setup caused the peak frequencies and magnitudes to differ from engine predictions. In reviewing the test response curves, it must be remembered that the valve was excited over the critical frequency range resulting in considerable response, which is the objective of random vibration testing.

After completion of the Phase II tests, the PDSV was subjected to a functional cycle and leak test and disassembled for inspection of the component parts.⁽⁸⁾ All of the leakage rates, except the butterfly gate lipseal, were well below the maximum values specified and the valve was actuated with no evidence of binding. The following anomalies, however, were noted during disassembly and inspection of the valve:

1. Cracks were observed in weld joints of the liquid nitrogen drip-shield. The other major components of the valve were subjected to a penetrant inspection (MIL-I-6866, Type I, Method B) and no cracks were detected. The weld-joint crack is shown in Figure 7.

2. The butterfly-gate metal lipseal gaseous helium leakage recorded during the post-vibration leak test was 3650 scc/sec compared to 6 scc/sec when the valve was leak tested following assembly. The increase in leakage above the specified maximum of 1000 scc/sec is attributed to a wearing away of the gold plating down to the base metal of the lipseal (at four contact points between the gate and the lipseal) with the gate in the normally open position. It is concluded that almost all of the wear occurred during vibration of the valve in the radial axis. In this axis, the butterfly shaft is parallel to the direction of shaker input. Since the radial clearance between the gate and the body thrust-washers was 0.010 in. (normal production radial tolerances

Figure 7 - Crack in Weld Joint of Liquid Nitrogen Drip-Shield

are 0.0075-in. minimum and 0.0125-in. maximum) and since the gate is supported only by the lipseal (which has a much lower effective spring rate when the valve is open), a relative motion occurred at the four contact points which caused the observed seal wear. The lipseal wear contact points are indicated by the dark areas in Figure 8. The corresponding contact points on the butterfly gate are indicated by the two dark areas at the edge of the gate on the lefthand side of Figure 9. The dark spots around the butterfly gate shaft bore, in the same photograph, show where contact occurred between the gate and body thrust-washers.

3. The end cover of the Model 100-514 Spectral potentiometer, which is held in place by six set-screws (see Figure 10) was jarred loose during the vibration test and was found inside the P/N 1114203-1 housing end-cover. It is concluded that the potentiometer cover was jarred loose when the valve was subjected to vibration in the radial axis. The cause was possibly a 0.020-in. peak-to-peak axial movement of the butterfly shaft. Since the end clearance of the potentiometer shaft is approximately 0.010 to 0.012-in. (measured), and since the potentiometer shaft is displaced toward the end cover when the potentiometer is installed, the mass load of the butterfly gate and shaft is transmitted to the end cover during vibration and the end cover is loosened. However, this did not affect the valve position trace recorded during the functional test following the vibration tests. Therefore, a design change is not necessary to assure a satisfactory position trace. This conclusion is based on the following:

a. In the event the potentiometer cover is jarred loose during engine operation, the potentiometer cover bearing and washer would remain on the shaft and would not interfere with the wiper or resistor: i.e., there is insufficient clearance between the potentiometer shaft and housing cover to allow the potentiometer cover to become completely disengaged from the shaft.

Figure 8 - Lipseal Wear Contact Points (Arrow)

Figure 9 - Butterfly-Gate Contact Points (Arrows)

Figure 10 - Potentiometer Assembly Cross-Section

b. The 0.125-in. width of the wiper element would allow approximately 0.060-in. axial movement of the potentiometer shaft before the wiper became disengaged from the resistor.

c. After the potentiometer is installed on the valve, the potentiometer cover and bearing are redundant since: (1) the potentiometer shaft is now supported and located by the butterfly shaft and the inner potentiometer bearing; and (2) the housing end-cover provides environmental protection for the potentiometer assembly.

Figure 11 shows the potentiometer end-cover and set-screw locations. Figure 12 shows the remaining portion of the potentiometer assembly with the end cover removed.

The PDSV was reassembled, using the same hardware, and subjected to a leak and functional test.⁽²⁾ The potentiometer cover was then installed on the potentiometer shaft and left in a loosened condition to simulate the state of the parts when the valve was disassembled following the Phase II tests.

The PDSV was then returned to the vibration laboratory where the Phase III 40-minute tests were conducted to provide additional margin testing and subject the valve to a "real" run time of 70 minutes in each axis. A review of the Phase III test results disclosed the same basic phase shifting and presence of "wells" or "dead spots" as noted during Phase II testing.

Following the 40-minute endurance tests, the valve was subjected to a functional cycle and leak test and disassembled.⁽⁸⁾ As noted following the Phase II tests, leakage rates, except those of the butterfly-gate lipseal, were well below the maximum values specified. The valve was actuated with no evidence of binding and the functional operation of the potentiometer was not impaired by the additional vibration testing. The liquid nitrogen drip-shield weld joints bore evidence of additional crack propagation: the drip shield, however, was still securely fastened to the actuator. Critical components

(e.g., valve body, actuator-to-body adapter, actuator piston, actuator housing, and valve gate lipseal) were also subjected to penetrant inspection and no cracks were detected.

Figure 11 - Potentiometer End Cover

Figure 12 - Potentiometer Assembly, End Cover Removed

VII. CONCLUSIONS

The basic test objectives were accomplished based on the following conclusions:

1. The PDSV withstood the vibration environment imposed by all phases of the test program and no detrimental structural failures were noted which were directly attributal to vibration.
2. Although cracks were observed in the liquid nitrogen drip shield, it was still securely attached to the actuator body and would continue to perform its intended function if the valve were installed on the engine.
3. The functional tests which were conducted following the vibration tests (to verify smooth cycling and consistent cycle times) were satisfactorily performed and no anomalies with respect to the cycle times and position traces were observed.
4. It is concluded that a potentiometer assembly design change is not necessary to assure a satisfactory position trace recording during engine operation.
5. The increased butterfly-gate lipseal leakage rate was approximately equivalent to a 1×10^{-3} lb/sec liquid hydrogen leakage which is not considered detrimental to engine operation.⁽⁹⁾
6. Based on Phase II run times in each axis, as tabulated in Table 3, the equivalent 70-minute run time objectives were achieved in the longitudinal direction and exceeded in the radial and tangential directions. Variance of the test-response peak frequencies and magnitudes with the engine-predicted responses is attributed to the difference in test setup configurations; therefore, it has been determined that the test objectives were achieved within the practical limits of the test program.

7. The additional objective of 70-minutes "real" time testing was met during the Phase IV tests with no further significant damage to the valve components.

Therefore, based on the test results and conclusions, the PDSV is considered acceptable for use during 70 minutes of XE-engine operation.

VIII. REFERENCES

1. Random Vibration Test Plan, XE Five-Inch Butterfly Valve Pump Discharge Vent Valve, P/N 1114342-9, RN-TP-0101.
2. Assembly Procedure, NERVA Five-Inch Butterfly Valve, P/N 1114342-9, Report 7770:AP:4096
3. Five-Inch Butterfly Valve (PDVV) Random Vibration Test - Final Report, Report RN-TD-0050
4. Five-Inch Butterfly Valve (PDSV) Vibration Test Data, Report 7770:R:6098
5. Memorandum, 7733:878, G. S. Kaveney to W. A. Sutter, 2 January 1969, "Summary of Results of the Vibration Survey of the XE-1 LMA/XECF-UTSM TPA - Upper Turbine Inlet Line Assembly (23 September 1968 to 1 October 1968)"
6. Memorandum, 9697:5.1-042, I. K. Hall to C. R. Snyder, 28 February 1969, "Random Vibration Testing"
7. Shock and Vibration Handbook, Vol. 2, C. M. Harris and C. E. Crede, McGraw-Hill Book Co. (1961)
8. Post Vibration Test - Disassembly Procedure (NERVA Five-Inch Butterfly Valve), Report 7770:AP:5171
9. Memorandum; 7400:8046, K. R. Conn to W. A. Sutter, 26 February 1969, "Evaluation of 5-Inch Engine Valve Leakage"