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DOCUMENT NO.	**Qualification Test Report**
TOTAL NO. OF PAGES	**130**
REVISION	R1

QUALIFICATION TEST REPORT
FOR THE

REDUNDANT SEAL, SHUT-OFF VALVE, LH_2

TAERON PART NUMBER: 13079000-01

TAERON PART NUMBER: 201-023702-5

SPACE LAUNCH SYSTEM (SLS) CORE STAGE

SDRL SE-007

APPROVED BY: _____ DATE: _____
Project Engineer

APPROVED BY: _____ DATE: _____
Engineering Manager

APPROVED BY: _____ DATE: _____
Quality Assurance

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QUALIFICATION TEST REPORT

1.0 INTRODUCTION

This report presents the results of the Qualification Test Program performed on the TAERON Industries Redundant Seal, Shut-off Valve, Flight Half, LH2, P/N 13079000-01 (TaeRon P/N 201-023702-5) for the TaeRon SLS Core Stage program. This Qualification Test Report (QTR) is in compliance with TaeRon's Statement of Work D201-10037-1, the SLS Core Stage specification 201-023702 (as modified by applicable Engineering Orders), and TaeRon's Supplier Data Requirement Description (SDRD) SE-007 of the Supplier Data Catalog Supplier Data Sheet (SDS) Document, D201-10002-1.

1.1 Summary

The Qualification Test Program consisted of performing Acceptance tests and Qualification tests as required per TaeRon's ED 201-023702. The results are that Redundant Seal qualification test units successfully completed the Qualification Test Program per TAERON Qualification Test Procedure 12039-00-QTP1. For complete test results, see the Test Results section 5.0

2.0 APPLICABLE DOCUMENTS

The below documents apply to this report to the extent noted. Unless otherwise specified, they are to be the latest issue date. In the event of a conflict between a below document and this report, this report will take precedence.

2.1 Government Documents

MIL-PRF-27201 Rev. E	Propellant, Hydrogen
MIL-PRF-27401 Rev. F	Propellant Pressurizing Agent, Nitrogen
MIL-PRF-27407 Rev. C, Change 1	Propellant Pressurizing Agent, Helium
MIL-STD-767 Rev. D	Control of Hardware Cleanliness
NPD-8730.1 Rev. C	NASA Policy Directive: Calibration and Metrology
NPR 6000.1 Rev. H	Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components
TT-I-735	Federal Specification Isopropyl Alcohol

2.2 TaeRon Documents

201-023702 Rev H, EO1, EO2, EO3, EO4, EO6 21 March 2018	LOX and LH2 Bleed Disconnects Envelope Drawing, Main Propulsion System, Core Stage
D201-10002-1 Rev New 20 October 2017	Attachment F, Supplier Data Catalog, Supplier Data Sheet (SDS) Document
D201-10037-1 Rev G, ADRN 001 03 March 2018	Space Launch System (SLS), TAERON Consolidated Contract: MPS Hardware, Supplier Statement of Work (SSOW) - Purchase Contract
Contracts Letter: QD Operational Life Clarification 14 December 2016	Contractual Letter from TaeRon providing corrections to ED 201-023702

2.3 TAERON Documents

12047-00-CPP1	Cleaning & Packaging Procedure for SLS Program
13079-00-ATP1	Acceptance Test Procedure, Redundant Seal
13079000	Redundant Seal, Shut-off Valve, Flight Half, LH_2 Envelope Drawing
13079423	Leakage Test Fixture, RS Assembly
13079444	Vibration/Shock Test Fixture
13079446	Mass Simulator
13079450	Flow Test Flange Assembly
VI-1000	Cleaning Facilities Document
VI-ACC-001	Test Equipment Accuracy Policy
VI-FOD-001	Foreign Object Damage Policy
VI-SLS-LB1	SLS Log Book

3.0 ABBREVIATIONS AND ACRONYMS

Abbreviation / Acronym and Definition			
APC	Automatic Particle Counter	ml	Milliliter
ASD	Acceleration Spectral Density	No.	Number
ATP	Acceptance Test Procedure	NCR	Non-conformance Report
ATPDS	Acceptance Test Procedure and Data Sheets	NPD	NASA Policy Directive
BOC	Break of Configuration	NPR	NASA Procedural Requirement
DI	Deionized (Water)	NVR	Nonvolatile Residue
ECF	Environmental Correction Factor	PC	Pneumatic Cylinder
ED	Envelope Drawing	PE	Project Engineer
EO	Engineering Order	PG	Pressure Gauge
FH	Flight Half	P/N	Part Number
FL	Filter	PR	Pressure Regulator
FM	Flowmeter	psia	Pounds per Square Inch Absolute
FOD	Foreign Object Debris	psig	Pounds per Square Inch Gauge
GH	Ground Half	PT	Pressure Transducer
GHe	Gaseous Helium	PTFE	Polytetrafluroethylene
GN_2	Gaseous Nitrogen	QA	Quality Assurance Representative
Grms	Root Mean Square Acceleration	QD	Quick Disconnect
GSE	Ground Support Equipment	QTP	Qualification Test Procedure
HFE	Hydrofluoroether	QTPDS	Qualification Test Procedure Data Sheets
Hg	Mercury	RV	Relief Valve
In	Inch	RS	Redundant Seal
IPA	Isopropyl Alcohol	scim	Standard Cubic Inches per Minute
l	Liter	SDRD	Supplier Data Requirement Description
lb	Pound	SDRL	Supplier Data Requirement List
lbf	Pound Force	SDS	Supplier Data Sheet
LC	Load Cell	sec	seconds
LH_2	Liquid Hydrogen	SLS	Space Launch System
LN_2	Liquid Nitrogen	S/N	Serial Number
LOX, LO2	Liquid Oxygen	SV	Solenoid Valve
MDP	Maximum Design Pressure	TC	Thermocouple
mg	Milligram	UUT	Unit Under Test
MV	Manual Valve		

4.0 HARDWARE DESCRIPTION

4.1 The Redundant Seal (RS) is a normally closed, pneumatically opened visor valve, which provides redundant sealing to the LH2 4-inch Flight Half Quick Disconnect (FH QD). The RS is a standalone, cryogenic valve that has been application-engineered to be assembled with the FH QD.

4.2 The RS consists of a visor assembly that is driven by a pneumatic actuator assembly by a rack and pinion assembly with a dual-motion eccentric mechanism. The actuator assembly is mounted adjacent to the visor valve assembly where the rack and pinion assembly is integrated. The flange on the inboard side of the main housing interfaces with the FH QD. Two relief valves provide relief from outlet to inlet in the case there is over-pressurization in the cavity between RS and FH QD when both valves are closed. A check valve provides pressure relief inside the housing cavity in case helium leaks through the actuator's dynamic piston seals and causes over-pressurization. Two electrical connectors are wired to four independent position-indicating switches for redundancy.

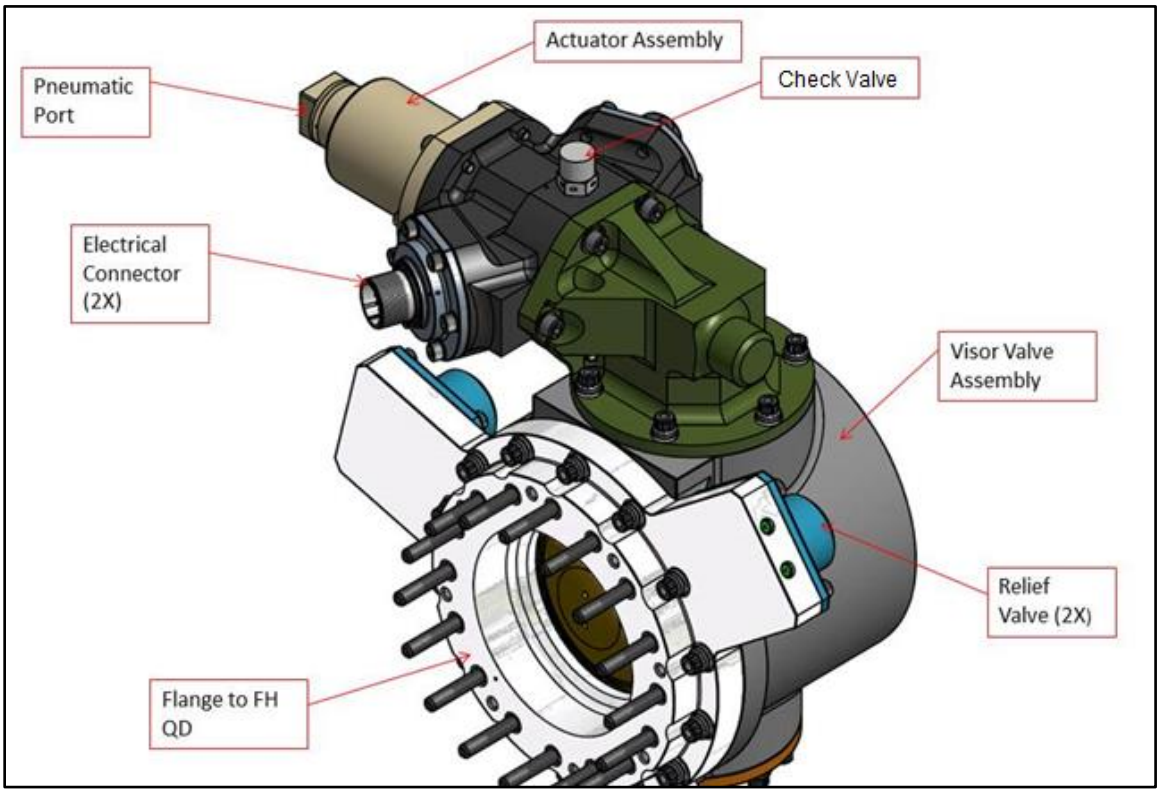


FIGURE 1
REDUNDANT SEAL: 13079000-01

5.0 QUALIFICATION TEST PROGRAM

5.1 Summary

5.1.1 The results of the Qualification Test Program presented in this report represent proof of product reliability, performance, and conformance to TaeRon's ED (Envelope Drawing) 201-023702, Rev. H and its associated EO1 to EO4 and EO6.

5.1.2 The part number and serial number of the Qualification test unit is below:

- Redundant Seal, Shut-off Valve, Flight Half, LH2 (RS)
  P/N 13079000-01
  S/N 99517-0003

5.1.3 The Qualification Test Program was successfully completed by first passing Acceptance testing per TAERON's Acceptance Test Procedure 13079-00-ATP1: Following successful completion, the RS passed all requirements in Qualification testing per TAERON's Qualification Test 13079-00-QTP1.

5.1.4 The Acceptance test data sheets (ATPDS) are in Appendix A.
The Qualification test data sheets (QTPDS) are in Appendix B. NTS Santa Clarita test report is in Appendix C. NTS San Bernardino test report is in Appendix D. Non-conformances and investigations are in Appendix E.

5.1.5 A summary of each Qualification test and its requirement, test condition, result, and photograph(s) is listed in the Test Results section 6.0.

5.1.6 Test Summary and Results Tables

Below are the Acceptance test summary and results in Table 1, followed by the Qualification test summary results in Table 2. The test sequences TAERON used for the Acceptance and Qualification and testing are in accordance with TaeRon's ED 201-023702.

TABLE 1
ACCEPTANCE TEST SEQUENCE

Test	Test Description	TaeRon ED Sections	Requirements	Results
1	Examination of Product	4.1.2.3	Not exceed 26.0 lb.	PASSED[1]
2	Proof Pressure	4.2.1.2.12 4.2.1.2.12.1	No visual evidence of damage or permanent deformation.	PASSED
3	Dielectric Strength	4.2.1.2.12.3	Current leakage ≤ 2.00 mA	PASSED

TABLE 1
ACCEPTANCE TEST SEQUENCE

Test	Test Description	TaeRon ED Sections	Requirements	Results
4	Circuit Rating	4.2.1.2.8.7	Current shall be between 5 and 11 mA.	PASSED
5	Voltage Drop	4.2.1.2.8.8	Voltage drop ≤ 0.5 mV	PASSED
6	Insulation Resistance	4.2.1.2.8.9	Insulation Resistance ≥ 100 MΩ	PASSED
7	Open Circuit Resistance	4.2.1.2.8.10	Open Circuit Resistance ≥ 10 MΩ	PASSED
8*	External Leakage Tare Test	N/A	N/A	PASSED
9	Actuation & Response Time (Ambient Temp: +70 ±20°F)	4.2.1.2.9.1, 4.2.1.2.9.5, 4.2.1.2.10.1, 4.2.1.2.10.2	The RS shall actuate to open position with 600 psig maximum applied to actuator and shall return to closed position upon removal of actuation pressure. Opening and closing response times ≤ 1.5 seconds (command-to-switch) and ≤ 0.75 seconds (switch to switch).	PASSED
10	Relief Function (Ambient Temp: +70 ±20°F)	4.2.1.2.7.2	Crack Pressure ≤ 20 psig	PASSED
11	Leakage, Internal (Ambient Temp: +70 ±20°F)	4.2.1.2.6.1, 4.2.1.2.6.2	Internal Leakage < 400 scim	PASSED
12	Leakage, External (Ambient Temp: +70 ±20°F)	4.2.1.2.6.3	External Leakage < 10 scim	PASSED
13	Leakage, Actuator (Ambient Temp: +70 ±20°F)	4.2.1.2.6.5	Actuator Leakage < 100 scim	PASSED
14	Actuation & Response Time (Cryo Temp: -300 ±20°F)	4.2.1.2.9.1, 4.2.1.2.9.5, 4.2.1.2.9.6, 4.2.1.2.10.1, 4.2.1.2.10.2	The RS shall actuate to open position with 600 psig maximum applied to actuator and shall return to closed position upon removal of actuation pressure. The RS shall actuate to open position with	PASSED

TABLE 1
ACCEPTANCE TEST SEQUENCE

Test	Test Description	TaeRon ED Sections	Requirements	Results
			905 psig minimum applied to actuator and shall return to closed position upon removal of actuation pressure. Opening and closing response times ≤ 1.5 seconds (command-to-switch) and ≤ 0.75 seconds (switch to switch).	
15	Relief Function (Cryo Temp: -300±20°F)	4.2.1.2.7.2	Crack Pressure ≤ 20 psig	PASSED
16	Leakage, Internal (Cryo Temp: -300 ±20°F)	4.2.1.2.6.1, 4.2.1.2.6.2	Internal Leakage < 400 scim	PASSED
17	Leakage, External (Cryo Temp: -300 ±20°F)	4.2.1.2.6.3	External Leakage < 10 scim	PASSED[2]
18	Leakage, Actuator (Cryo Temp: -300 ±20°F)	4.2.1.2.6.5	Actuator Leakage < 100 scim	PASSED
19	Leakage, Bellows Assembly (Ambient Temp: +70 ±20°F)	4.2.1.2.6.4	Bellows Leakage < 2.0 scim	PASSED
20	Cleanliness, Internal (Valve and Actuator)	4.3.1.3.1 4.3.1.3.1.1	Valve: 0 particles > 400 microns per 500mL sample size. There shall be no silting. NVR for 500mL sample ≤ 2.0 mg. Actuator: See particle requirement table. NVR for 500mL sample ≤ 1 mg.	PASSED[3]
21	Electrical Bonding	4.4.1.1.5	Resistance < 1Ω	PASSED
22	Post-Test Inspection	4.1.2.3.3	No visible evidence of parameters out of specification.	PASSED

TABLE 1
ACCEPTANCE TEST SEQUENCE

Test	Test Description	TaeRon ED Sections	Requirements	Results
23	Cleanliness, External	4.3.1.3.2	The non-wetted surfaces of RS shall be cleaned per 12047-00-CPP1 Class V, Visually Clean. Test unit shall be free of dirt, scale, oil or other contamination when viewed at a distance of 2 to 4 feet under a minimum incident light level of 500 lumens/meter[2].	PASSED
24	Preparation for Delivery	5	The RS shall be packaged per 12047-00-CPP1.	PASSED

[1]Reference NCM0055710 for weighing of the unit to the nearest 0.1 lb instead of 0.01 lb. The unit was re-weighed per an internal squawk ticket.

[2]Reference NCM0055287 for External Leakage (LN2) test failure. The unit was reworked to disassemble and polish various sealing surfaces. Spherical bearings showed abnormal wear and were replaced with new ones. After unit was re-assembled the external leakage met requirement.

[3]Reference NCM0055698 for Actuator NVR having been tested at part level before the requirement changed from 100mL to 500mL. The unit was dispositioned as USE AS IS.

TABLE 2
QUALIFICATION TEST SEQUENCE AND RESULTS

Test	Test Description	TaeRon ED Section	Requirements	Results
1	Acceptance	4.1.2.3	Completion of Acceptance Testing	PASSED
2	Bench Shock	4.2.5.1.4.1	RS shall be dropped four times per face for a total of 24 drops. No visual evidence of damage or permanent deformation.	PASSED
3	Shock	4.2.5.2.5	No visual evidence of structural damage or loosening of fasteners.	PASSED[1]
4	External Leakage Tare (Ambient Temp: +70 ±20°F)	N/A	N/A	N/A

TABLE 2
QUALIFICATION TEST SEQUENCE AND RESULTS

Test	Test Description	TaeRon ED Section	Requirements	Results
5	Vibration, Flight (180 sec./axis) Random and Sinusoidal (Cryo Temp: -300 ±20°F)	4.2.5.2.4 4.2.5.2.4.2 4.2.5.2.7	There shall be no physical damage to test unit after exposure to vibration levels.	PASSED
	Post-Vibration Internal Leakage (Cryo Temp: -300 ±20°F)	4.2.1.2.6.1	Internal Leakage < 400 scim	
6	Relief Function: 100 cycles at Ambient (Ambient Temp: +70 ±20°F)	4.2.1.2.1.2.1	Actuate the relief mechanism 100 cycles at ambient temperature.	PASSED
	Post-Relief Function: Crack and Reseat (Ambient Temp: +70 ±20°F)	4.2.1.2.7.2	Crack Pressure ≤ 20 psig	
7	Operating Life with Response Times: 300 cycles (Ambient Temp +70±20°F)	4.2.1.2.1.2, 4.2.1.2.10.1, 4.2.1.2.10.2	All opening and closing response times ≤ 1.5 seconds (command-to-switch) and ≤ 0.75 seconds (switch to switch).	PASSED
8	Relief Function: 100 cycles at LH2 (Cryo Temp: -400 ±20°F)	4.2.1.2.1.2.1	Actuate the relief mechanism 100 cycles at LH2 temperature.	PASSED[2]
9	Operating Life with Response Times: 200 cycles at -400 ±20°F	4.2.1.2.1.2, 4.2.1.2.10.1, 4.2.1.2.10.2 4.2.5.2.2.1 4.2.5.2.2.2	All opening and closing response times ≤ 1.5 seconds (command-to-switch) and ≤ 0.75 seconds (switch to switch).	PASSED[3]
	Post-Op Life: Operating Pressure	4.2.1.2.2	The RS unit shall have no visual evidence of damage or permanent deformation.	
	Post-Op Life: Operating Temperature	4.2.1.2.3	See 201-023702H-EO4 for amended requirement.	

TABLE 2
QUALIFICATION TEST SEQUENCE AND RESULTS

Test	Test Description	TaeRon ED Section	Requirements	Results
10	Post-Op Life: Actuation & Response (Cryo Temp: -400 ±20°F)	4.2.1.2.9.1 4.2.1.2.9.5 4.2.1.2.9.6 4.2.1.2.9.7.1 4.2.1.2.9.7.2 4.2.1.2.10.1 4.2.1.2.10.2	The RS unit shall be pneumatically actuated to the open position with 905 psig minimum, and shall return to the closed position upon removal of actuation pressure. The time actuation pressure to go from 0 psig to greater than 905 psig < 0.5 second. The time for actuation pressure to go from 905 psig to less than 100 psig < 0.5 second. Application of and removal of 905 psig actuation pressure shall not result in slam damage or any other type of valve damage.	PASSED
11	Post Relief Function: Crack/Reseat (Cryo Temp: -400 ±20°F)	4.2.1.2.7.2	Crack Pressure ≤ 20 psig	PASSED
12	Leakage, External (Cryo Temp: -400 ±20°F)	4.2.1.2.6.3	External Leakage < 20 scim	PASSED
13	Leakage, Actuator (Cryo Temp: -400 ±20°F)	4.2.1.2.6.5	Actuator Leakage < 100 scim	PASSED[4]
14	Leakage, Internal (Cryo Temp: -400 ±20°F)	4.2.1.2.6.1,	Internal Leakage < 400 scim	PASSED[5]
15	Post Relief Function: Crack/Reseat (Hot Temp: +170 ±20°F)	4.2.1.2.7.2	Crack Pressure ≤ 20 psig	PASSED
16	Leakage, External (Hot Temp: +170 ±20°F)	4.2.1.2.6.3	External Leakage < 20 scim	PASSED
17	Leakage, Internal (Hot Temp: +170 ±20°F)	4.2.1.2.6.1,	Internal Leakage < 400 scim	PASSED
18	Leakage, Actuator (Hot Temp: +170 ±20°F)	4.2.1.2.6.5	Actuator Leakage < 100 scim	PASSED

TABLE 2
QUALIFICATION TEST SEQUENCE AND RESULTS

Test	Test Description	TaeRon ED Section	Requirements	Results
19	Post-Op Life: Actuation & Response (Hot Temp: +170 ±20°F)	4.2.1.2.9.1 4.2.1.2.9.5 4.2.1.2.9.7.1 4.2.1.2.9.7.2 4.2.1.2.10.1 4.2.1.2.10.2	The RS shall actuate to open position with 600 psig maximum applied to actuator and shall return to closed position upon removal of actuation pressure. Opening and closing response times ≤ 1.5 seconds (command-to-switch) and ≤ 0.75 seconds (switch to switch).	PASSED
20	Post-Op Life: Leakage, Internal (Cryo Temp: -300 ±20°F)	4.2.1.2.6.1,	Internal Leakage < 400 scim	PASSED
21	Post-Op Life: Leakage, External (Cryo Temp: -300 ±20°F)	4.2.1.2.6.3	External Leakage < 10 scim	PASSED
22	Post-Op Life: Leakage, Actuator (Cryo Temp: -300 ±20°F)	4.2.1.2.6.5	Actuator Leakage < 100 scim	PASSED
23	Post-Op Life: Relief Function (Cryo Temp: -300 ±20°F)	4.2.1.2.7.2	Crack Pressure ≤ 20 psig	PASSED
24	Post-Op Life: Response Time (Cryo Temp: -300 ±20°F)	4.2.1.2.10.1 4.2.1.2.10.2	The RS shall actuate to open position with 600 psig maximum applied to actuator and shall return to closed position upon removal of actuation pressure. The RS shall actuate to open position with 905 psig minimum applied to actuator and shall return to closed position upon removal of actuation pressure. Opening and closing response times ≤ 1.5 seconds (command-to-switch) and ≤ 0.75 seconds (switch to switch).	PASSED

TABLE 2
QUALIFICATION TEST SEQUENCE AND RESULTS

Test	Test Description	TaeRon ED Section	Requirements	Results
25	Post-Op Life: Leakage, Internal (Ambient Temp: +70 ±20°F)	4.2.1.2.6.1,	Internal Leakage < 400 scim	PASSED
26	Post-Op Life: Leakage, External (Ambient Temp: +70 ±20°F)	4.2.1.2.6.3	External Leakage < 10 scim	PASSED
27	Post-Op Life: Leakage, Bellows Assembly (Ambient Temp: +70 ±20°F)	4.2.1.2.6.4	Bellows Leakage < 2.0 scim	PASSED
28	Post-Op Life: Leakage, Actuator (Ambient Temp: +70 ±20°F)	4.2.1.2.6.5	Actuator Leakage < 100 scim	PASSED
29	Post-Op Life: Relief Function (Ambient Temp: +70 ±20°F)	4.2.1.2.7.2	Crack Pressure ≤ 20 psig	PASSED
30	Particle Generation	4.2.2.4.1	0 particles > 400 microns per 500mL sample size. There shall be no silting.	PASSED[6]
31	Post-Op Life: Closing Response with Flow (Ambient Temp: +70 ±20°F)	4.2.1.2.10.2	Closing response time ≤ 1.5 seconds (command-to-switch) and ≤ 0.75 seconds (switch-to-switch).	PASSED
32	Burst Pressure	4.2.1.2.11 4.2.1.2.11.1	The RS body shall withstand burst pressures without rupture.	PASSED
33	Teardown and Inspection	4.1.2.3.3	RS shall be visually examined and have no sign of structural damage, deformation, and/or excessive wear.	PASSED

TABLE 2
QUALIFICATION TEST SEQUENCE AND RESULTS

Test	Test Description	TaeRon ED Section	Requirements	Results

[1]Reference NCM0055807 for shock over-test condition which was deemed acceptable.

[2]Reference NCM0055979 for test failure after cycle 1 due to venting test step that caused nitrogen to enter the system and impede on the flow to the test unit. After redlining the test procedure to vent test unit through a different line, the test was conducted with no further issues.

[3]Reference NCM0056069 for closing response time failure due to actuator getting too cold (LH2 temperature) with the test setup configuration which was set up to externally chill the test unit. A new test setup configuration was used to internally chill the test unit and insulate the body from actuator, which allowed the unit to pass the test.

[4]Reference NCM0056965 for actuator leakage failure due to actuator getting too cold (LH2 temperature) with the test setup configuration. TaeRon generated EO6 to 201-023702H ED to allow the successful completion of the Actuator Leakage at LN2 temperature test to satisfy this requirement.

[5]Reference NCM0056966 for internal leakage failure due to actuator getting too cold (LH2 temperature) with test setup configuration, contributing to the test unit not closing properly. Per NCM disposition, the test unit was returned to ambient temperature and test was repeated with test unit already in closed position prior to chilldown and passed the test.

[6]Reference NCM0057058 for particle generation failure; 24 particles over 400 micron were found. M&P analysis showed that most of the particles over 400 micron were foreign and fiber-like materials and the other particles over 400 micron were not considered to be generated from the valve operation by rationale included in the NCM final disposition.

5.2 Test Equipment and Facilities

5.3 Testing was completed at TAERON Industries and at National Testing Systems (NTS) in Santa Clarita and San Bernardino. The facilities at NTS were utilized because they are specially equipped for extreme conditions and hazardous testing.

5.4 Test equipment used during Qualification testing consisted of standard calibrated scales, multi-meters, pressure gauges, torque wrenches, mass spectrometers, and timers, as documented on the Qualification test data sheets. These devices are standard test equipment at TAERON, and test equipment used at NTS has been verified to be calibrated to the requirements of VI-ACC-001.

5.5 Test Personnel and Witnesses

Testing was performed by TAERON technicians and witnessed by Quality Assurance personnel as indicated on the test data sheets. During testing NTS, a TAERON Engineer was present to witness all testing. TaeRon and DCMA witnessed the Shock and Vibration test setup (tests 3 and 5).

6.0 TEST RESULTS

6.1 This section presents the tests and results from the Qualification Test Program per TaeRon's ED 201-023702. Refer to the "Qualification Test Sequence and Results" in Table 2 for each test's corresponding TaeRon requirement.

6.2 Copies of the original test data sheets that were used to document test results are provided in Appendices A to C. In data sheets where 0 scim or a negative value is recorded as measured leakage values, it indicates no measurable mass flow.

6.3 Test 1 - Acceptance Testing

6.3.1 Requirements: The RS unit shall have successfully completed acceptance testing per 13079-00-ATP1.

6.3.2 Test Conditions: Refer to the Test Data sheets in Appendix A for test conditions.

6.3.3 Results: The RS unit passed all ATP test criteria. TaeRon verified workmanship after completion of all testing, and all documentation has been reviewed and approved by TaeRon SQMR and DCMA during the acceptance data review. See Appendix A for test data sheets.

6.4 Test 2 - Bench Shock

This test was performed by NTS, Santa Clarita. Refer to Appendix C for the NTS report.

6.4.1 Requirements: The RS unit shall be raised at one edge 4 inches above a solid wooden bench top (see Figure 2) or until the unit forms a 45-degree angle with the bench top—whichever is less—and then released so that the component lands on its supporting face. This procedure shall be repeated using other practical edges of the same horizontal face as pivot points for four drops, repeated on each face for a total of 24 drops. The RS unit shall remain intact and show no visible structural damage.

6.4.2 Test Conditions: The RS unit was subjected to a total of 24 drops (4 drops per 6 sides) from an angle of 45 degrees onto the wooden bench top. See Figure 3, Figure 4, and Figure 5.

6.4.3 Results: The RS unit remained intact and showed no visible structural damage after the 24 drops. See Figure 6.

FIGURE 2
BENCH SHOCK TEST BENCH

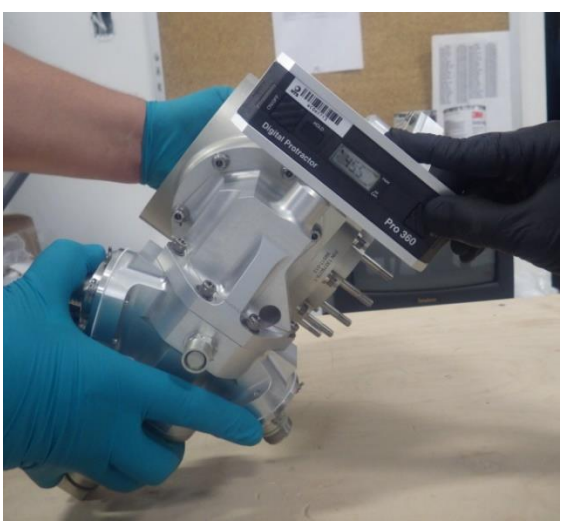


FIGURE 3
BENCH SHOCK (SIDES 1 AND 2)

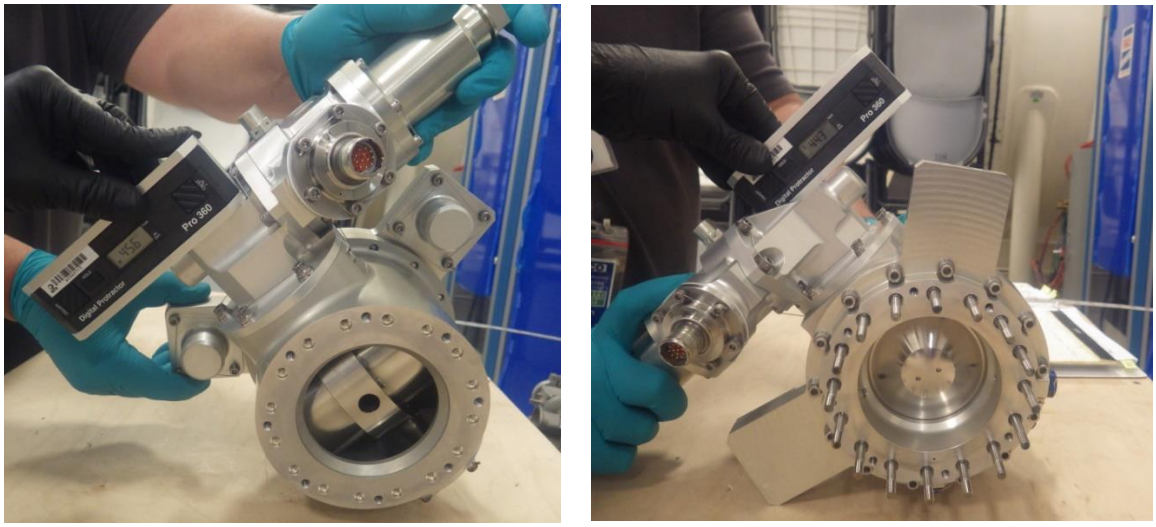


FIGURE 4
BENCH SHOCK (SIDES 3 AND 4)

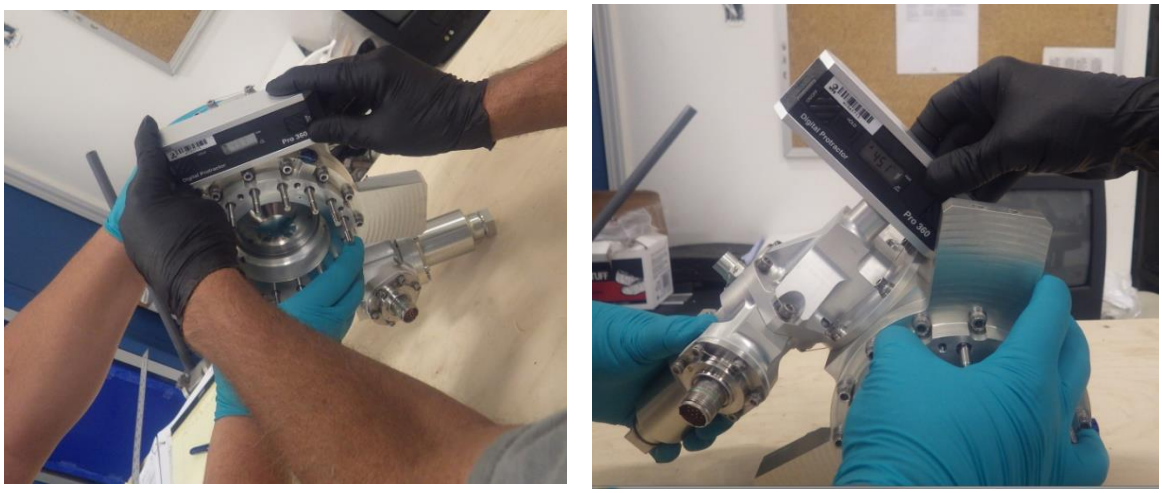


FIGURE 5
BENCH SHOCK (SIDES 5 AND 6)

FIGURE 6
POST-BENCH SHOCK: TEST UNIT CONDITION

6.5 Test 3- Shock

This test was performed by NTS, Santa Clarita. Refer to Appendix C for the NTS report.

6.5.1 Requirements: With the RS unit in normally closed position, the shock shall be applied in each of three mutually perpendicular axes. The shock levels to be applied are shown in Table 3.2.5.2.5-1 in TaeRon's ED. The component shall be subjected to three shocks per axis in both the positive and

negative directions for a total of six shocks per axis (18 total shock events). The shape of the shock pulse (in time domain) shall be representative of a typical shock pulse and decay to lower than 10% of the peak amplitude within 20 milliseconds. After exposure to the shock environment, the RS unit shall remain intact and show no visible structural damage.

6.5.2 Test Conditions: Prior to shock testing, a series of equalization shocks and a fixture survey were performed using the RS mass simulator P/N 13079446-01. See Figure 7, Figure 8, and Figure 9. The RS mass simulator and RS qualification unit were each installed on the Shock/Vibration Test Fixture P/N 13079446-01-1 (originally designed for vibration testing but approved as an acceptable equivalent test fixture for shock), which was fastened onto a test plate welded onto the impact table. See Figure 7 and Figure 10. Mounting fasteners for both the simulator unit and test unit were torqued to 125 in-lb above running torque and torqued striped to be visually inspected for any loosening after each axis. Two control accelerometers were attached to the test fixture and two response accelerometers were attached to the test unit at the locations shown in Figure 8, Figure 9, Figure 11, and Figure 12.

6.5.3 Shock test was performed at ambient temperature, utilizing the Mechanical Impulse Pyroshock Simulator (MIPS) method, where one projectile strike to the test fixture (with test unit installed) can be interpreted as up to 6 shock events: positive/negative directions across all three axes, thereby subjecting the unit to 18 shocks using only 3 strikes.

6.5.4 Results: The RS unit passed the Shock test as it remained intact and showed no visible structural damage. Visual inspection of the torque stripe verified that the mounting fasteners did not loosen during the test. The RS unit was subjected to a total of 4 strikes:

6.5.5 During the first shock event, the X-Axis for Triax 2 was undertested (within lower limit but not meeting 50 percent above nominal requirement, ref. PR065733-00 in Appendix C). TaeRon VS&A deemed it acceptable for only one of the controls being within required limits. Both response accelerometers fell off the test unit which was considered a test setup failure and the response accelerometers were remounted for a re-do test. During the second shock event, both response accelerometers fell off the unit again. During the third shock event, response accelerometer R1 fell off the test unit. During the fourth shock event, response accelerometer R2 fell of the test unit. All shock test data were reviewed and approved by TaeRon VS&A.

6.5.6 Shock levels applied on the test unit exceeded the shock tolerance band at several frequencies. The over-test was an expected non-conformance based on the known condition of the fixture survey and shock equalization results which NTS could not rectify. NCM0055807 was generated to address this over-test and provide rationale for Use-As-Is disposition. Ref. NCM0055807 in Appendix E.

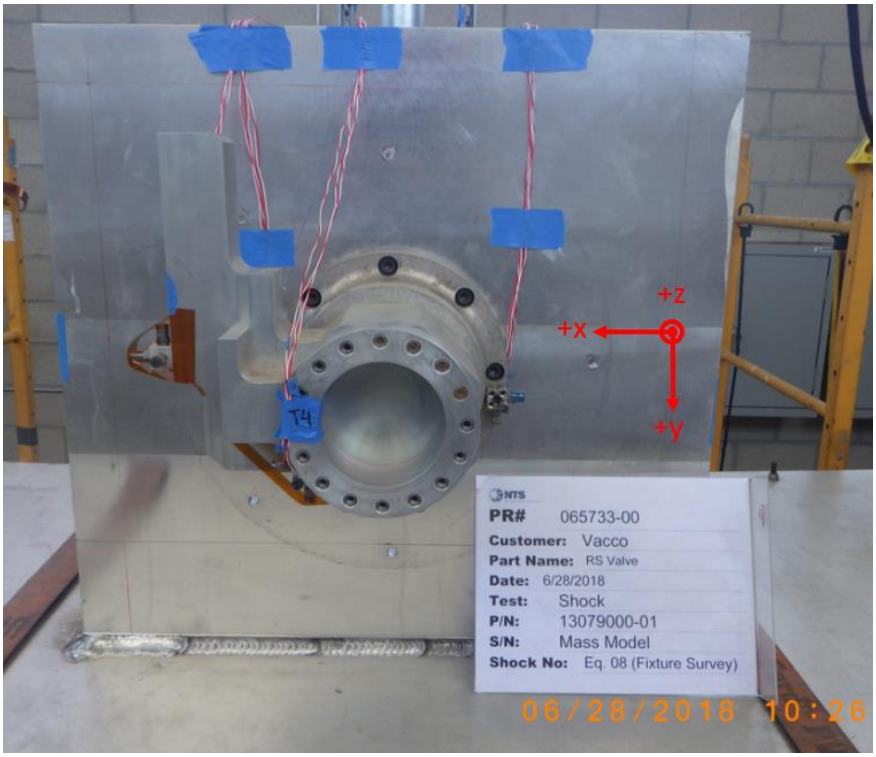


FIGURE 7
SHOCK FIXTURE SURVEY: TEST SETUP

FIGURE 8
SHOCK FIXTURE SURVEY: ACCELEROMETER PLACEMENTS (SIDE 1)

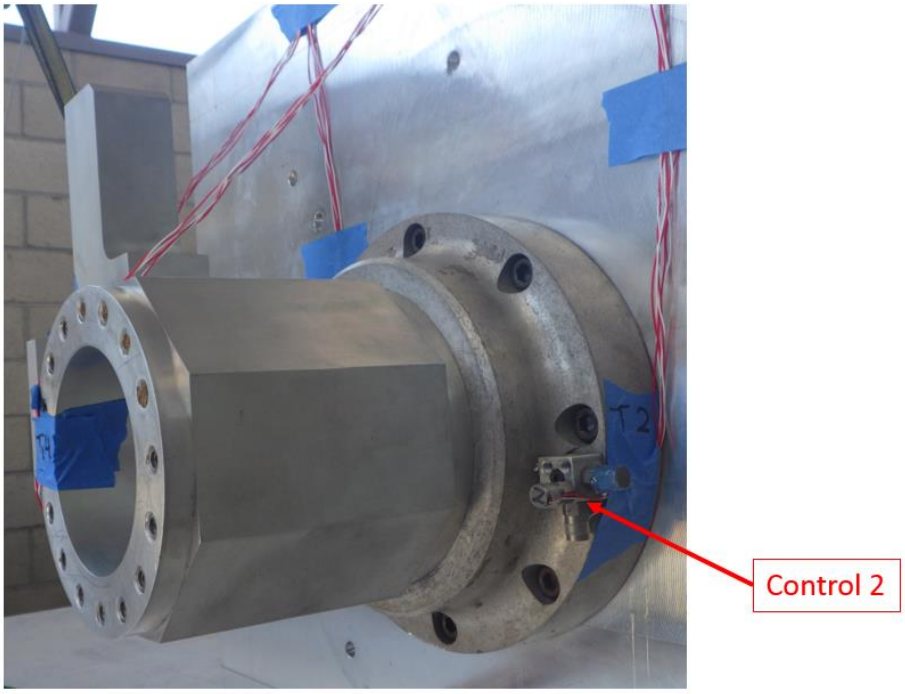


FIGURE 9
SHOCK FIXTURE SURVEY: ACCELEROMETER PLACEMENTS (SIDE 2)

FIGURE 10
SHOCK TEST: TEST SETUP

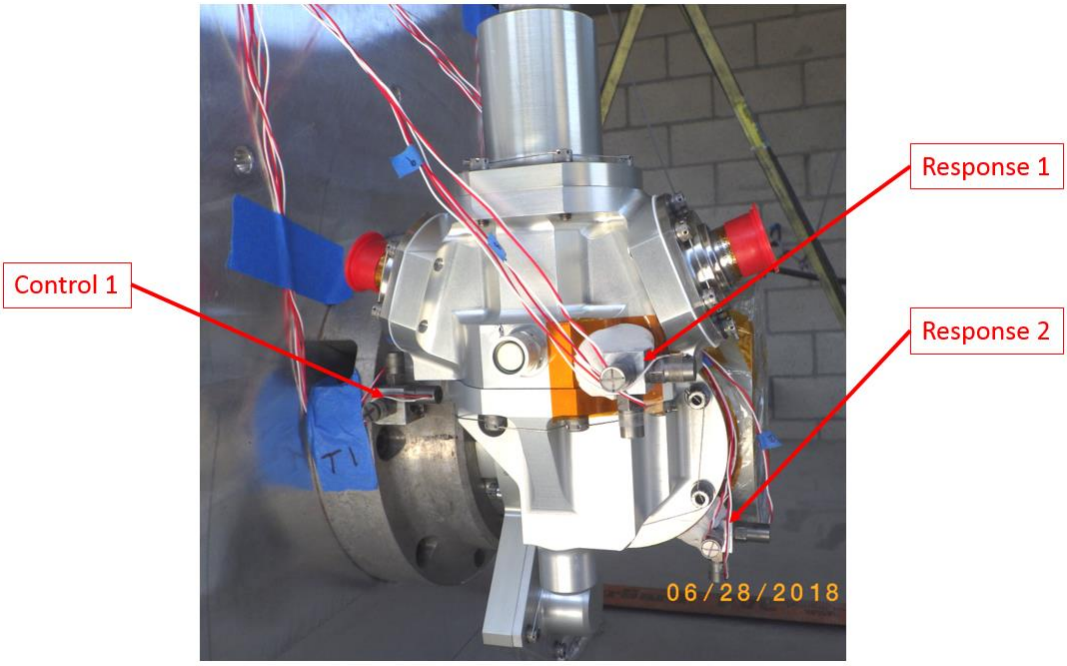


FIGURE 11
SHOCK TEST: ACCELEROMETER PLACEMENTS (SIDE 1)

FIGURE 12
SHOCK TEST: ACCELEROMETER PLACEMENTS (SIDE 2)

6.6 Test 4- External Leakage Tare (Ambient)

6.6.1 Requirements: The external leakage, internal leakage, and actuator leakage tares shall be performed and recorded in the datasheet. There is no acceptance criteria.

6.6.2 Test Conditions: With the hoses attached to the test panel and plugged at the ends, the test system was pressurized and maintained for five (5) minutes for each of the following test configurations: external leakage, internal leakage, and actuator leakage. See Figure 13.

6.6.3 Results: The leakage tare values for each test configuration.

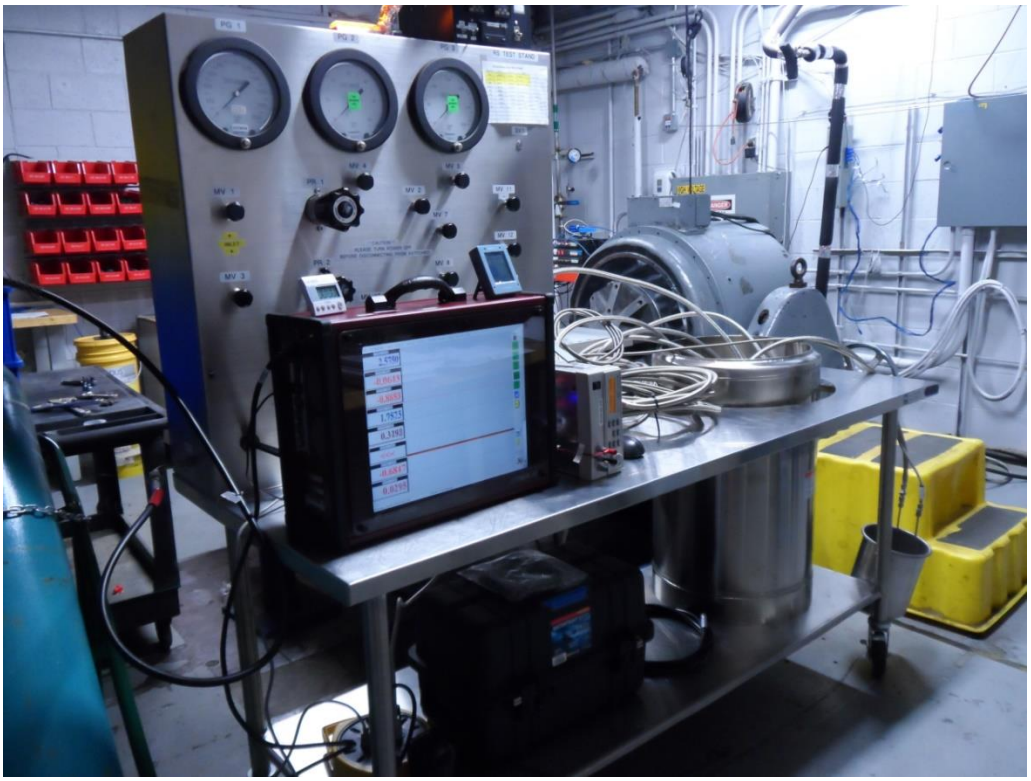


FIGURE 13
EXTERNAL LEAKAGE TARE TEST SETUP

6.7 Test 5- Vibration, Flight (LN2)

This test was performed by NTS, Santa Clarita. Refer to Appendix C for the NTS report.

6.7.1 Requirements: With the RS unit mounted on a vibration fixture, chill the unit until stabilized at -300±20°F. The RS unit shall be subjected to the random vibration specified in Table 3.2.5.2.4-1 of TaeRon's ED for the time specified in the table per axis at ambient pressure. The sinusoidal vibration specified in Table 3.2.5.2.7-1 shall be applied to the test unit in each of three orthogonal axes at a sweep rate of 3 octaves per minute from 5 to 50 Hz. After completion of all three axes, the test unit shall be examined for any physical damage and torque striped mounting fasteners shall be

visually inspected for loosening. There shall be no physical damage to test unit and no loosened mounting fastener after exposure to vibration levels.

6.7.2 Test Conditions: Prior to Random and Sinusoidal Vibration testing, fixture surveys were performed using the RS mass simulator P/N 13079446-01. See Figure 14, Figure 24, and Figure 33. The simulator unit and RS test unit were each installed on the Vibration Test Fixture P/N 13079446-01-1. The mounting fasteners for both the simulator unit and the RS test unit were torqued to 125 in-lb and torque-striped for visual inspection for any loosening after testing each axis. Two control accelerometers were attached to the test fixture and two response accelerometers were attached to the test unit in locations shown in Figure 15, Figure 17, Figure 18, Figure 25, Figure 26, Figure 28, Figure 29, Figure 34, Figure 35, Figure 37, and Figure 38.

6.7.3 Random and Sinusoidal Vibration testing: The RS test unit was chilled to -300±20°F (see datasheets in Appendix B for actuals) for 30 minutes minimum in an insulated enclosure. The inlet and outlet of the RS test unit were connected to the test panel per the QTP schematic in order to apply blanket pressure on the unit during vibration testing and to perform an internal leakage test immediately after the last axis. The RS connectors were also connected to the DAQ to monitor the closed position indications during the vibration test. See Figure 16, Figure 19, Figure 20, Figure 27, and Figure 36. After each axis, the test unit was returned to ambient temperature and visually inspected for any physical damage.

6.7.4 Results: The RS unit passed the test as there was no visual evidence of damage or permanent deformation of the test unit after the first two axes. Visual inspection of the torque stripe verified no loosened mounting fasteners. See Figure 22, Figure 23, Figure 31, and Figure 32. The post-inspection for the last axis was done after the post-vibration leakage test (ref. section 6.8).

6.7.5 During the Y-Axis sinusoidal vibration testing, test data acquisition was switched over to single point control (using Control 2) due to low frequency (below 10Hz) issues on one of the accelerometers related to the signal to noise ratio. All vibration test data was reviewed and approved by VS&A.

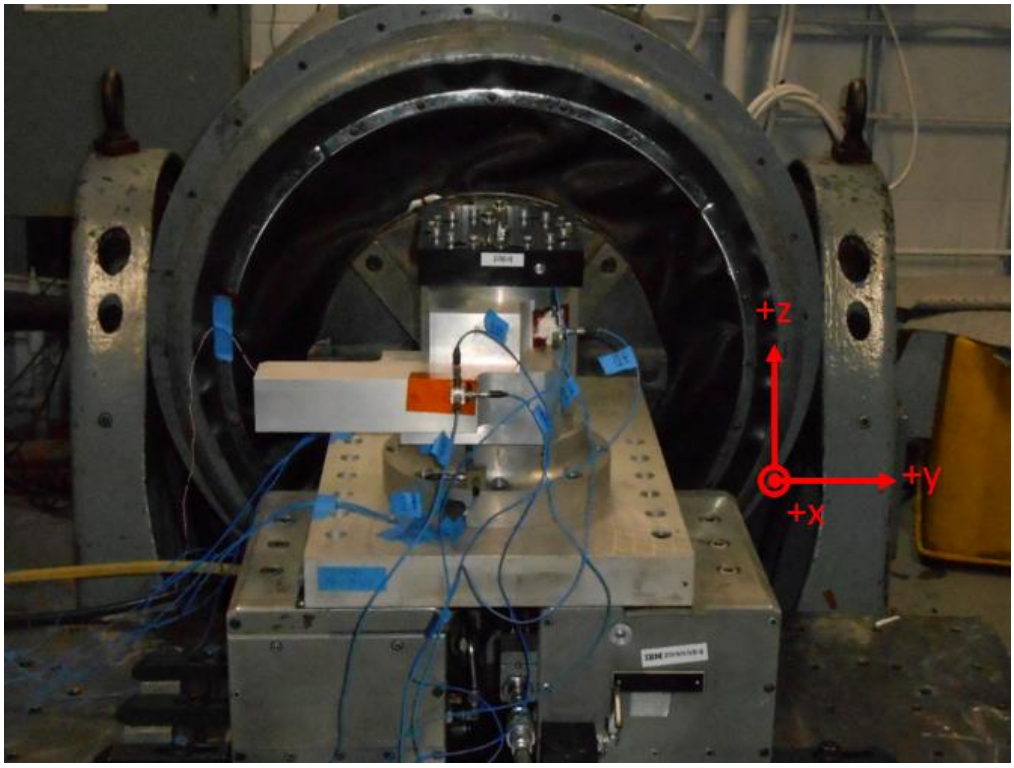


FIGURE 14
X-AXIS FIXTURE SURVEY SETUP WITH MASS SIMULATOR

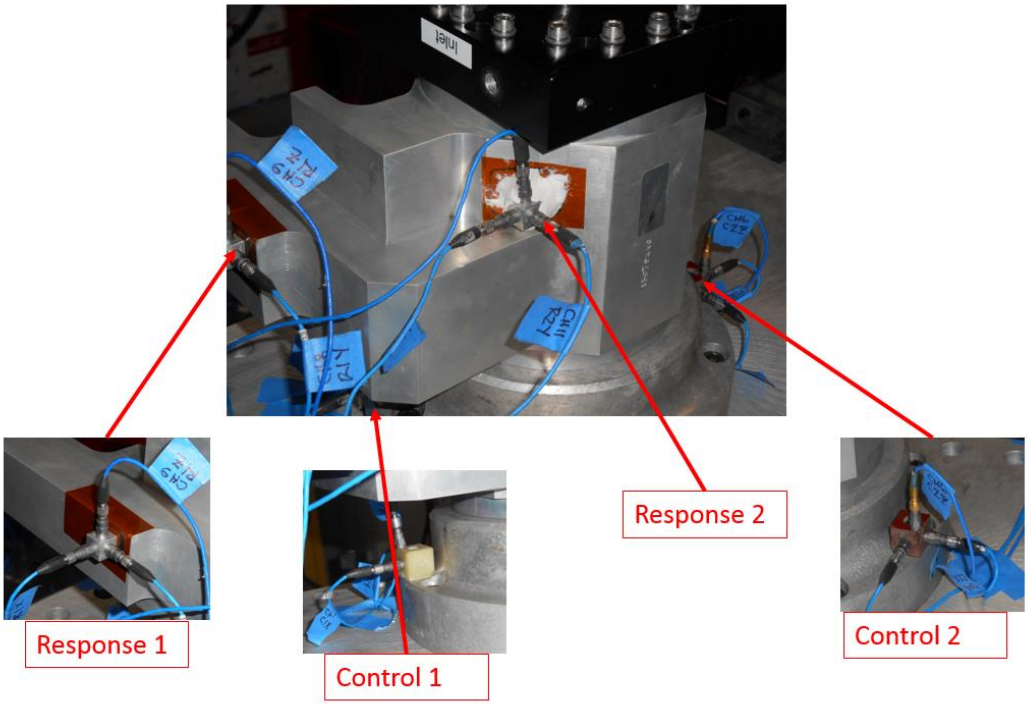


FIGURE 15
X-AXIS FIXTURE SURVEY ACCELEROMETER PLACEMENTS

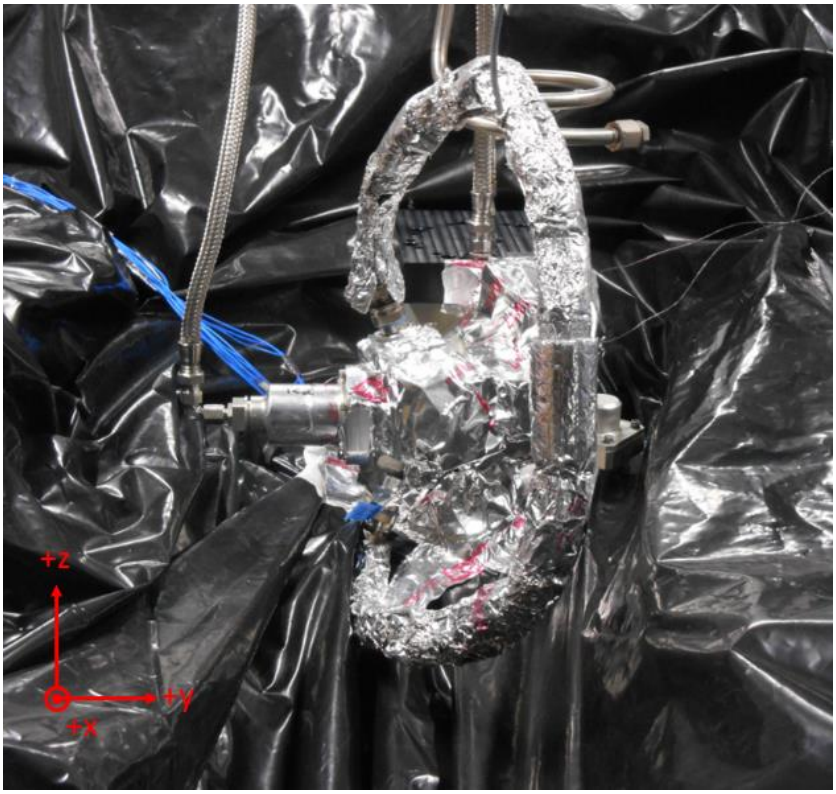


FIGURE 16
X-AXIS VIBRATION TEST SETUP

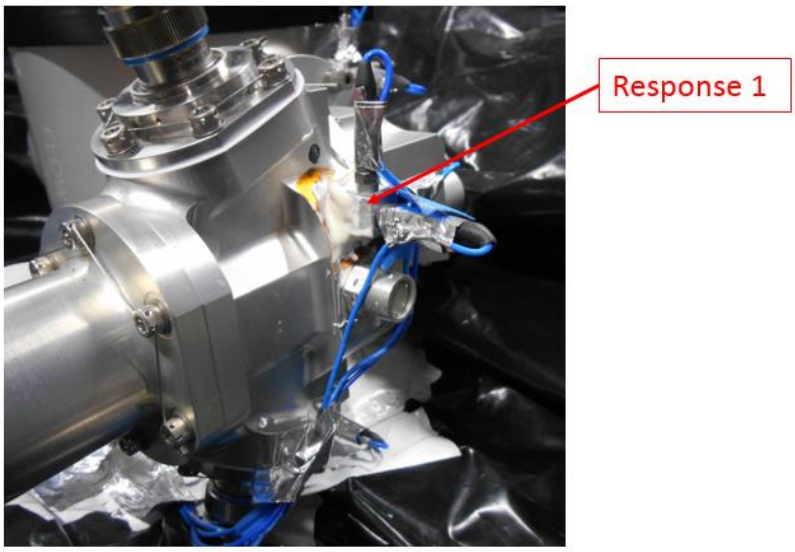


FIGURE 17
X-AXIS VIBRATION TEST SETUP: ACCELEROMETER LOCATIONS (SIDE 1)

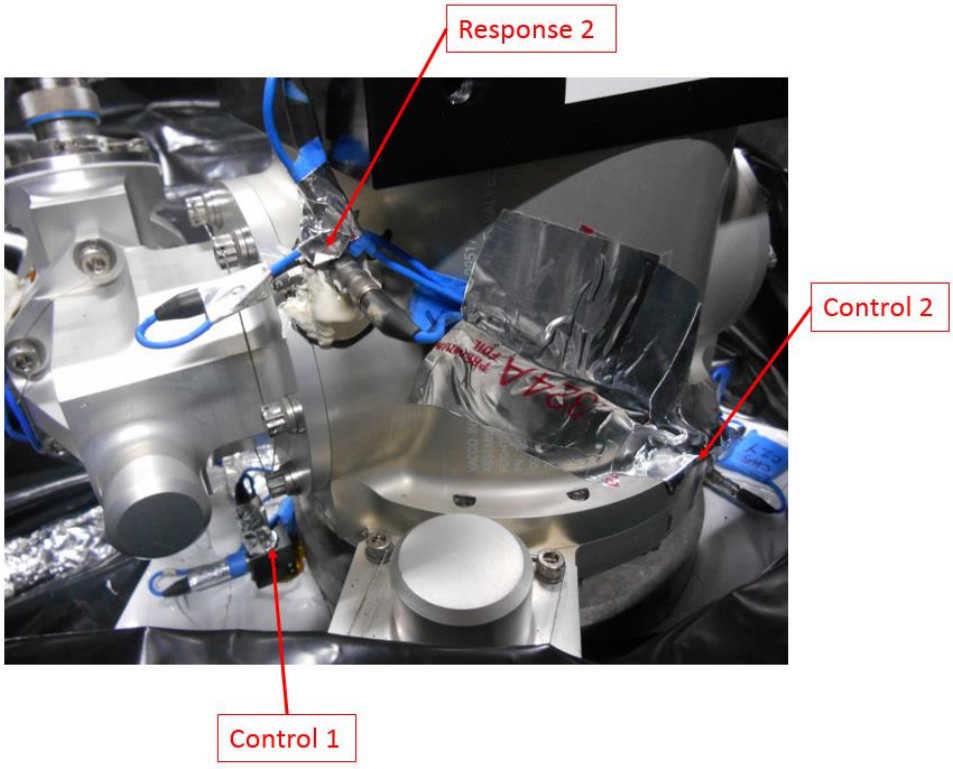


FIGURE 18
X-AXIS VIBRATION TEST SETUP: ACCELEROMETER LOCATIONS (SIDE 2)

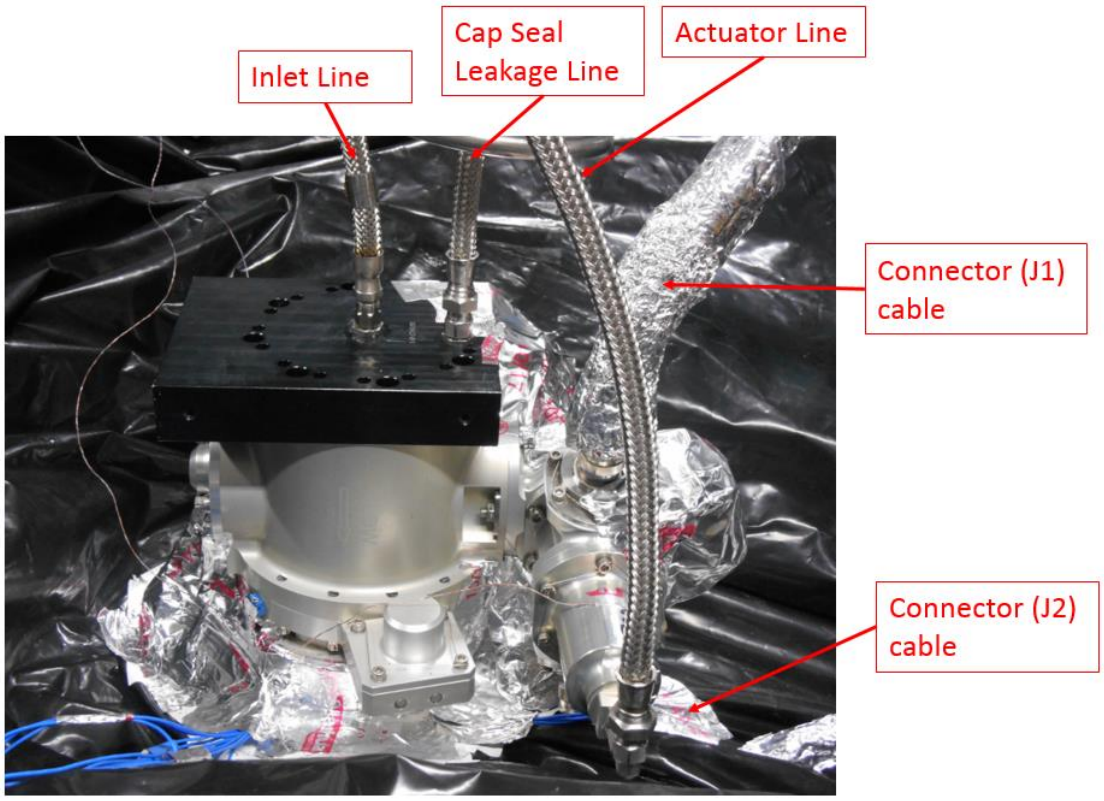


FIGURE 19
VIBRATION TEST SETUP: LINE/CABLE CONNECTIONS

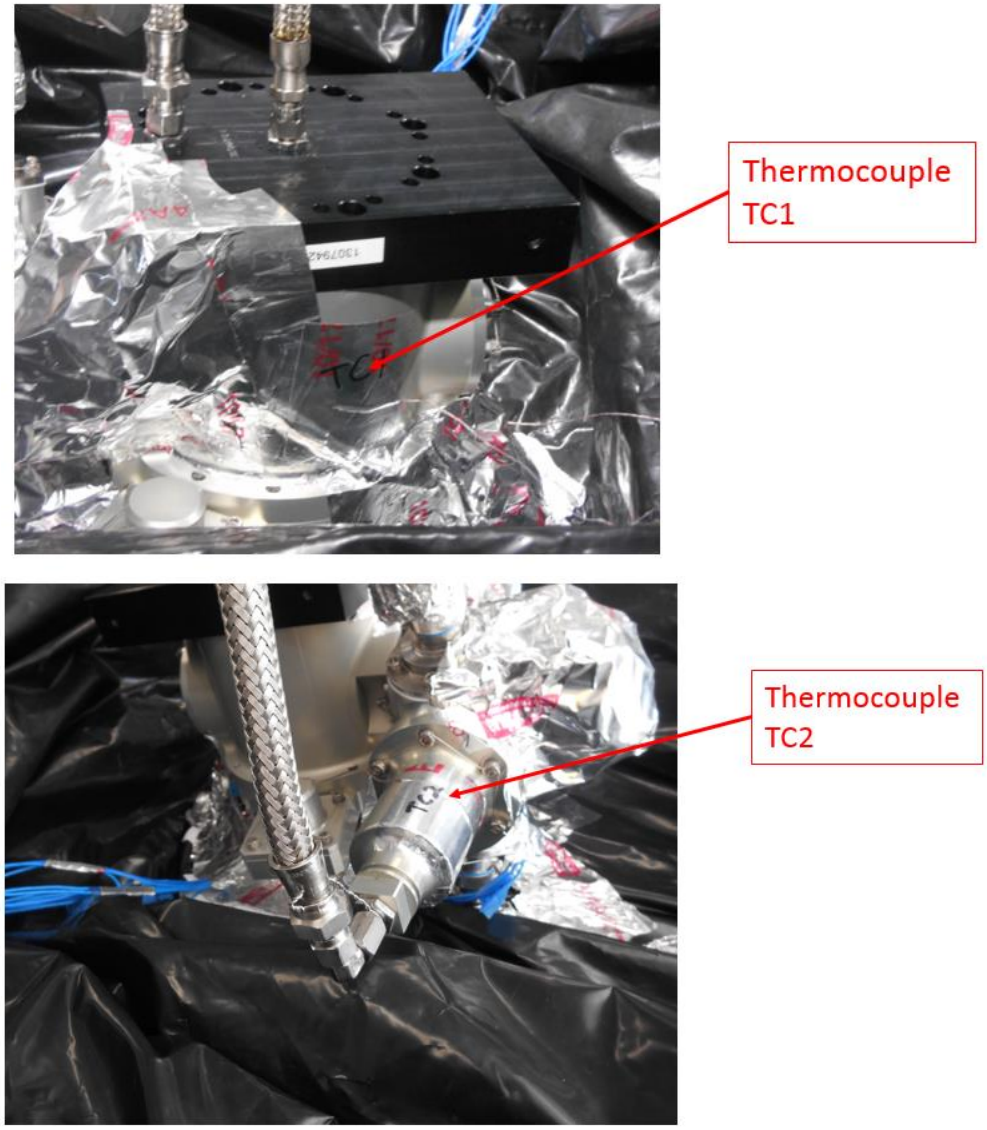


FIGURE 20
VIBRATION TEST SETUP: THERMOCOUPLE LOCATIONS

FIGURE 21
X-AXIS VIBRATION TEST CRYO SETUP

FIGURE 22
X-AXIS VIBRATION: PRE-TEST TORQUE STRIPE

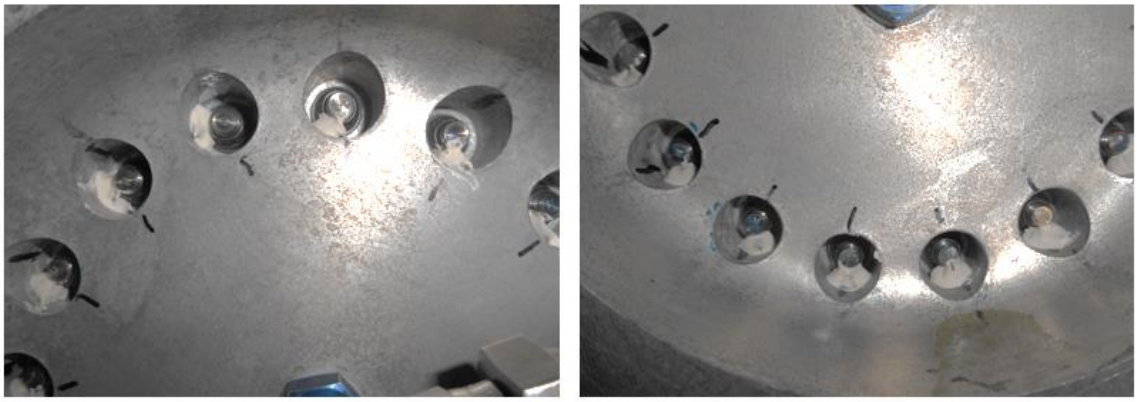


FIGURE 23
X-AXIS VIBRATION: POST-TEST TORQUE STRIPE

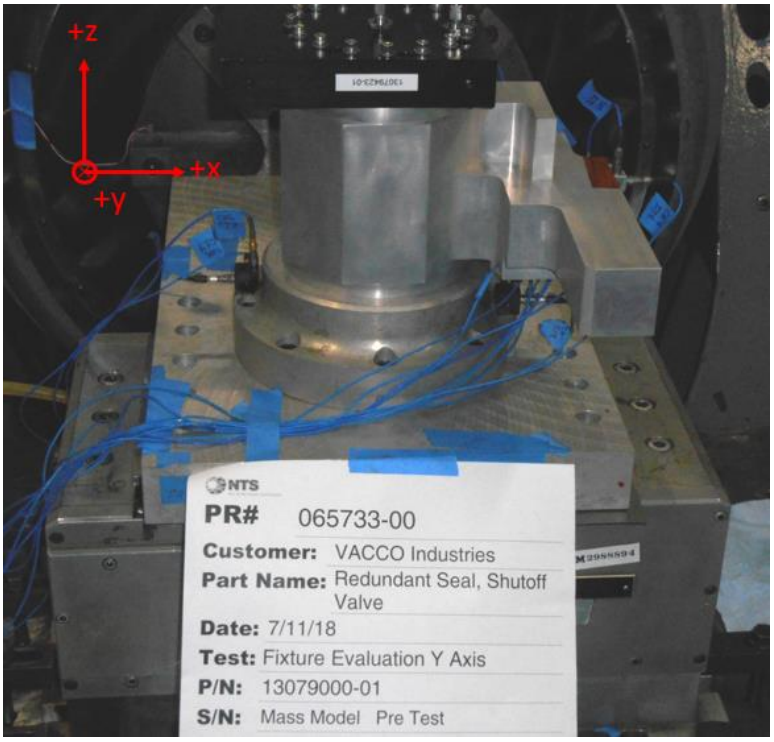


FIGURE 24
Y-AXIS FIXTURE SURVEY SETUP WITH MASS SIMULATOR

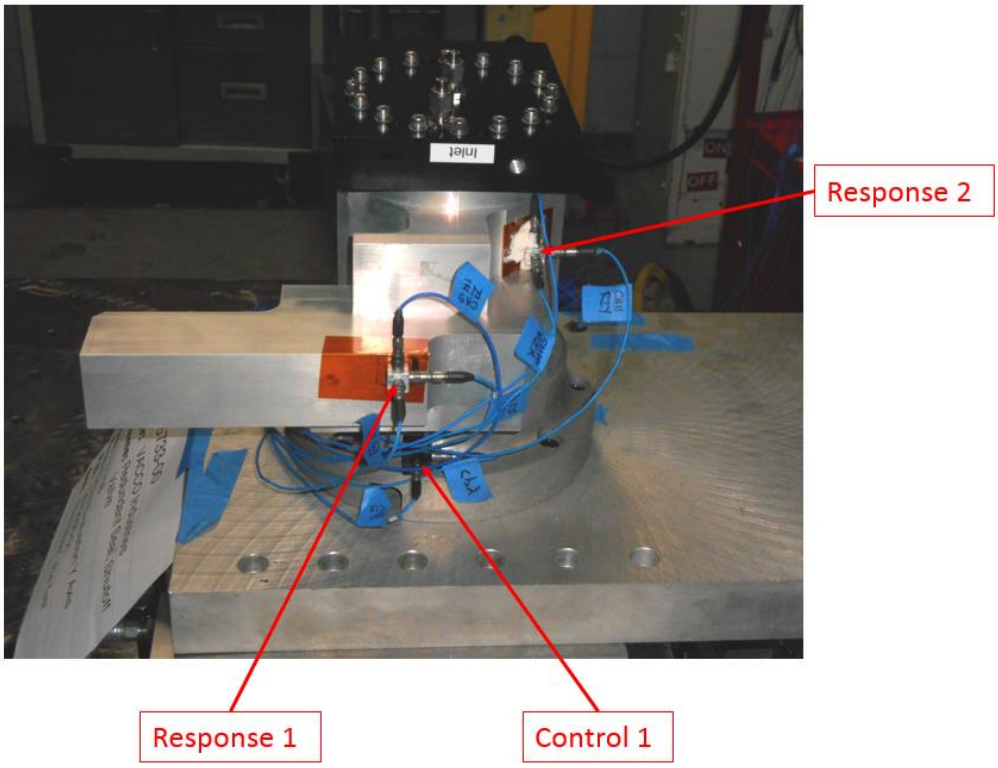


FIGURE 25 Y-AXIS FIXTURE SURVEY: ACCELEROMETER PLACEMENTS (SIDE 1)

FIGURE 26
Y-AXIS FIXTURE SURVEY: ACCELEROMETER PLACEMENTS (SIDE 2)

FIGURE 27
Y-AXIS VIBRATION TEST SETUP

FIGURE 28
Y-AXIS VIBRATION TEST SETUP: ACCELEROMETER LOCATIONS (SIDE 1)

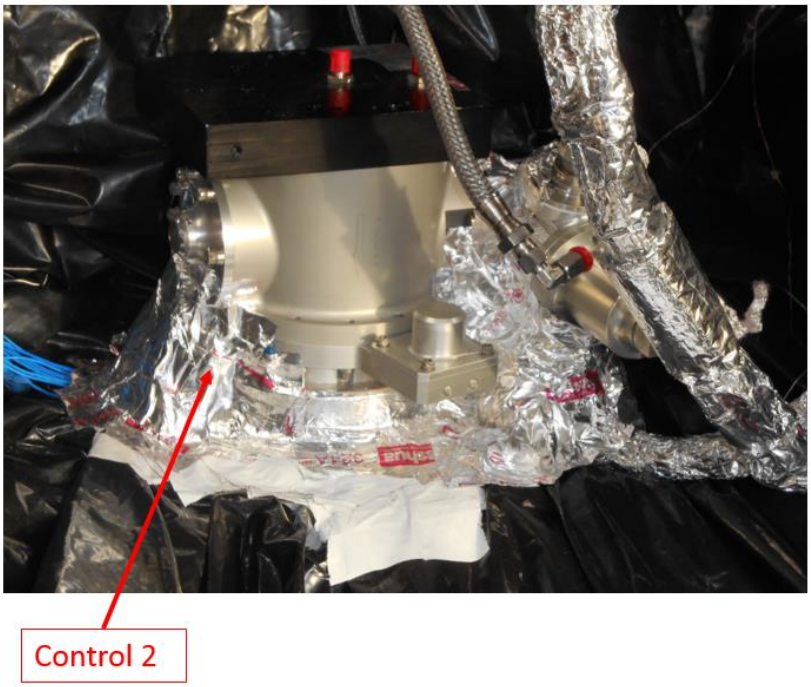


FIGURE 29
Y-AXIS VIBRATION TEST SETUP: ACCELEROMETER LOCATIONS (SIDE 2)

FIGURE 30
Y-AXIS VIBRATION TEST

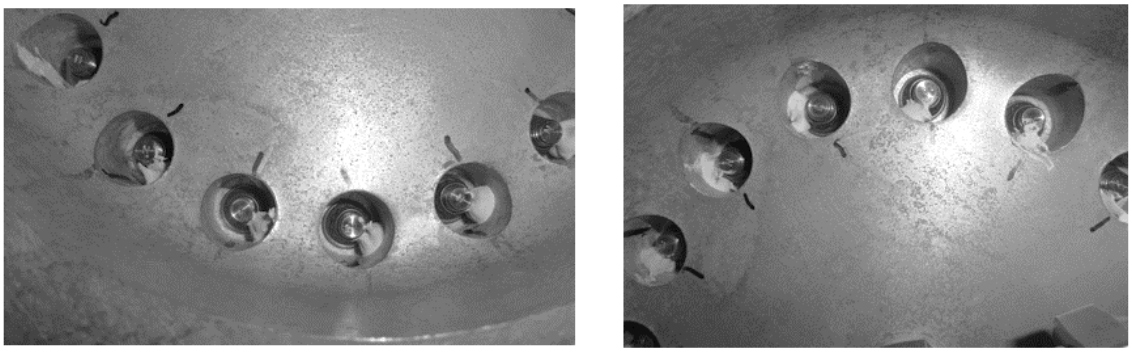


FIGURE 31
Y-AXIS VIBRATION: PRE-TEST TORQUE STRIPE

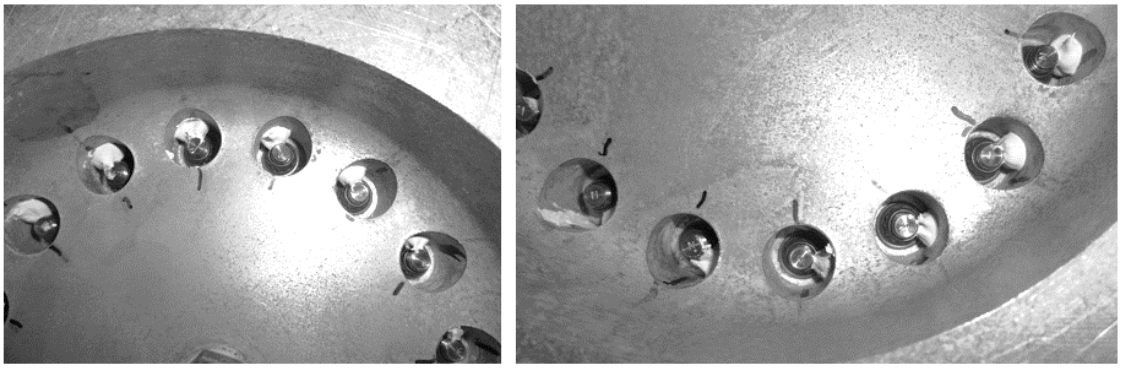


FIGURE 32
Y-AXIS VIBRATION: POST-TEST TORQUE STRIPE

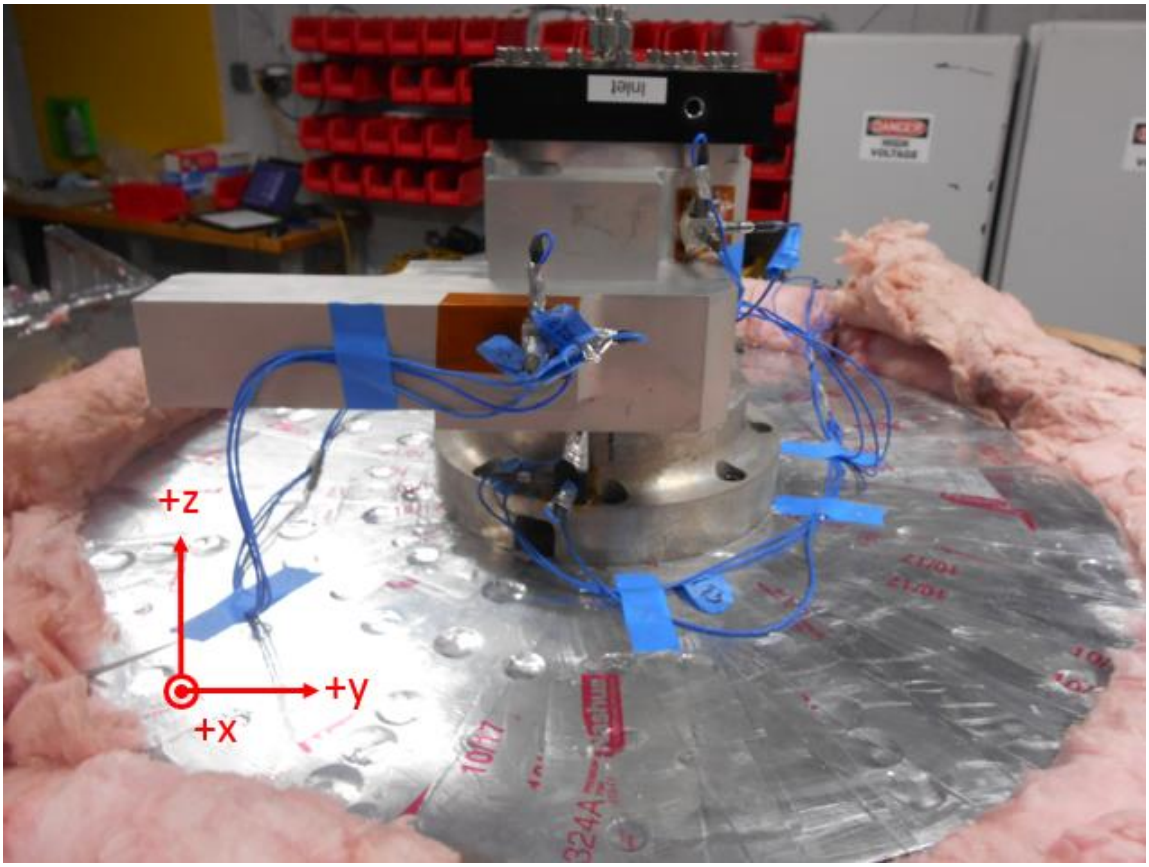


FIGURE 33
Z-AXIS FIXTURE SURVEY SETUP WITH MASS SIMULATOR

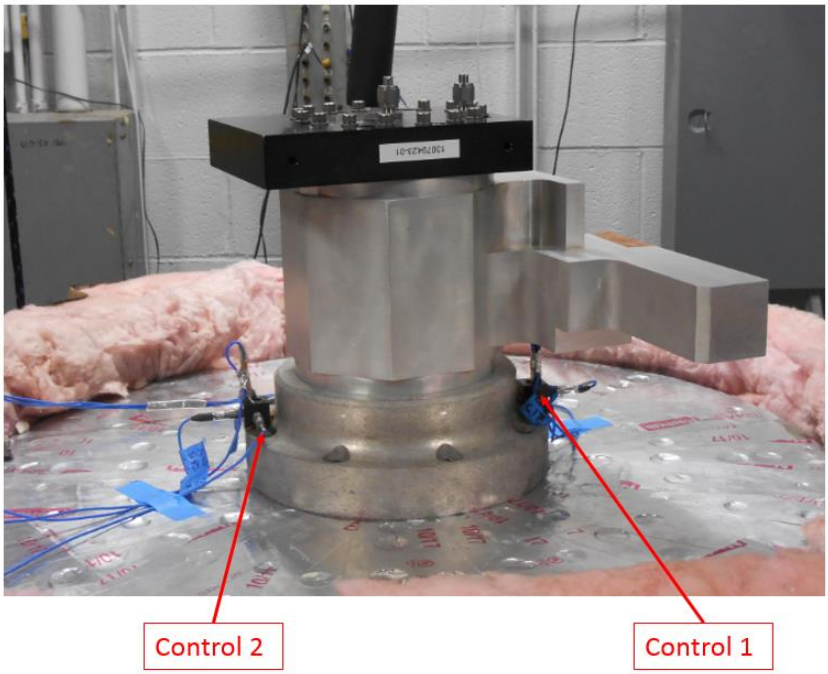


FIGURE 34
Z-AXIS FIXTURE SURVEY: ACCELEROMETER PLACEMENTS (SIDE 1)

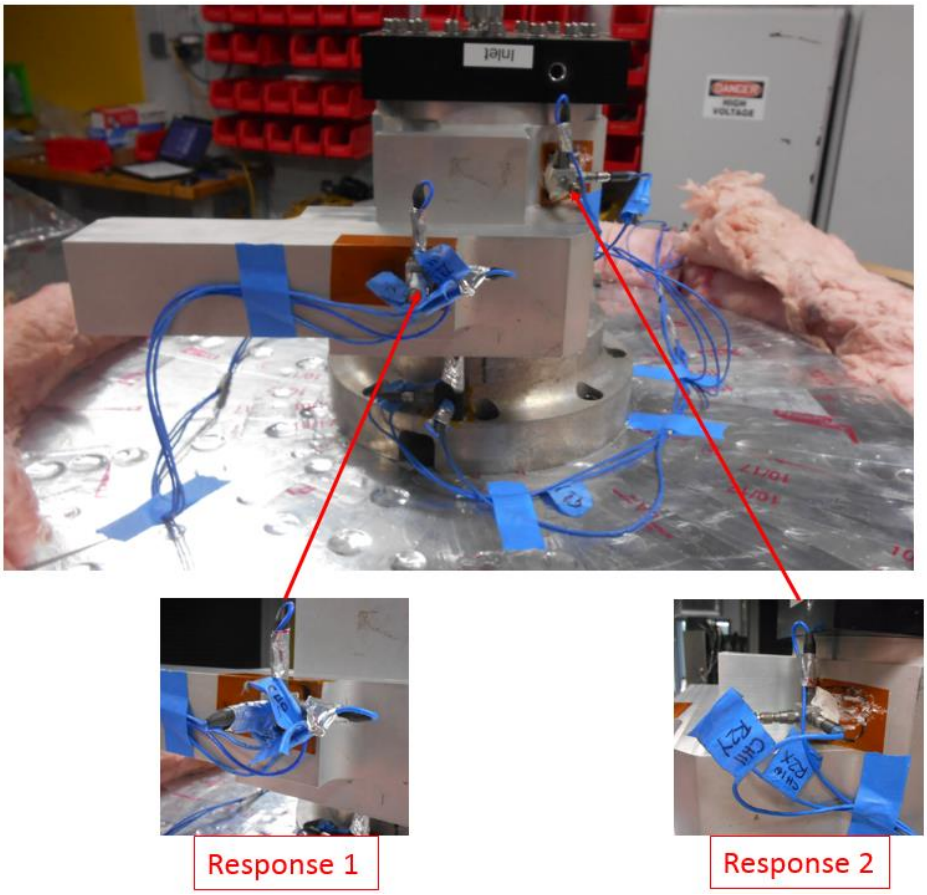


FIGURE 35
Z-AXIS FIXTURE SURVEY: ACCELEROMETER PLACEMENTS (SIDE 2)

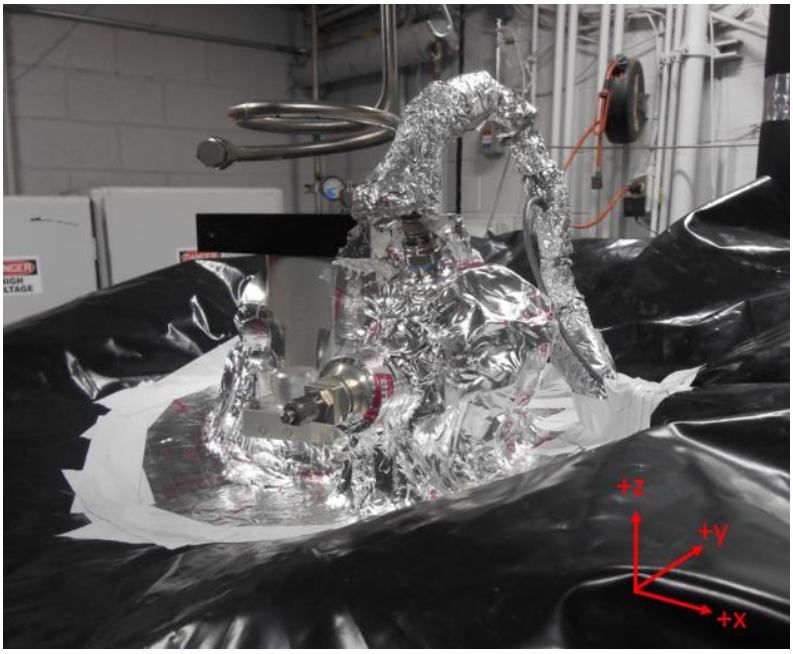


FIGURE 36
Z-AXIS VIBRATION TEST SETUP

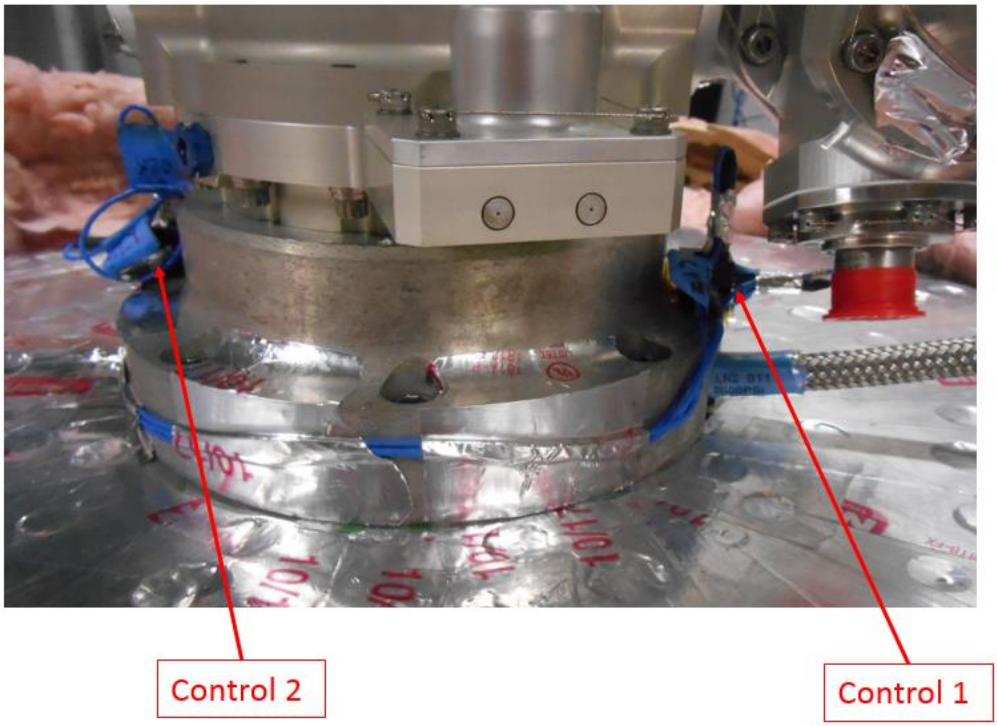


FIGURE 37
Z-AXIS VIBRATION TEST SETUP: ACCELEROMETER LOCATIONS (SIDE 1)

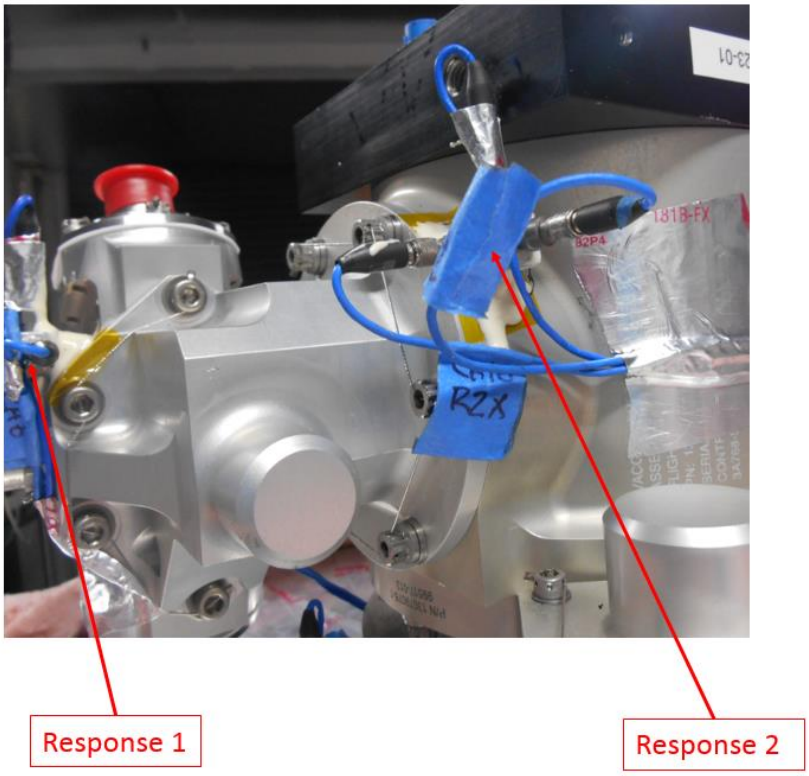


FIGURE 38
Z-AXIS VIBRATION TEST SETUP: ACCELEROMETER LOCATIONS (SIDE 2)

FIGURE 39
Z-AXIS VIBRATION: PRE-TEST TORQUE STRIPE

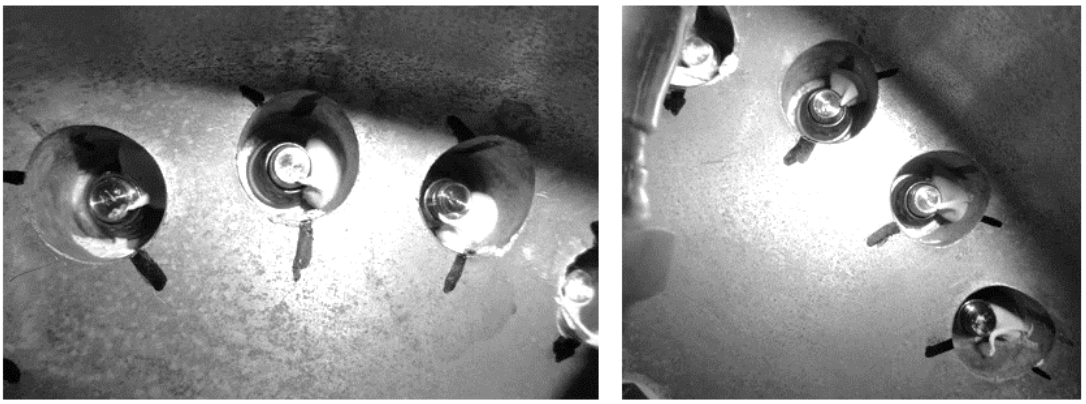


FIGURE 40
Z-AXIS VIBRATION: POST-TEST TORQUE STRIPE

6.8 Test 5- Vibration, Flight (cont.) - Post-Vibration Internal Leakage (LN2)

6.8.1 Requirements: The RS inlet-to-outlet leakage shall be less than 400 scim. There shall be no visual evidence of damage or permanent deformation of the test unit. Mounting fasteners shall not have loosened as verified by visual inspection.

6.8.2 Test Conditions: While the RS unit was still stabilized at -300±20°F immediately after the last axis of vibration testing (ref. Figure 36), the test unit was internally pressurized to 75.3 psig and inlet-to-outlet leakage was measured and recorded. After the internal leakage test, the test unit was returned to ambient temperature and visually inspected for any physical damage.

6.8.3 Results: The RS unit passed the test with inlet-to-outlet leakage of 0 scim. There was no visual evidence of damage or permanent deformation of the test unit. Visual inspection of the torque stripe verified no loosened mounting fasteners. See Figure 39 and Figure 40.

6.9 Test 6- Relief Function (Ambient)

6.9.1 Requirements: The RS relief valves shall be actuated for 100 ambient cycles.

6.9.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. See Figure 52 for similar test setup, except this test was performed outside at NTS SBO and test unit was placed on tabletop.

6.9.3 The pressure was gradually increased to 25+/-2 psig at RS outlet to open the relief valves and downstream flow at RS inlet was verified to be a minimum of 100 scim. Then the pressure was gradually decreased to 0 psig to close the relief valves. This was repeated for a total of 100 cycles.

6.9.4 Results: The RS relief valves were actuated for 100 ambient cycles.

6.10 Test 6 (cont.) – Post-Relief Function: Crack and Reseat (Ambient)

6.10.1 Requirements: The RS relief valves shall have a cracking pressure of 20 psig maximum.

6.10.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. Test unit skin temperatures were at +85.0°F (body) and +85.1°F (actuator). See Figure 52 for similar test setup, except this test was performed outside at NTS SBO and test unit was placed on tabletop.

6.10.3 While monitoring the downstream flow at RS inlet, the pressure was gradually increased at RS outlet until crack occurred (indicated by sudden increase of downstream flow) and recorded.

6.10.4 Results: The RS unit passed the test with a crack pressure of 4.4 psig.

6.11 Test 7 - Operating Life (Ambient)

6.11.1 Requirements: All opening and closing response times (command-to-switch and switch-to-switch) shall not exceed 1.5 seconds.

6.11.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. Test unit skin temperatures were at +85.1°F (body) and +85.3°F (actuator). See Figure 52 for similar test setup, except this test was performed outside at NTS SBO and test unit was placed on tabletop.

6.11.3 The RS inlet was pressurized to and maintained at 80+0/-10 psig throughout cycling. For cycles 1, 20, 40… 260, 280, 300: With the RS unit in closed position, the RS actuator was instantaneously pressurized to 600+0/-25 psig (with a solenoid valve) and opening response times were recorded on the PIB timer. With the RS unit in open position, the pressure was gradually increased to 880+7.5/-0 psig and then instantaneously depressurized to 0 psig. For all other cycles, the RS actuator was instantaneously pressurized to 740±25 psig to open the valve and pressure was instantaneously removed to close the valve.

6.11.4 Results: The RS unit passed the Operating Life (Ambient) test as all opening and closing response times did not exceed 1.5 seconds. Test results are summarized in the table below:

Cycle #	Opening Response Time		Closing Response Time	
	COMM-SW	SW-SW	COMM-SW	SW-SW
1	0.394	0.19	1.175	0.18
20	0.289	0.15	0.818	0.15
40	0.293	0.15	0.764	0.15
60	0.264	0.13	0.810	0.15

80	0.263	0.13	0.778	0.15
100	0.266	0.14	0.735	0.16
120	0.259	0.13	0.738	0.16
140	0.256	0.15	0.738	0.15
160	0.256	0.15	0.719	0.16
180	0.259	0.13	0.817	0.16
200	0.262	0.13	0.768	0.17
220	0.258	0.15	0.762	0.17
240	0.261	0.13	0.773	0.16
260	0.262	0.13	0.732	0.17
280	0.265	0.13	0.740	0.16
300	0.270	0.13	0.734	0.16

6.12 Test 8 - Relief Function (LH2)

This test was performed by NTS, San Bernardino, per NTS test procedure TP065733-01. Refer to Appendix D for the NTS report.

6.12.1 Requirements: The RS relief valves shall be actuated for 100 LH2 cycles.

6.12.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. Test unit was placed in sealed chamber and externally chilled with liquid hydrogen using a spray bar. Test unit skin temperatures were stabilized at between -425°F to -400°F (body and actuator) for 30 minutes. The pressure was gradually increased to 25+/-2 psig at RS outlet to open the relief valves and downstream flow at RS inlet was verified to be a minimum of 100 scim. Then the pressure was gradually decreased to 0 psig to close the relief valves. This was repeated for a total of 100 cycles. See Figure 41.

6.12.3 Results: The RS relief valves completed 1 cycle but then could not be actuated at cycle #2. NCM0055979 was generated for this test failure. Per the NCM disposition, the test unit was warmed back up to ambient temperature and relief valves were successfully cycled 3 times as verified by measuring flow of more than 100 scim through the relief valves for each cycle. Based on this finding, it was suspected that the GN2 and/or air in the test chamber entered the test system when venting pressure out of the system after cycle #1, and the frozen nitrogen impeded the flow through the relief valves. Therefore, the test procedure was modified to add positive pressure on the lines to the test unit and vent through the downstream flowmeter station instead of through the original vent lines (SV3 and SV4). (Ref. 13079-00-QTP1 Rev C R5.) With the updated test procedure, the test was repeated and the RS relief valves were successfully actuated for 100 LH2 cycles. Ref. NCM0055979 in Appendix E.

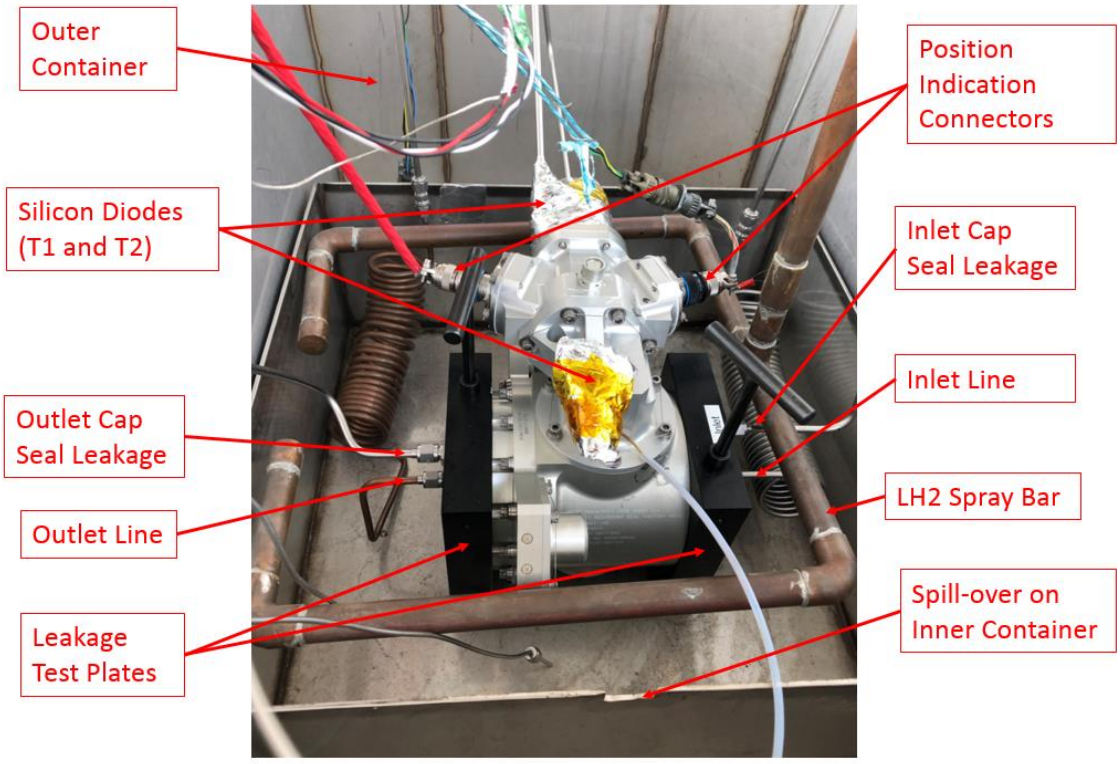


FIGURE 41
LH2 RELIEF FUNCTION: TEST SETUP

6.13 Test 9 - Operating Life (LH2)

This test was performed by NTS, San Bernardino. Refer to Appendix D for the NTS report.

6.13.1 Requirements: All opening and closing response times (command-to-switch and switch-to-switch) shall not exceed 1.5 seconds.

6.13.2 Test Conditions: This test followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, placed in sealed chamber, and externally chilled with liquid hydrogen using a spray bar. See Figure 41. Test unit skin temperatures were stabilized at -425°F to -400°F (body and actuator) for 30 minutes.

6.13.3 For cycles 1, 20, 40… 160, 180, 200: With the RS unit in closed position, the RS actuator was instantaneously pressurized to 600+0/-25 psig (with a solenoid valve) and opening response times were recorded on the DAQ. With the RS unit in open position, the pressure was gradually increased to 880+7.5/-0 psig and then instantaneously depressurized to 0 psig. For all other cycles, the RS actuator was instantaneously pressurized to 740±25 psig to open the valve and pressure was instantaneously removed to close the valve.

6.13.4 Results: The RS unit failed at the first cycle. The opening response times met requirement, with command-to-switch time of 0.76 seconds and switch-to-switch time of .65 seconds. However, the closing response times did not meet requirement: command-to-switch time was 14.4 seconds and switch-to-switch time was 7.05 seconds. NCM0056069 was generated for this test failure.

6.13.5 The failure investigation during NCM0056069 led to the probable cause that the RS actuator housing being chilled to LH2 temperature constricts the piston dynamic seals which adds more resistance that the return spring needs to overcome, causing the delayed actuation during closing. The RS actuator housing was at -423°F during the test.

6.13.6 Based on this conjecture, the test setup configuration was changed from externally chilling the entire RS unit to internally chilling the RS unit and insulating the RS body to thermally isolate it from the RS actuator portion. Additionally, a helium purge bag was installed on the RS actuator portion to prevent nitrogen to freeze onto it and inadvertently insulate it. Ref. NCM0056069 in Appendix E.

6.13.7 The test was repeated with the new test configuration. See Figure 42, Figure 43, Figure 44, and Figure 45 for new test setup configuration. This new test configuration allowed the RS body to be at -425°F to -420°F while the RS actuator housing is at a “warmer” temperature of approximately -218.8°F, which allowed the piston to actuate normally. The body and actuator temperatures were stabilized for 31 minutes. The RS unit passed, with all response times meeting requirements. Test results are summarized in the table below:

Cycle #	Opening Response Time		Closing Response Time	
	COMM-SW	SW-SW	COMM-SW	SW-SW
1	.392	.325	.759	.214
20	.389	.322	.759	.215
40	.387	.316	.757	.212
60	.386	.315	.747	.206
80	.384	.312	.754	.209
100	.385	.311	.757	.207
120	.393	.319	.761	.209
140	.387	.315	.751	.203

160	.388	.314	.754	.206
180	.389	.313	.757	.207
200	.392	.317	.752	.205

6.13.8 Based on the successful test with the new test configuration, the foaming configuration on the vehicle was changed to only foam the RS main housing and leave the actuator portion un-foamed. TaeRon also redefined the RS Body Operating Temperature requirement to distinguish between the temperatures of the RS Body and of the RS Actuator and Switching Housing portion. (Ref. 201-023702H EO2).

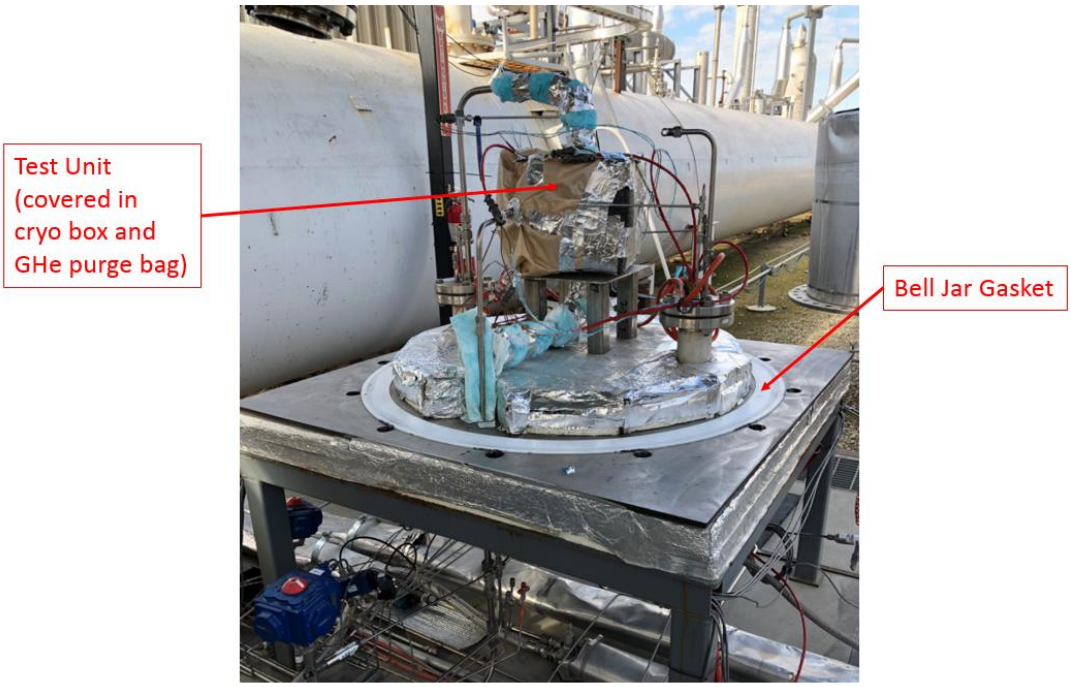


FIGURE 42
LH2 OPERATING LIFE TEST: NEW TEST SETUP CONFIGURATION

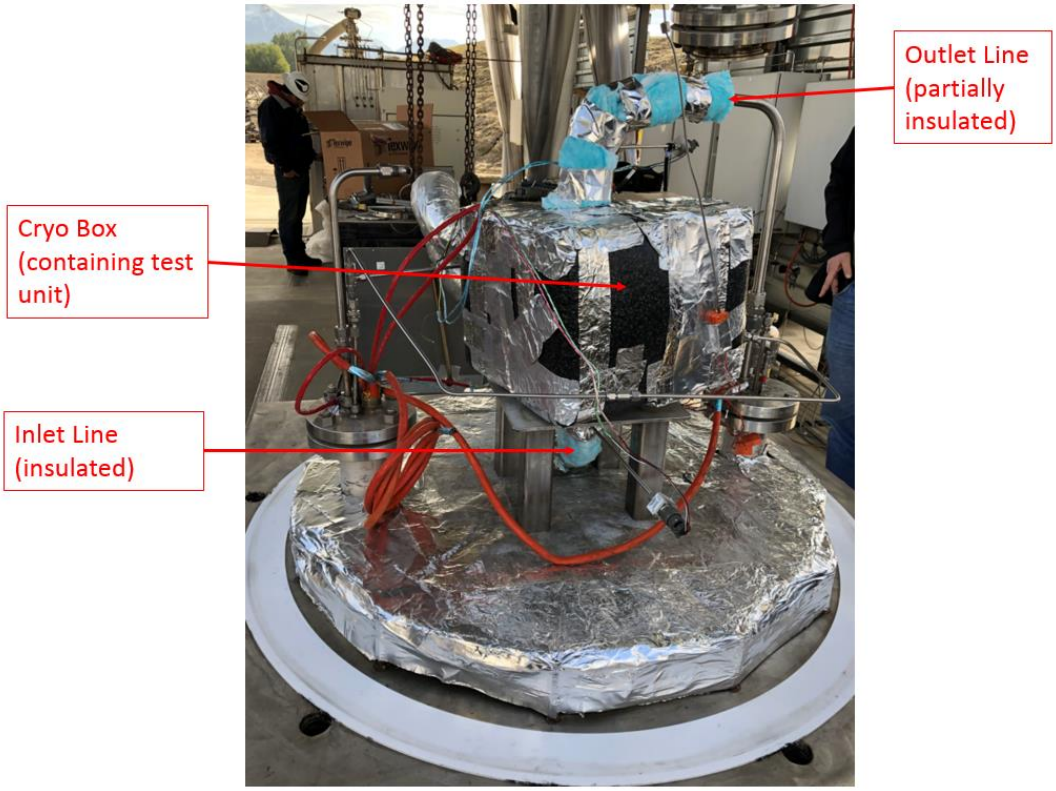


FIGURE 43
LH2 OPERATING LIFE TEST: NEW TEST SETUP (SIDE 1)

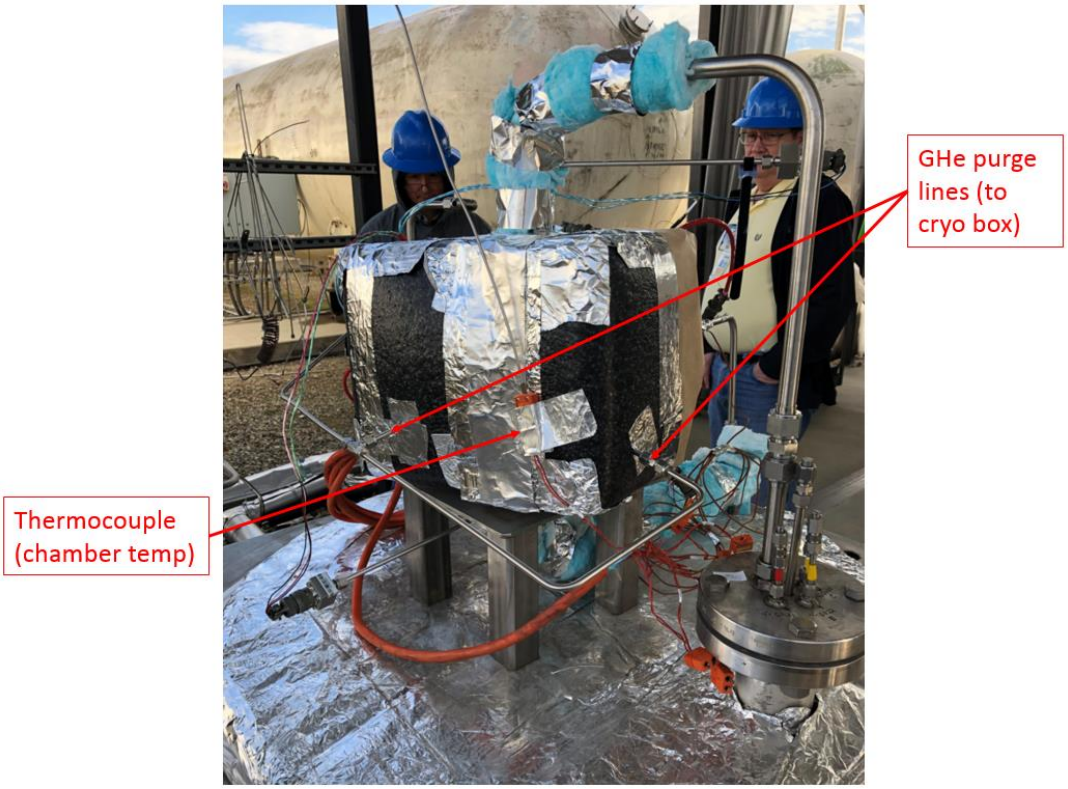


FIGURE 44
LH2 OPERATING LIFE TEST: NEW TEST SETUP (SIDE 2)

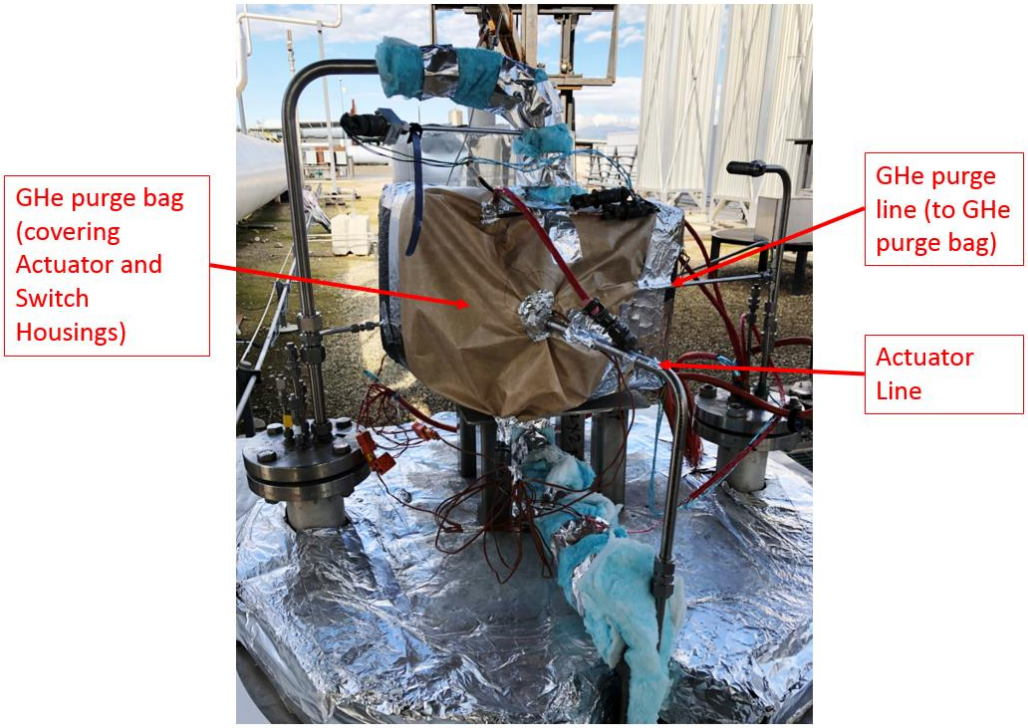


FIGURE 45
LH2 OPERATING LIFE TEST: NEW TEST SETUP (SIDE 3)

6.14 Test 9 (cont.) – Post-Op Life: Operating Pressure (LH2)

This test was performed by NTS, San Bernardino, per NTS test procedure TP065733-08. Refer to Appendix D for the NTS report.

6.14.1 Requirements: The RS unit shall have no visual evidence of damage or permanent deformation.

6.14.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, and the test unit was placed in sealed chamber and internally chilled by flowing liquid hydrogen through the unit. See Figure 42 for test setup. Test unit skin temperatures had been stabilized at -425°F to -420°F (body) for a total running time of 282 minutes. The actuator skin temperature was monitored to ensure it was colder than -41°F throughout testing.

6.14.3 With the RS unit in closed position, the RS inlet was pressurized to 87.7 psig and RS outlet was pressurized to 94.7 psig. Then the RS unit was actuated to open position, and RS inlet and outlet were pressurized to 95.2 psig and 95.4 psig, respectively.

6.14.4 Results: The RS unit passed the test as it had no visual evidence of damage or permanent deformation after the test.

6.15 Test 10 – Post-Op Life: Actuation & Response Time (LH2)

This test was performed by NTS, San Bernardino, per NTS test procedure TP065733-08. Refer to Appendix D for the NTS report.

6.15.1 Requirements: The RS unit shall be pneumatically actuated to the open position with 905 psig minimum applied to the actuator port by a solenoid valve, and shall return to the closed position upon removal of actuation pressure. The time for actuation pressure to go from 0 psig to greater than 905 psig shall be less than 0.5 second. The time for actuation pressure to go from 905 psig to less than 100 psig shall be less than 0.5 second. Application of and removal of 905 psig actuation pressure shall not result in slam damage or any other type of valve damage.

6.15.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, and the test unit was placed in sealed chamber and internally chilled by flowing liquid hydrogen through the unit. See Figure 42 for test setup. Test unit skin temperatures had been stabilized at -425°F to -420°F (body) for a total running time of 325 minutes. The actuator skin temperature had been monitored to ensure it was colder than -41°F throughout testing.

6.15.3 With the RS unit in open position, 920.4 psig on RS Actuator, and 86 psig on RS inlet, the actuation pressure was removed instantaneously. Then, with RS unit in closed position and 84 psig at RS inlet, 762.7 psig actuation pressure was applied instantaneously. Actuation pressure response times were recorded for both pressurization and depressurization of UUT.

6.15.4 Results: The RS unit passed the test as it actuated to open position with 600 psig minimum applied to the actuator and returned to closed position upon removal of actuation pressure. Application and removal of 905 psig did not result in slam damage or any other type of valve damage. Actuation pressure to go from 0 psig to greater than 905 psig was less than 0.378 seconds. Actuation pressure to go from 905 psig to less than 100 psig was 0.462 seconds.

6.16 Test 11- Post-Op Life: Crack and Reseat (LH2)

This test was performed by NTS, San Bernardino, per NTS test procedure TP065733-03. Refer to Appendix D for the NTS report.

6.16.1 Requirements: The RS relief valves shall have a cracking pressure of 20 psig maximum.

6.16.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. Test unit was placed in a sealed chamber where it was externally chilled with liquid hydrogen using a spray bar. Test unit skin temperatures were stabilized at -425°F to -420°F (body and actuator) for 31 minutes. See Figure 46 and Figure 47.

6.16.3 With the RS unit in closed position, the pressure at RS outlet was increased until flow at inlet exceed 100 scim. Then pressure at RS outlet was removed and pressure allowed to decay until flow at inlet reduced to less than 100 scim.

6.16.4 Results: The RS unit passed the test with a cracking pressure of 11.5 psig.

FIGURE 46
POST-OP LIFE TESTS: TEST SETUP (INSIDE CONTAINER)

FIGURE 47
POST-OP LIFE TESTS: TEST SETUP (PRIOR TO CLOSING BELL JAR)

6.17 Test 12- Leakage, External (Cryo)

This test was performed by NTS, San Bernardino, per NTS test procedure TP065733-02. Refer to Appendix D for the NTS report.

6.17.1 Requirements: External leakage shall be less than 20 scim.

6.17.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, and the test unit was placed in a sealed chamber where it was externally chilled with liquid hydrogen using a spray bar. Test unit skin temperatures had been stabilized at -425°F to -420°F (body and actuator) for a total running time of 70 minutes. See Figure 46 and Figure 47.

6.17.3 With the RS unit in open position, the unit was pressurized to 100+0/-10 psig and held for 5 minutes. Then the upstream (total) leakage and cap seal leakage were recorded.

6.17.4 Results: The RS unit passed the test with an upstream leakage of 9.09 scim and cap seal leakage of 0.34 scim for a net leakage of 8.75 scim. (Note: the leakage result is based on an average of the leakage fluctuations seen on the flowmeter.)

6.18 Test 13- Leakage, Actuator (LH2)

This test was performed by NTS, San Bernardino. Refer to Appendix D for the NTS report.

6.18.1 Requirements: Actuator leakage shall be less than 100 scim.

6.18.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, and the test unit was placed in a sealed chamber where it was externally chilled with liquid hydrogen using a spray bar. Test unit skin temperatures had been stabilized at -425°F to -420°F (body and actuator) for a total running time of 115 minutes. See Figure 46 and Figure 47.

6.18.3 The pressure at actuator was gradually increased to 770±30 psig and held for 5 minutes. Then the actuator leakage was recorded.

6.18.4 Results: The RS unit failed the test with actuator leakage of greater than 6.1 slm (372 scim). NCM0056965 was generated for this test failure. While test unit was at LH2 temperature, NTS was authorized to proceed with the LH2 Internal Leakage test.

6.18.5 Per NCM0056965 disposition, after the LH2 Internal Leakage test (first attempt, see Test Step 14) the test unit was warmed back up to ambient temperature. Test setup remained unchanged (ref. Figure 46 and Figure 47). With the test unit at ambient temperature, 770±30 psig was applied on the RS Actuator and maintained during chilldown. This allowed the test unit to be properly opened at ambient temperature (and avoid any temperature effect on opening of actuator) and remain in open position throughout chilldown and testing. The test unit was externally chilled with liquid hydrogen using a spray bar. Test unit skin temperatures were stabilized at -425°F to -420°F (body and actuator) for 30 minutes. Then the actuator leakage was recorded.

6.18.6 The RS unit failed the test again, with actuator leakage of 202 scim but showed a significant improvement from the first attempt with leakage of greater than 372 scim (see above). The improved leakage, however, still did not meet the allowable of 100 scim. Ref. NCM0056965 in Appendix E.

6.18.7 The excessive actuator leakage was attributed to the test setup which externally chills the test unit which causes the RS Actuator to be at a much colder temperature (-400±20°F) than what it would see in actual application (approximately -270°F, as demonstrated with the LH2 Operating Life test setup). TAERON and TaeRon agreed that the actuator leakage using this test setup is not indicative

of actuator leakage in actual application. Instead, the LN2 Actuator Leakage test would be a closer simulation to actual application as the Actuator will not be colder than LN2 temperature. Therefore, TaeRon has revised the ED requirement to allow LN2 Actuator Leakage test to satisfy the RS Actuator Leakage requirement. Ref. 201-023702H EO6.

6.19 Test 14- Leakage, Internal (LH2)

This test was performed by NTS, San Bernardino. Refer to Appendix D for the NTS report.

6.19.1 Requirements: Internal leakage shall be less than 400 scim.

6.19.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, and the test unit was placed in a sealed chamber where it was externally chilled with liquid hydrogen using a spray bar (ref. Figure 46). Test unit skin temperatures had been stabilized at -400±20°F (body) and -400±20°F (actuator) for a total running time of 140 minutes.

6.19.3 With the RS unit was in open position, it was pressurized to 75±5 psig through the RS inlet. Then the RS unit was actuated to closed position. The RS inlet was not holding the 75±5 psig and the RS outlet was not venting out; the pressures at inlet and outlet were equalizing. Per test procedure redlines, the RS unit was warmed back up to -300±20°F and then actuated open and closed. Then the RS unit was chilled back down to -400±20°F and the leakage test was repeated: with RS unit in open position, it was pressurized to 75±5 psig through the RS inlet. Then the RS unit was actuated to closed position. The RS inlet was not holding the 75±5 psig and the RS outlet was not venting out; the pressures at inlet and outlet were equalizing again. The test was terminated.

6.19.4 Results: The RS unit failed the test with excessive leakage from inlet to outlet, causing inlet pressure to be unstable and outlet pressure not being able to vent out NCM0056966 was generated for this test failure.

6.19.5 Per NCM0056966 disposition, after the LH2 Actuator Leakage retest per NCM0056965, the test unit was warmed back up to ambient temperature. Test setup remained unchanged (ref. Figure 42). With the test unit at ambient temperature and unit in closed position, a blanket pressure of 5+4/-3 psig was applied on the RS actuator and maintained during chilldown. This allowed the test unit to be properly closed at ambient temperature (and avoid any temperature effect on closing of actuator) and remain in closed position throughout chilldown and testing. The test unit was externally chilled with liquid hydrogen using a spray bar. Test unit skin temperatures were stabilized at -400±20°F (body) and -400±20°F (actuator) for 30 minutes. Then the internal leakage was recorded.

6.19.6 The RS unit passed the test with internal leakage of 6 scim. For information only, at the end of the test while UUT was still at LH2 temperature, the RS was actuated open and back to closed, at which point the internal leakage was excessive; inlet pressure and outlet pressure were tracking together. This confirmed our theory that the root cause of the Internal Leakage test failure is the RS actuator not being able to fully close the valve when the RS actuator is at LH2 temperature. By performing the test such that the RS actuator was set to closed position at ambient temperature and maintained closed throughout testing, it was verified that the test unit can meet the internal leakage requirement with RS body temperature at -400±20°F. Ref. NCM0056966 in Appendix E.

6.20 Test 15- Post Relief Function: Crack/Reseat (Hot)

6.20.1 Requirements: The RS relief valves shall have a cracking pressure of 20 psig maximum.

6.20.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. The test unit was placed inside the dewar and warmed up to hot temperature with a heat gun. Test unit skin temperatures were stabilized at +178.7°F (actuator) for 10 minutes. While monitoring the downstream flow at RS inlet, the pressure was gradually increased at RS outlet until crack occurred (indicated by sudden increase of downstream flow) and recorded. See Figure 48 and Figure 49.

6.20.3 Results: The RS unit passed the test with a crack pressure of 0.5 psig.

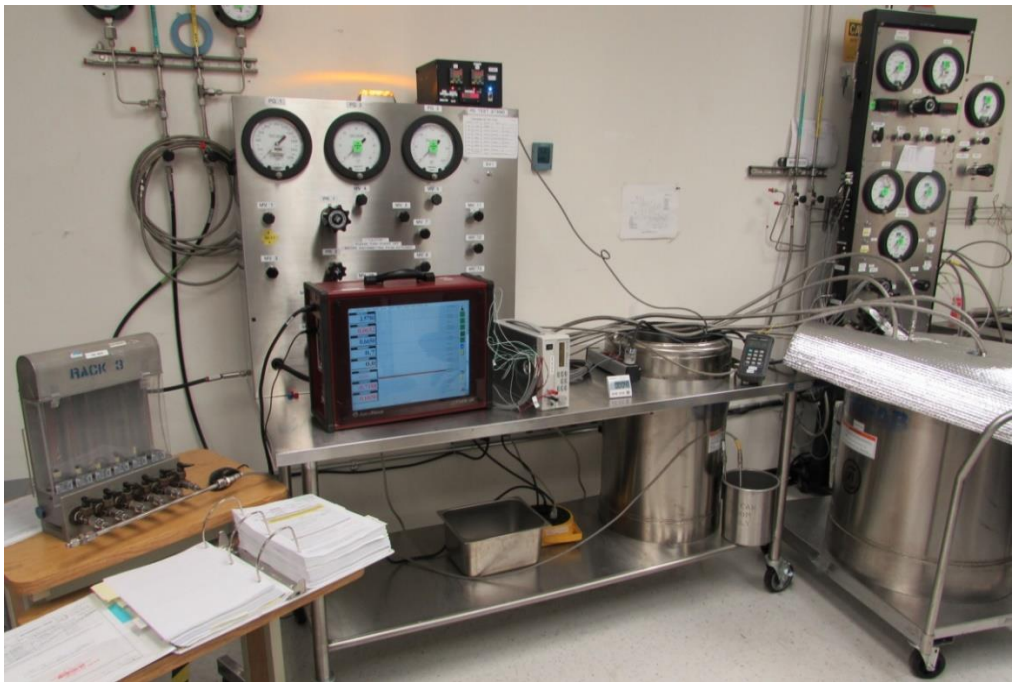


FIGURE 48
HOT LEAKAGE TESTS: TEST SETUP

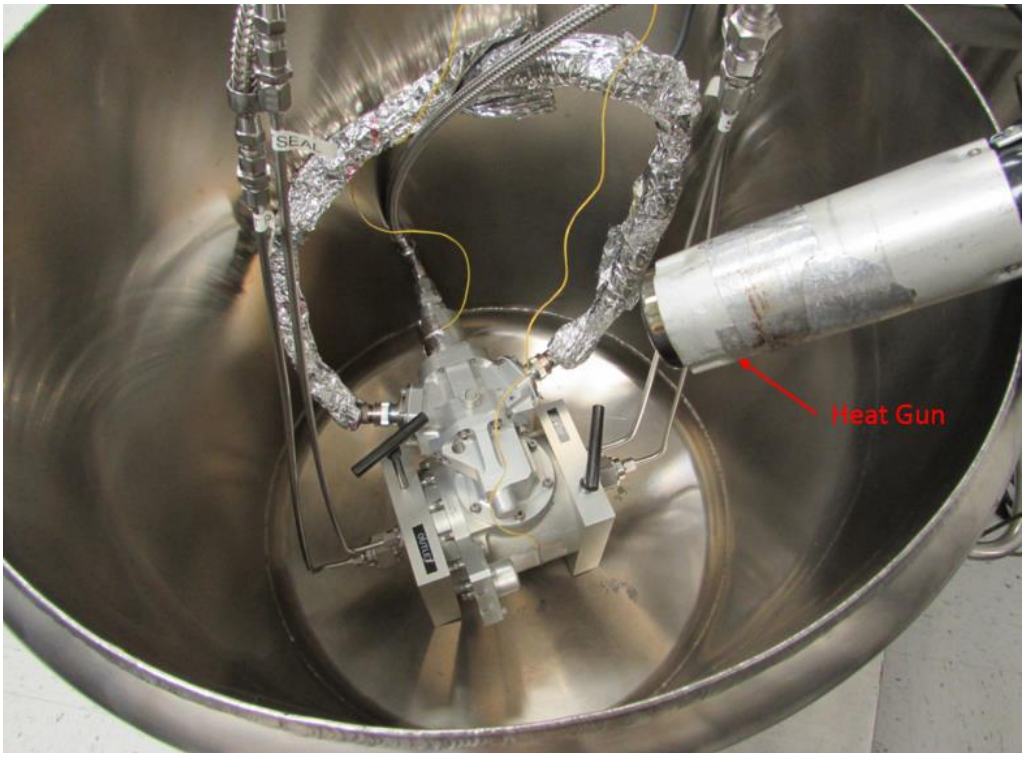


FIGURE 49
HOT LEAKAGE TESTS: TEST UNIT INSIDE DEWAR WITH HEAT GUN

6.21 Test 16- Leakage, External (Hot)

6.21.1 Requirements: With the RS unit in open position and internally pressurized to 100+0/-10 psig, the external leakage shall be less than 20 scim.

6.21.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, the test unit was placed inside the dewar, and then warmed to hot temperature with a heat gun. See Figure 48 and Figure 49. Test unit skin temperatures were stabilized at +173.6°F (actuator) for a running total time of 25 minutes. Then, the test unit was internally pressurized to 95 psig and held for 30 minutes before leakage reading was recorded.

6.21.3 Results: The RS unit passed the test with an external leakage of 0 scim.

6.22 Test 17- Leakage, Internal (Hot)

6.22.1 Requirements: With the RS unit in closed position and inlet pressurized to 80+0/-10 psig, the inlet-to-outlet leakage shall be less than 400 scim.

6.22.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, test unit was placed inside the dewar, and then

warmed up to hot temperature with a heat gun. See Figure 48 and Figure 49. Test unit skin temperatures were stabilized at +167.9°F (actuator) for a running total time of 60 minutes. Then, the RS inlet was pressurized to 74.5 psig and held for 3 minutes before leakage reading was recorded.

6.22.3 Results: The RS unit passed the test with inlet-to-outlet leakage of 0 scim.

6.23 Test 18- Leakage, Actuator (Hot)

6.23.1 Requirements: With RS actuator pressurized to 770±30 psig, the actuator leakage shall be less than 100 scim.

6.23.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. The test unit was placed inside the dewar and warmed up to hot temperature with a heat gun. Test unit skin temperatures were at +170.2°F (body) and +171.5°F (actuator). See Figure 48 and Figure 49. The RS actuator was gradually pressurized to 770 psig and leakage was recorded.

6.23.3 Results: The RS unit passed the test with an actuator leakage of 0 scim.

6.24 Test 19- Post-Op Life: Actuation and Response (Hot)

6.24.1 Requirements: The RS shall actuate to open position with 600 psig maximum applied to actuator and shall return to closed position upon removal of actuation pressure. Opening and closing response times shall not exceed 1.5 seconds for command-to-switch and 0.75 seconds for switch-to-switch.

6.24.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit, test unit was placed inside the dewar, and warmed up to hot temperature with a heat gun. See Figure 48 and Figure 49. Test unit skin temperatures were stabilized at +168.9°F (body) for a running total time of 150 minutes. The test was conducted two times because the during the BOC review of the first test it was noted that the RS inlet pressure was not within the required 80+10/-0 psig. See datasheets in Appendix B for more details.

6.24.3 The RS actuator was instantaneously pressurized to 584 psig (with solenoid valve) and test unit was verified for open position indication. Then, the actuation pressure was removed and test unit was verified for closed position indication.

6.24.4 With the test unit in closed position and RS inlet pressurized to 86 psig, the RS actuator was instantaneously pressurized to 600 psig (with solenoid valve) and response times were recorded on the position indication box timers. With the test unit now in open position, the actuation pressure was gradually increased to 910 psig and instantaneously removed (with solenoid valve), and response times were recorded.

6.24.5 Results: The RS unit passed the test by opening with 600 psig, closing at 910 psig, and having the following response times:

Opening Response Time (Command-to-switch)	0.279 seconds
Opening Response Time (Switch-to-switch)	0.16 seconds
Closing Response Time (Command-to-switch)	0.712 seconds
Closing Response Time (Switch-to-switch)	0.14 seconds

6.25 Test 20- Post-Op Life: Leakage, Internal (LN2)

6.25.1 Requirements: With the RS unit in closed position and inlet pressurized to 80+0/-10 psig, the inlet-to-outlet leakage shall be less than 400 scim.

6.25.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit. The test unit was placed inside the dewar and partially submerged with LN2. See Figure 50 and Figure 51. Test unit skin temperatures were stabilized at -308.0°F (body) and -301.2°F (actuator) for 30 minutes. Then, the RS inlet was pressurized to 73.5 psig and held for 3 minutes before leakage reading was recorded.

6.25.3 Results: The RS unit passed the test with inlet-to-outlet leakage of 0 scim.

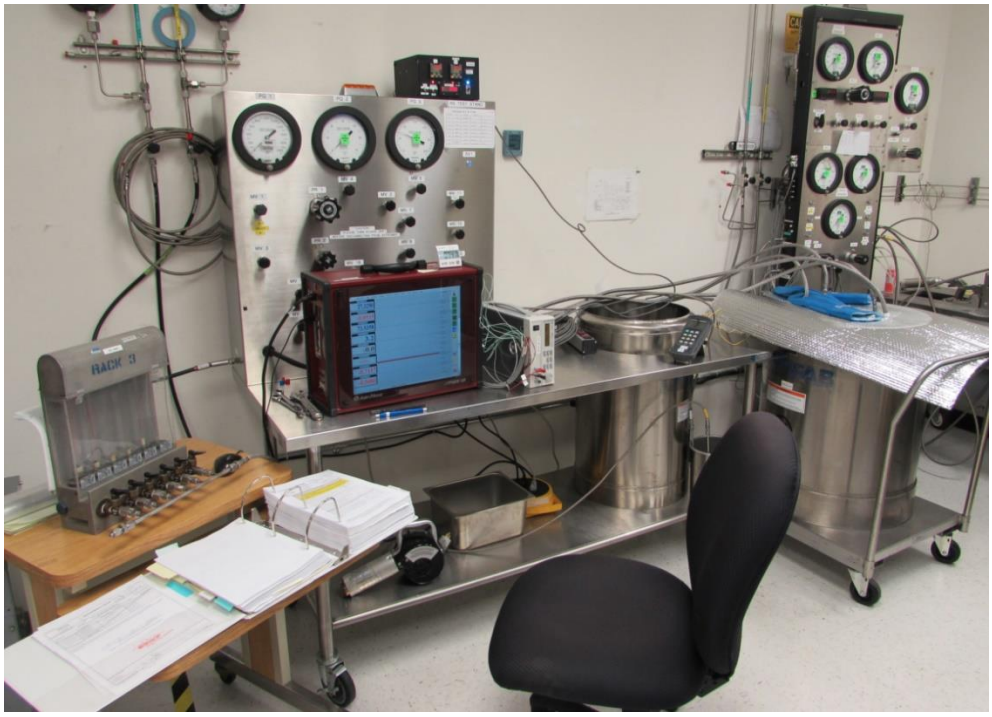


FIGURE 50
LN2 LEAKAGE TESTS: TEST SETUP

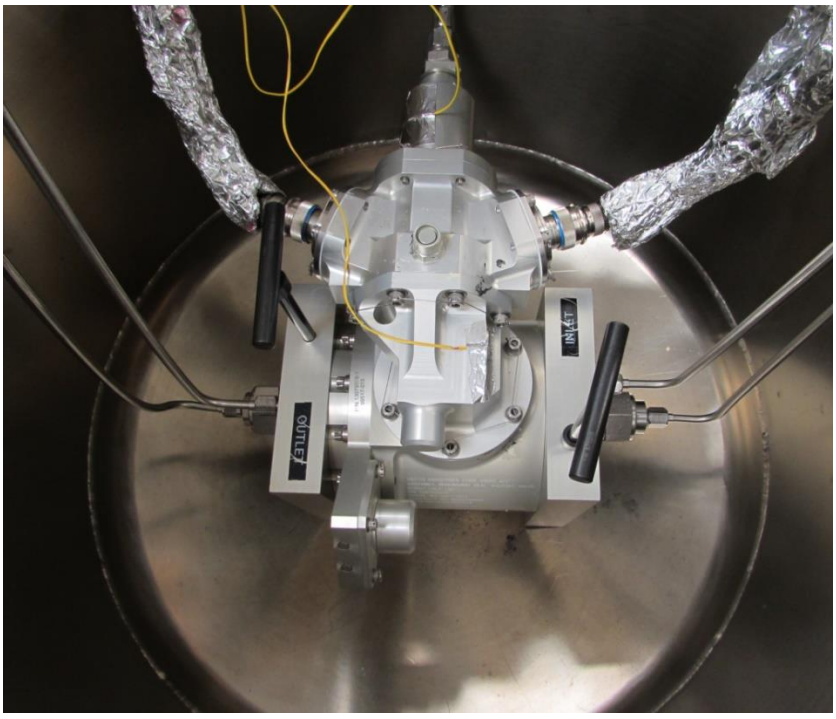


FIGURE 51
LN2 LEAKAGE TESTS: TEST UNIT INSIDE DEWAR (PRIOR TO LN2 FILL)

6.26 Test 21- Post-Op Life: Leakage, External (LN2)

6.26.1 Requirements: With the RS unit in open position and internally pressurized to 100+0/-10 psig, the external leakage shall be less than 10 scim.

6.26.2 Test Conditions: This test immediately followed the previous test, where the leakage test fixtures (P/N 13079423-01) were installed on the test unit, test unit was placed inside the dewar, and partially submerged with LN2. See Figure 50 and Figure 51. Test unit skin temperatures were stabilized at -308.1°F (body) and -302.0°F (actuator) for a running total time of 40 minutes. Then, the test unit was internally pressurized to 95.6 psig and held for 5 minutes before leakage reading was recorded.

6.26.3 Results: The RS unit passed the test with an external leakage of 0.9 scim.

6.27 Test 22- Post-Op Life: Leakage, Actuator (LN2)

6.27.1 Requirements: With RS actuator pressurized to 770±40 psig, the actuator leakage shall be less than 100 scim.

6.27.2 Test Conditions: This test immediately followed the previous test, where the leakage test fixtures (P/N 13079423-01) were installed on the test unit, test unit was placed inside the dewar, and partially submerged with LN2. See Figure 50 and Figure 51. Test unit skin temperatures were stabilized at -307.7°F (body) and -298.8°F (actuator) for 60 minutes. The RS actuator was gradually pressurized to 765 psig and held for 5 minutes before leakage reading was recorded.

6.27.3 Results: The RS unit passed the test with an actuator leakage of 91.9 scim.

6.28 Test 23- Post-Op Life: Relief and Function (LN2)

6.28.1 Requirements: The RS relief valves shall have a cracking pressure of 20 psig maximum.

6.28.2 Test Conditions: This test immediately followed the previous test, where the leakage test fixtures (P/N 13079423-01) were installed on the test unit, test unit was placed inside the dewar, and partially submerged with LN2. See Figure 50 and Figure 51. Test unit skin temperatures were stabilized at -307.7°F (body) and -301.0°F (actuator) for a total running time of 70 minutes. While monitoring the downstream flow at RS inlet, the pressure was gradually increased at RS outlet until crack occurred (indicated by sudden increase of downstream flow) and recorded.

6.28.3 Results: The RS unit passed the test with a crack pressure of 0.6 psig.

6.29 Test 24- Post-Op Life: Response Time (LN2)

6.29.1 Requirements: The RS shall actuate to open position with 600 psig maximum applied to actuator and shall return to closed position upon removal of actuation pressure. The RS shall actuate to open position with 905 psig minimum applied to actuator and shall return to closed position upon removal of actuation pressure. Opening and closing response times shall not exceed 1.5 seconds for command-to-switch and 0.75 seconds for switch-to-switch.

6.29.2 Test Conditions: This test immediately followed the previous test, where the leakage test fixtures (P/N 13079423-01) were installed on the test unit, test unit was placed inside the dewar, and partially submerged with LN2. See Figure 50 and Figure 51. Test unit skin temperatures were stabilized at -307.7°F (body) and -301.1°F (actuator) for a total running time of 90 minutes.

6.29.3 The RS actuator was instantaneously pressurized to 600 psig (with solenoid valve) and test unit was verified for open position indication. Then, the actuation pressure was removed and test unit was verified for closed position indication. The RS actuator was instantaneously pressurized to 930 psig (with solenoid valve) and test unit was verified for open position indication. Then, the actuation pressure was removed and test unit was verified for closed position indication.

6.29.4 With the test unit in closed position and RS inlet pressurized to 86 psig, the RS actuator was instantaneously pressurized to 600 psig (with solenoid valve) and response times were recorded on the position indication box timers. With the test unit now in open position, the actuation pressure was gradually increased to 927 psig and instantaneously removed (with solenoid valve), and response times were recorded.

6.29.5 Results: The RS unit passed the test by opening with 600 psig, closing at 927 psig, and having the following response times:

Opening Response Time (Command-to-switch)	0.472 seconds
Opening Response Time (Switch-to-switch)	0.34 seconds
Closing Response Time (Command-to-switch)	1.182 seconds
Closing Response Time (Switch-to-switch)	0.36 seconds

6.30 Post-Op Life: Leakage, Internal (Ambient) — Test 25

6.30.1 Requirements: With the RS unit in closed position and inlet pressurized to 80+0/-10 psig, the inlet-to-outlet leakage shall be less than 400 scim.

6.30.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit and placed inside the dewar. See Figure 52 and Figure 53. Test unit was body temperature was at 73.7°F (body) and 77.7°F (actuator).

6.30.3 The RS inlet was pressurized to 75.5 psig and held for 5 minutes before leakage reading was recorded.

6.30.4 Results: The RS unit passed the test with inlet-to-outlet leakage of 0 scim.

FIGURE 52
AMBIENT LEAKAGE TESTS: TEST SETUP

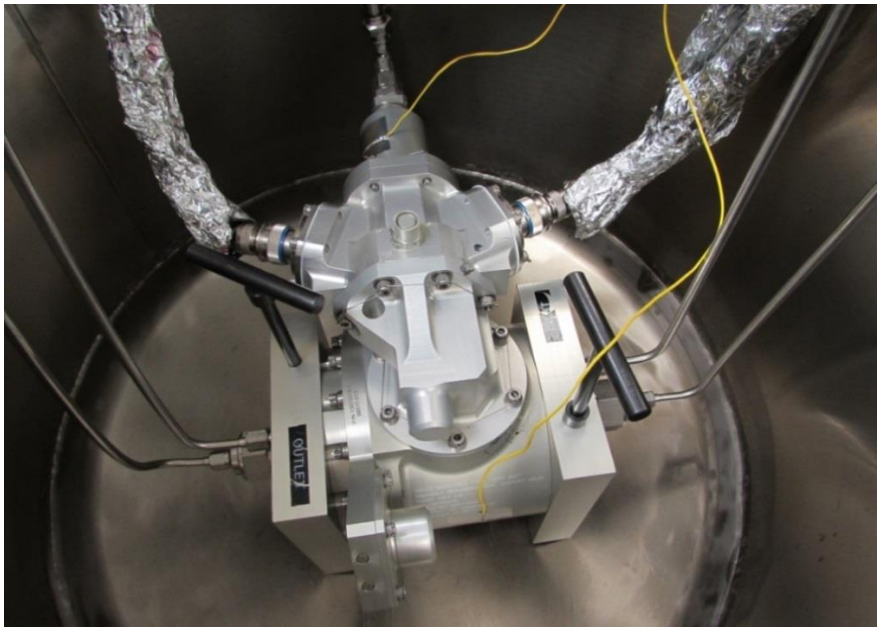


FIGURE 53
AMBIENT LEAKAGE TESTS: TEST UNIT INSIDE DEWAR

6.31 Test 26- Post-Op Life: Leakage, External (Ambient)

6.31.1 Requirements: With the RS unit in open position and internally pressurized to 100+0/-10 psig, the external leakage shall be less than 10 scim.

6.31.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit and placed inside the dewar. See Figure 52 and Figure 53. Test unit was body temperature was at 69.3°F (body) and 73.0°F (actuator).

6.31.3 The test unit was internally pressurized to 95 psig and held for 30 minutes before leakage reading was recorded.

6.31.4 Results: The RS unit passed the test with an external leakage of 0 scim.

6.32 Test 27- Post-Op Life: Leakage, Bellows Assy (Ambient)

6.32.1 Requirements: With the RS unit in closed position and internally pressurized to 100+0/-10 psig, the bellows leakage shall be less than 2.0 scim.

6.32.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit. The relief valve on the Switch Housing was removed temporarily to connect the Switch Housing cavity to a pipette. See Figure 54 and Figure 55. Test unit was body temperature was at 66.4°F (body) and 66.9°F (actuator). Then, the test unit was internally pressurized to 94.5 psig and leakage reading on the pipette was recorded.

6.32.3 Results: The RS unit passed the test with a bellows leakage of 0 scim.

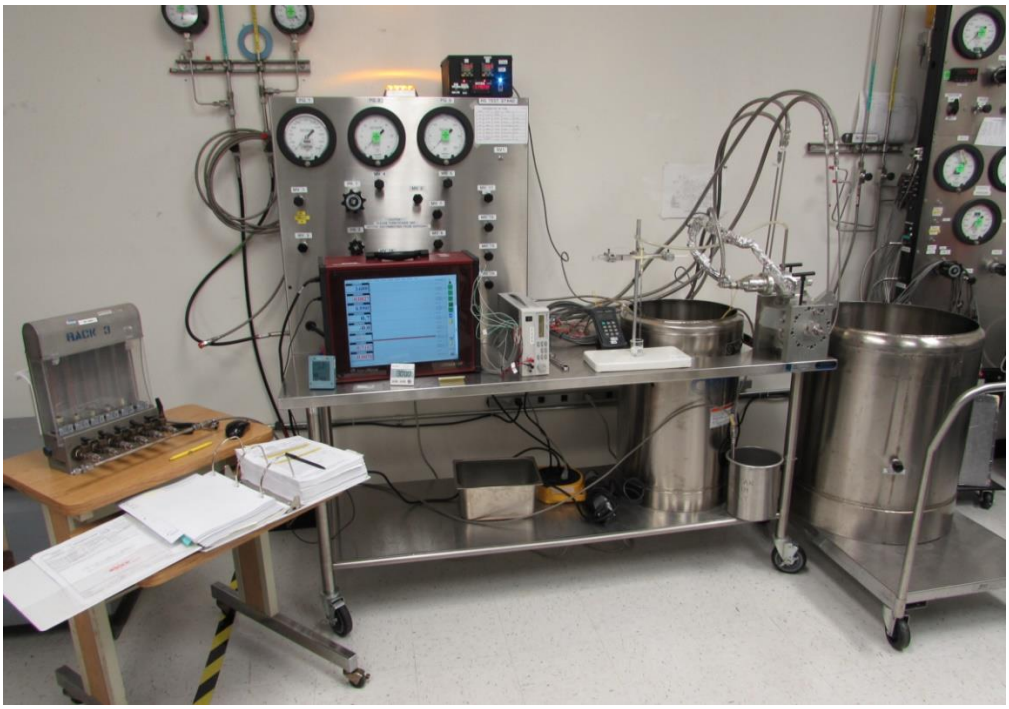


FIGURE 54
BELLOWS ASSEMBLY LEAKAGE TEST SETUP

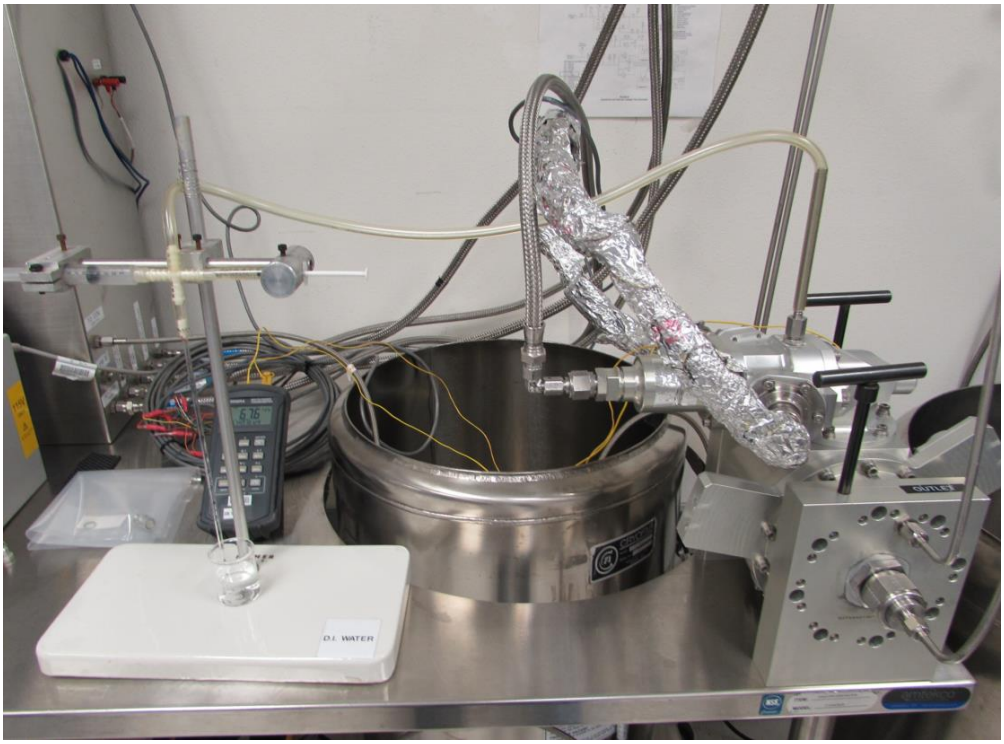


FIGURE 55
BELLOWS ASSEMBLY LEAKAGE TEST: PIPETTE SETUP

6.33 Test 28- Post-Op Life: Leakage, Actuator (Ambient)

6.33.1 Requirements: With RS actuator pressurized to 770±40 psig, the actuator leakage shall be less than 100 scim.

6.33.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit and placed inside the dewar. See Figure 52 and Figure 53. Test unit was body temperature was at 67.6°F (body) and 68.5°F (actuator). The RS actuator was gradually pressurized to 773 psig and leakage was recorded.

6.33.3 Results: The RS unit passed the test with an actuator leakage of 0 scim.

6.34 Test 29- Post-Op Life: Relief Function (Ambient)

6.34.1 Requirements: The RS relief valves shall have a cracking pressure of 20 psig maximum.

6.34.2 Test Conditions: This test immediately followed the previous test, where leakage test fixtures (P/N 13079423-01) were installed on the test unit and placed inside the dewar. See Figure 52 and Figure 53. Test unit was body temperature was at 67.8°F (body) and 68.0°F (actuator). While monitoring the downstream flow at RS inlet, the pressure was gradually increased at RS outlet until crack occurred (indicated by sudden increase of downstream flow) and recorded.

6.34.3 Results: The RS unit passed the test with a crack pressure of 3.2 psig.

6.35 Test 30- Particle Generation

6.35.1 Requirements: Actual particle count on the first sample effluent for particle generation verification shall be 0 particles of greater than 400 microns per 1L sample size. There shall be no silting.

6.35.2 Test Conditions: Using 1L of IPA, the RS unit was filled at both inlet and outlet sides, agitated inside the unit, and collected into a Millipore pad for particle count.

6.35.3 Results: The particle count did not meet the requirement, as there were 24 particles over 400 microns, ranging up to 1000 microns. NCM0057058 was generated for this test failure. The particles from the particle generation test were collected and analyzed by TAERON M&P.

6.35.4 Most of the particles over 400 microns were foreign and fiber-like materials. Of the other particles over 400 microns, a couple were metallic, possibly 7075 aluminum alloy near a source of fluorine. Based on this finding, M&P recommendation was to examine threaded 7075 alloy regions where Krytox (fluorinated lubricant) is applied or where there is a polytetraflurorethylene (PTFE) seal.

6.35.5 During the teardown, no evidence of wear was noted on any threads located within the wetted area of the valve (all fastener threads are on valve external surfaces). If 7075 particles originated from any of the internal threaded ports and/or seal areas, it would have been a result of installation and not of operation of the valve as there is no relative motion between seals and sealing surfaces and between port plugs and threaded ports.

6.35.6 Based on this rationale, none of the particles found during the particle generation test were generated during the operation of the valve. Ref. NCM0057058 in Appendix E and associated M&P Report 19R1 in Appendix F.

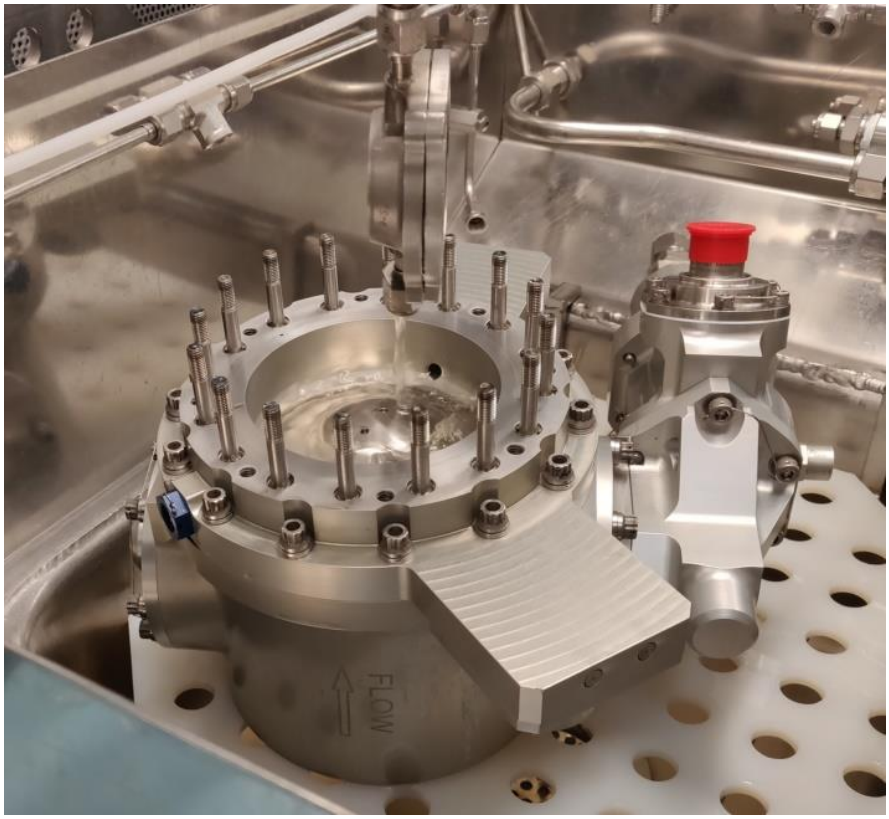


FIGURE 56
PARTICLE GENERATION TEST: IPA FILL AT OUTLET

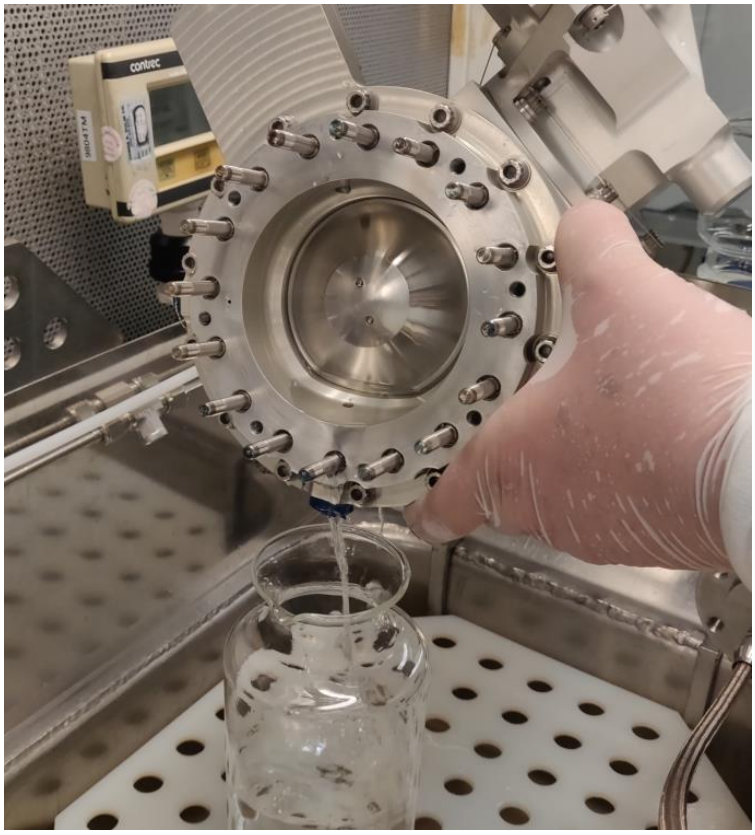


FIGURE 57
PARTICLE GENERATION TEST: IPA COLLECTION AT OUTLET

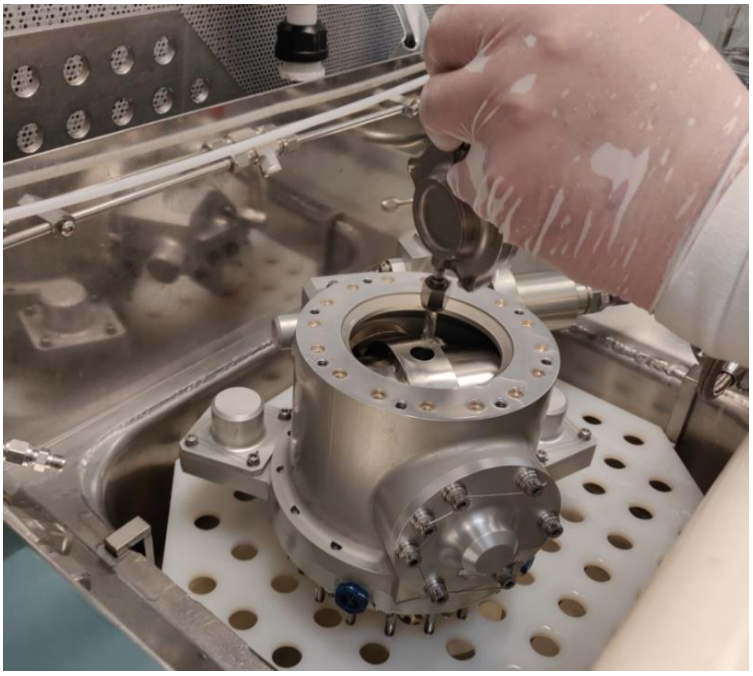


FIGURE 58
PARTICLE GENERATION TEST: IPA FILL AT INLET

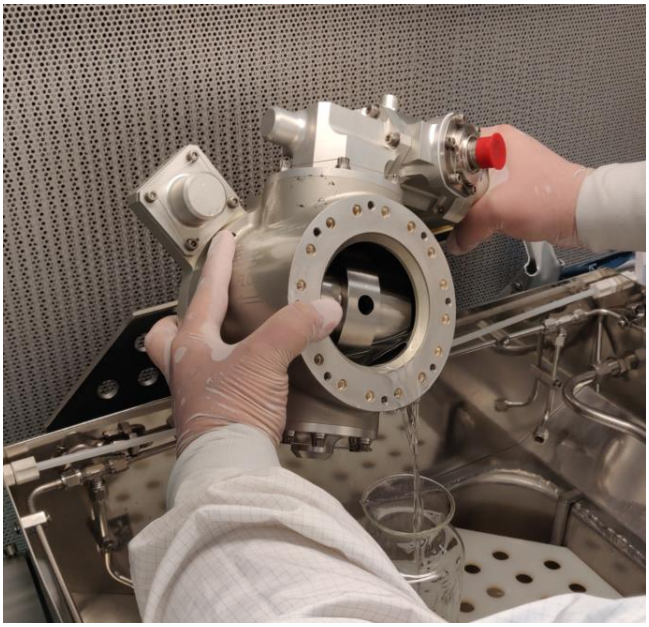


FIGURE 59
PARTICLE GENERATION TEST: IPA COLLECTION AT INLET

6.36 Test 31- Post-Op Life: Closing Response with Flow (Ambient)

6.36.1 Requirements: Closing command-to-switch response time shall not exceed 1.5 seconds. Closing switch-to-switch response time shall not exceed 0.75 seconds.

6.36.2 Test Conditions: The RS unit was installed on the water flow test stand with the inlet and outlet test fixtures (P/N 13079450-01). See Figure 60, Figure 61, and Figure 62. The RS unit was actuated to open position by applying 600 psig at the actuator. The water flow was adjusted to 95 GPM and 53 psig downstream (PG4). The actuator pressure was increased to 910 psig and then suddenly depressurized using test stand solenoid valve. The closing response times were recorded using the Position Indication Box.

6.36.3 Results: The RS unit passed the test with closing response times of 0.791 seconds (command-to-switch) and 0.14 seconds (switch-to-switch).

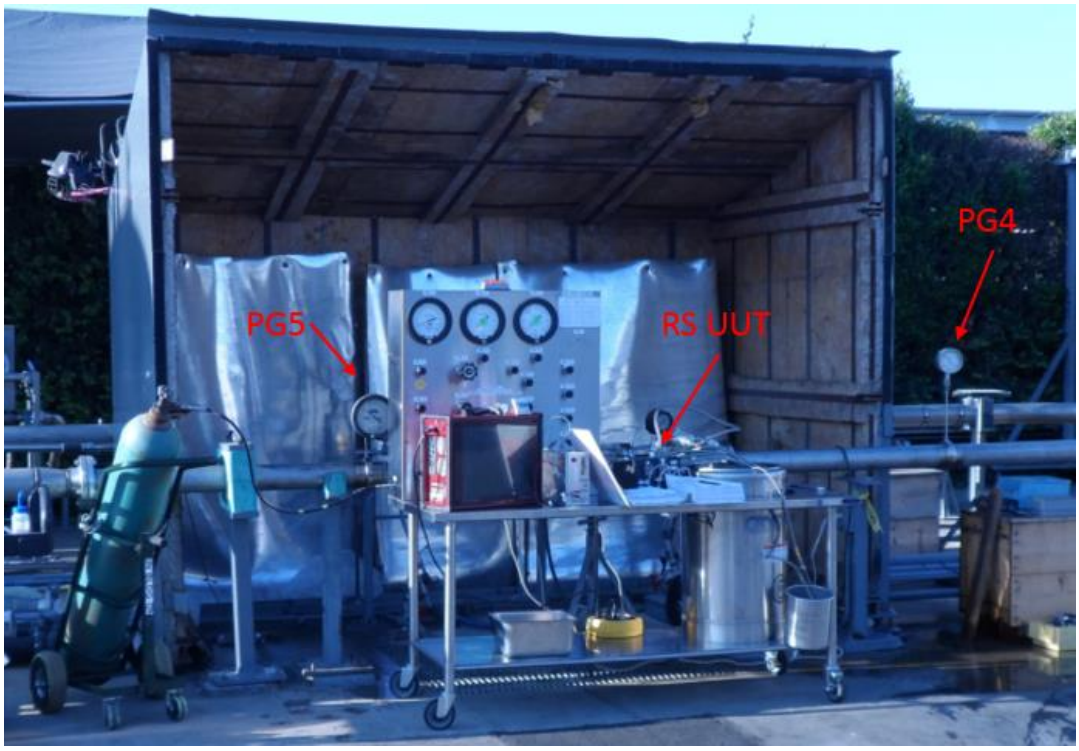


FIGURE 60
CLOSING RESPONSE WITH FLOW: WATER FLOW TEST STAND

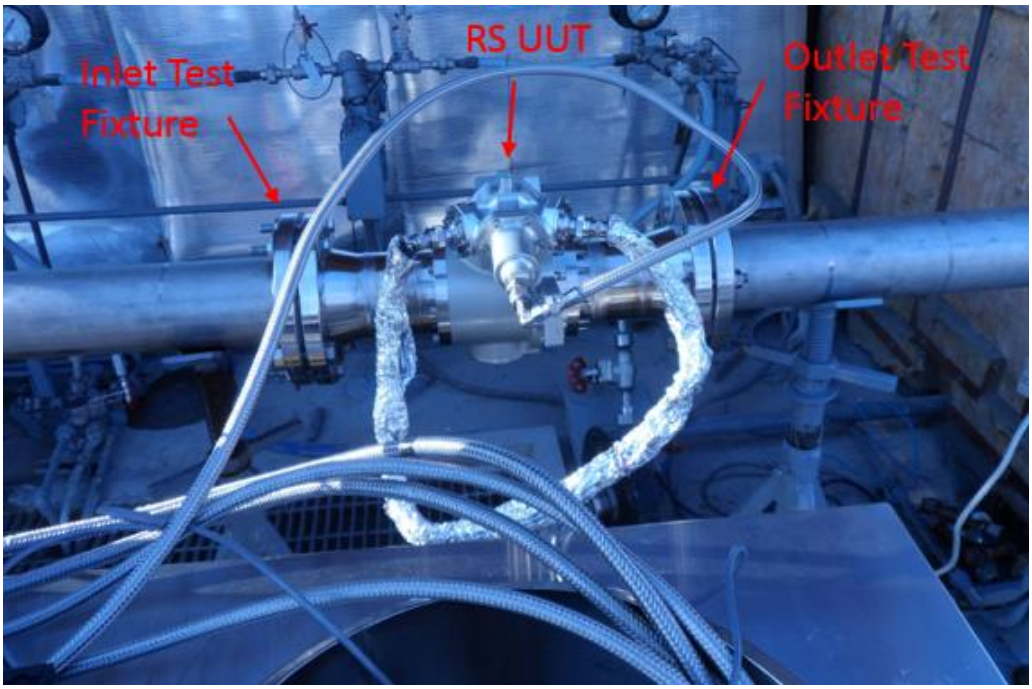


FIGURE 61
CLOSING RESPONSE WITH FLOW: TEST SETUP

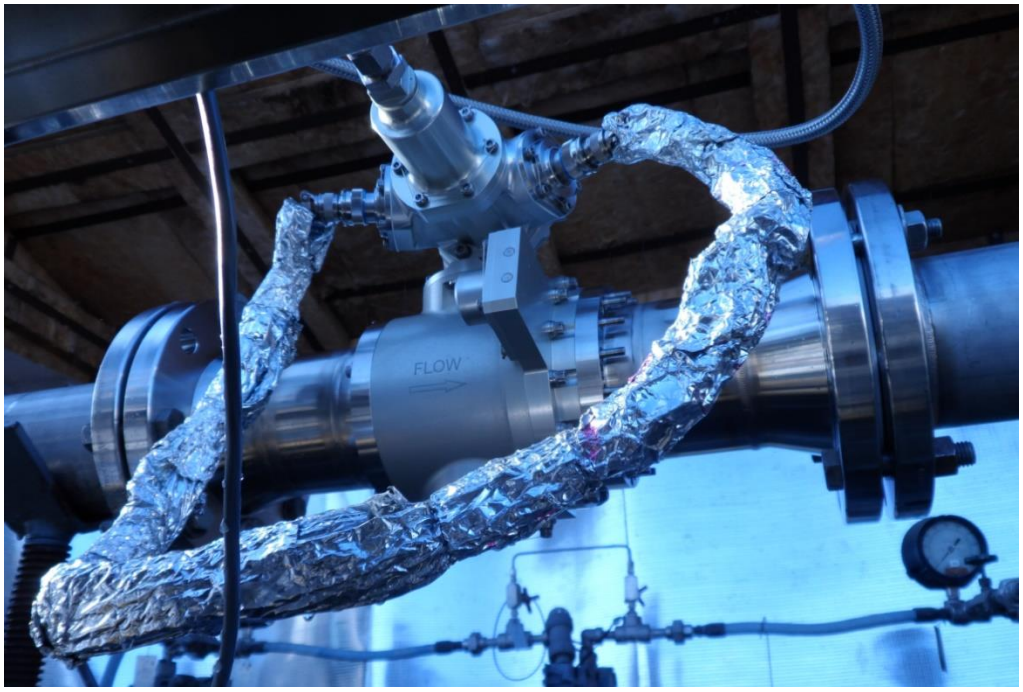


FIGURE 62
CLOSING RESPONSE WITH FLOW: TEST SETUP (BOTTOM VIEW)

6.37 Test 32- Burst Pressure

6.37.1 Requirements: The RS body shall withstand burst pressure without rupture when pressurized in open position and when pressurized at inlet in closed position. The RS actuator shall withstand burst pressure without rupture.

6.37.2 Test Conditions: The leakage test fixtures (P/N 13079423-01) were installed on the test unit and placed inside test chamber. At ambient temperature of 71.4°F, the RS was actuated to open position by applying 740±40 psig at actuator. In the open position, the RS was internally pressurized to 290 psig and pressure was maintained for five (5) minutes. See Figure 63. The RS unit was removed from test fixture and examined for any damage or permanent deformation. The RS was returned to closed position and internally pressurized at inlet to 225 psig and maintained for five (5) minutes. See Figure 64. The RS unit was removed from test fixture and examined for any damage or permanent deformation. Finally, the RS actuator was pressurized to 2500 psig and maintained for five (5 minutes). See Figure 65. The RS unit was removed from test fixture and examined for any damage or permanent deformation.

6.37.3 Results: The RS unit passed all three burst cases, for it withstood the burst pressures without rupture.

FIGURE 63
BURST PRESSURE TEST: RS INLET (OPEN POSITION)

FIGURE 64
BURST PRESSURE TEST: RS INLET (CLOSED POSITION)

FIGURE 65
BURST PRESSURE TEST: ACTUATOR

6.38 Test 33- Teardown and Inspection

6.38.1 Requirements: Take photographs to show post-QTP condition of test unit. Carefully disassemble the RS unit and record all observations, especially any evidence of degradation, contamination, or excessive wear. Take photographs to document all aspects of components and disassembled parts, clearly identifying part number and serial number.

6.38.2 Test Conditions: The RS unit was disassembled and inspected in the cleanroom. Photographs were taken of the post-test conditions of the unit (see Figure 66 through Figure 73) and of each part upon disassembly (see Figure 74 through Figure 144).

6.38.3 Results: No damage or anomaly was observed on the RS unit and its piece parts. Normal wear was noted on contact areas, such as the switch levers (Figure 83and Figure 88), Switch Skirt ID (Figure 99), the Rack teeth (Figure 104), the Pinion teeth (Figure 113), the Pinion OD (Figure 113 and Figure 114), the Rotator Ring (Figure 116), and pins (Figure 115 and Figure 119).

6.38.4 No scratches were found on all the sealing surfaces: Actuator Housing (Figure 75 and Figure 76), Piston (Figure 79), Bellows Disc (Figure 102), Top Cover (Figure 107 and Figure 108), Bottom Cover (Figure 121), Visor (Figure 127), Housing (Figure 129, Figure 130, and Figure 131), Flange (Figure 135, Figure 136, Figure 139, and Figure 142), and Relief Valves (Figure 143 and Figure 144). No damaged seals were found. (See Figure 74, Figure 79, Figure 82, Figure 87, Figure 94, Figure 108, Figure 121, Figure 137, Figure 138, Figure 143, and Figure 144.) No cracks were found

on the welded joints: Bellows Weldment (Figure 103), and Flow Guide Weldment and Lock (Figure 126).

6.38.5 There were particles found on some parts. One particle of significant size resembling a metal shaving was found on the stem of the Piston (Figure 74). Another particle of significant size was found on the static seal between Actuator Housing and Switch Housing (Figure 74). Smaller, black, powder-like particles were found on the Switch Skirt OD (Figure 96), inside Bottom Cover (Figure 120), inside Switch Housing bore (Figure 90) and cavities (Figure 92). All particles were collected and analyzed by TAERON M&P. All particles over 400 microns were identified as foreign material except one particle—the particle found on the Piston stem. Ref. Report 19S in Appendix F. Based on the M&P analysis, there is some evidence to suggest this particle could have originated from the Piston. The Piston was then visually inspected again for any evidence of degradation or removal of material and none was found.

6.38.6 Some parts had remnants of epoxy on the exterior surfaces that remained after the dynamic testing, in which the epoxy was used to adhere accelerometers directly onto the unit. The residual epoxy can be seen on the external surfaces of the Switch Housing (Figure 93
Switch Housing: Relief Valve Port and ValveFigure 93; see beige epoxy around the port), the Top Cover (Figure 107), and the Housing (Figure 73 and Figure 129).

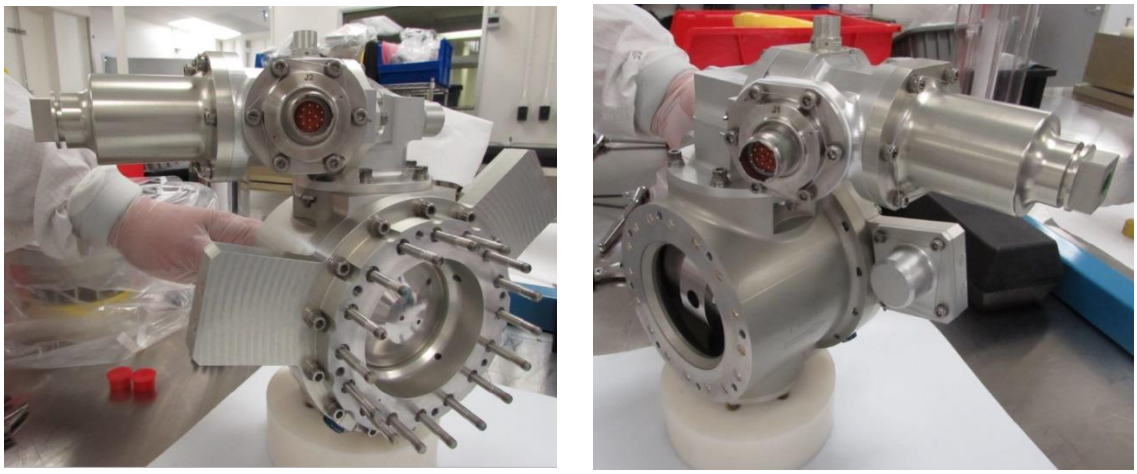


FIGURE 66
POST-TEST PHOTOS: RS UUT (ISO VIEW FRONT & BACK)

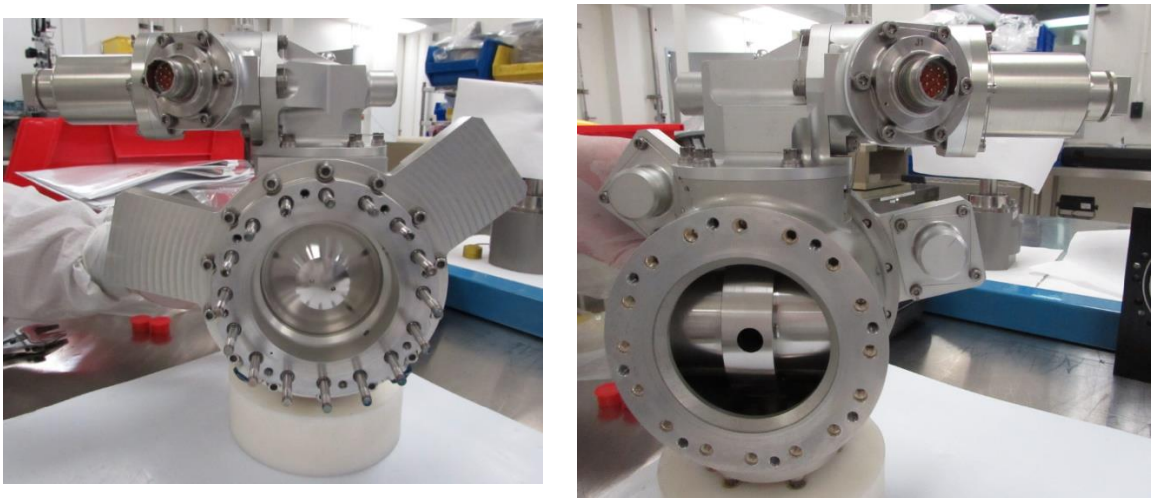


FIGURE 67
POST-TEST PHOTOS: RS UUT (FRONT/OUTLET & BACK/INLET)

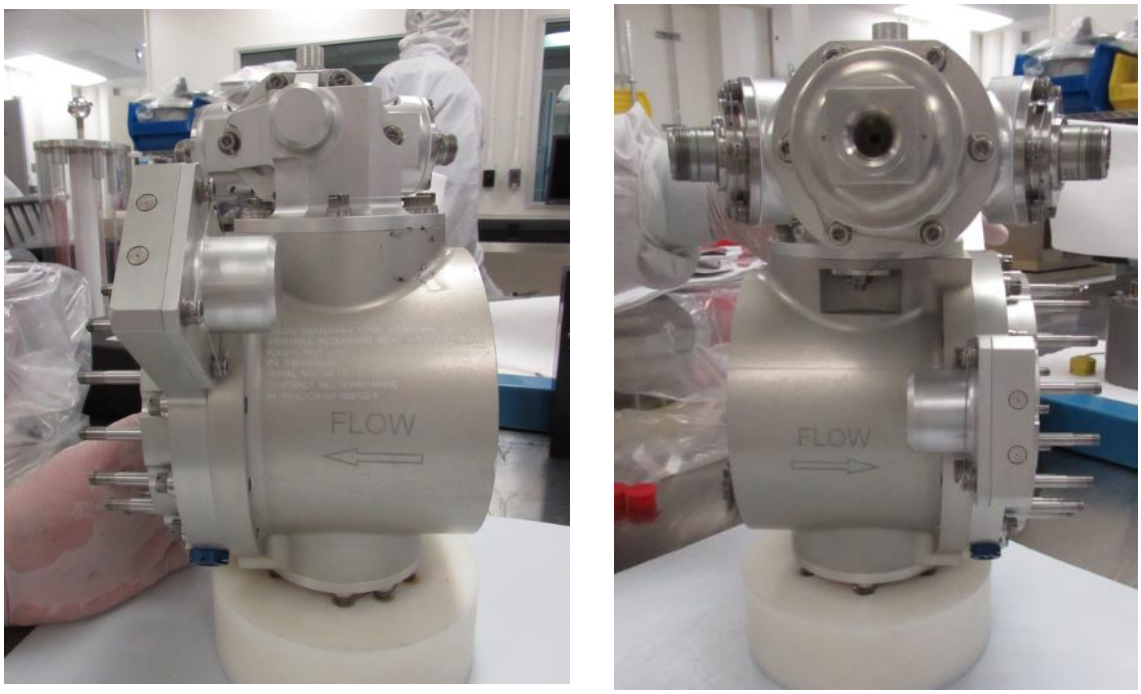


FIGURE 68
POST-TEST PHOTOS: RS UUT (SIDE VIEWS)

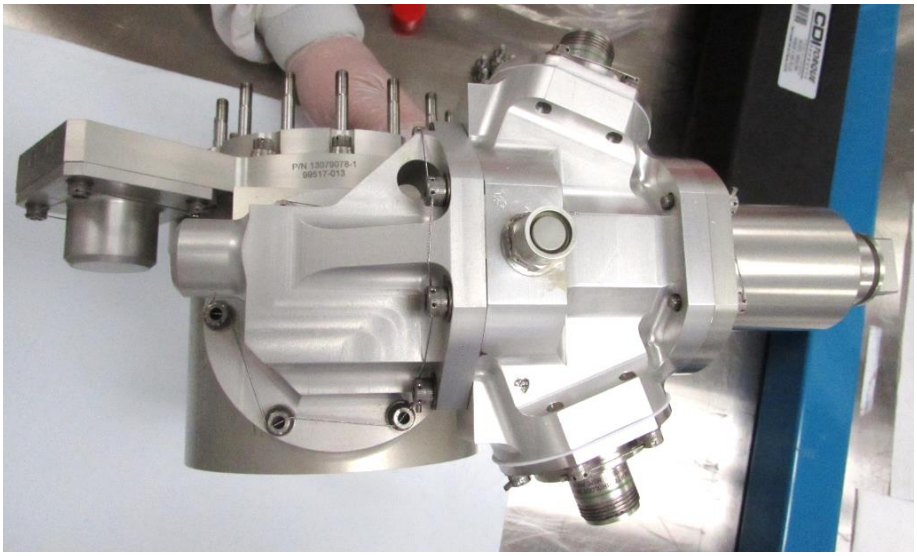


FIGURE 69
POST-TEST PHOTOS: RS UUT (TOP VIEW)

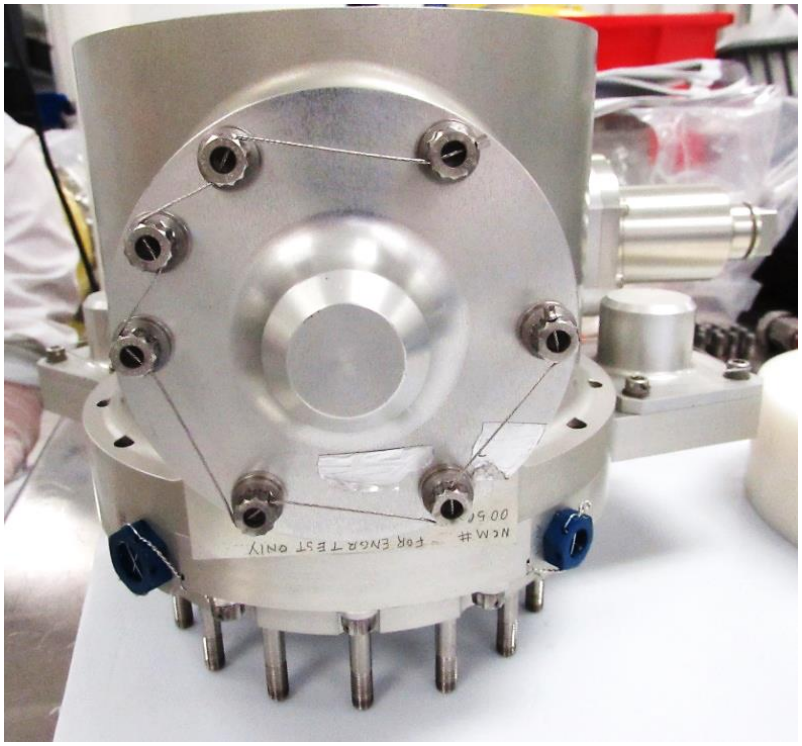


FIGURE 70
POST-TEST PHOTOS: RS UUT (BOTTOM VIEW)

FIGURE 71
POST-TEST PHOTOS: RS UUT (PART IDENTIFICATION)

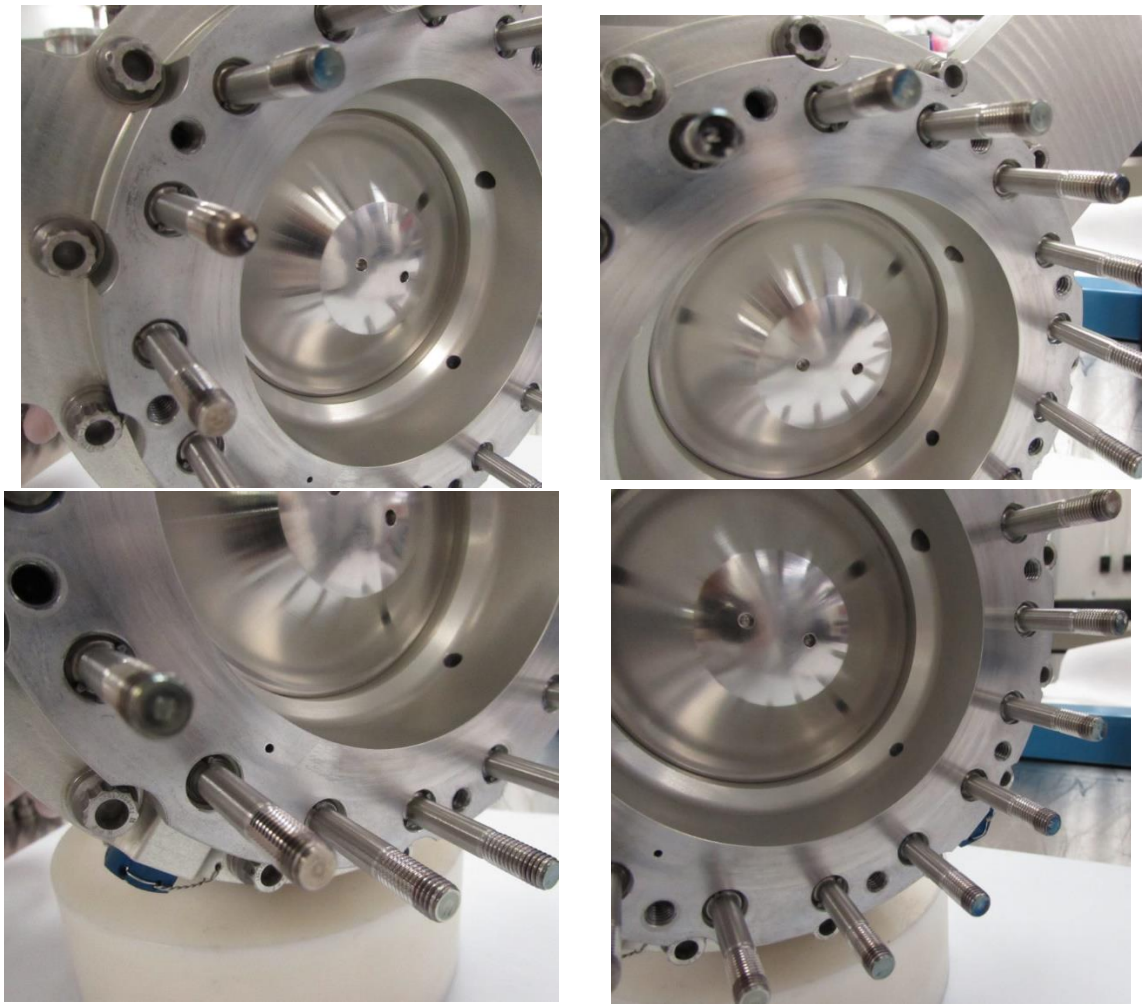


FIGURE 72
POST-TEST PHOTOS: RS UUT OUTLET SEALING SURFACE (CLOSE-UP)

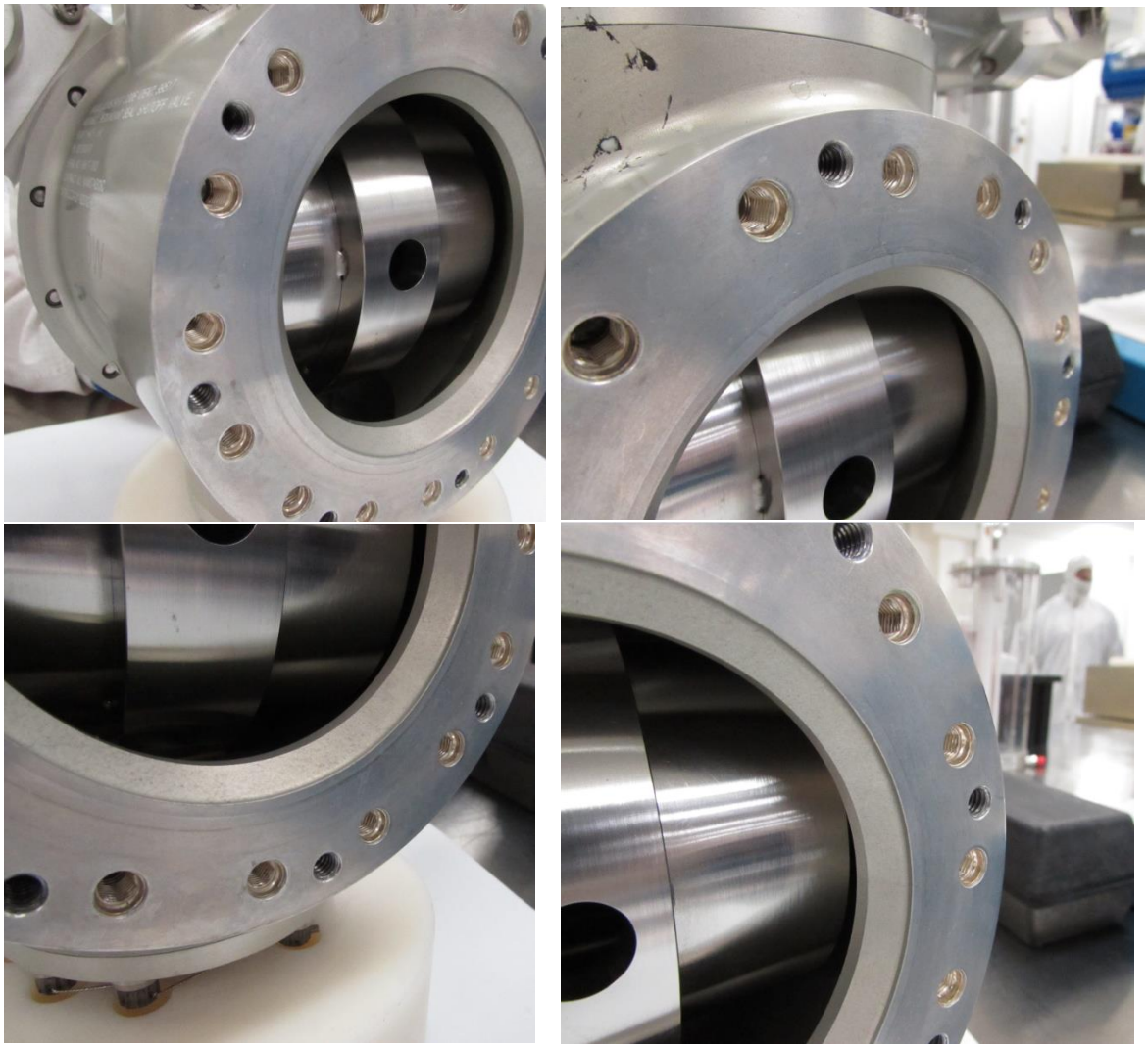


FIGURE 73
POST-TEST PHOTOS: RS UUT INLET SEALING SURFACE (CLOSE-UP)

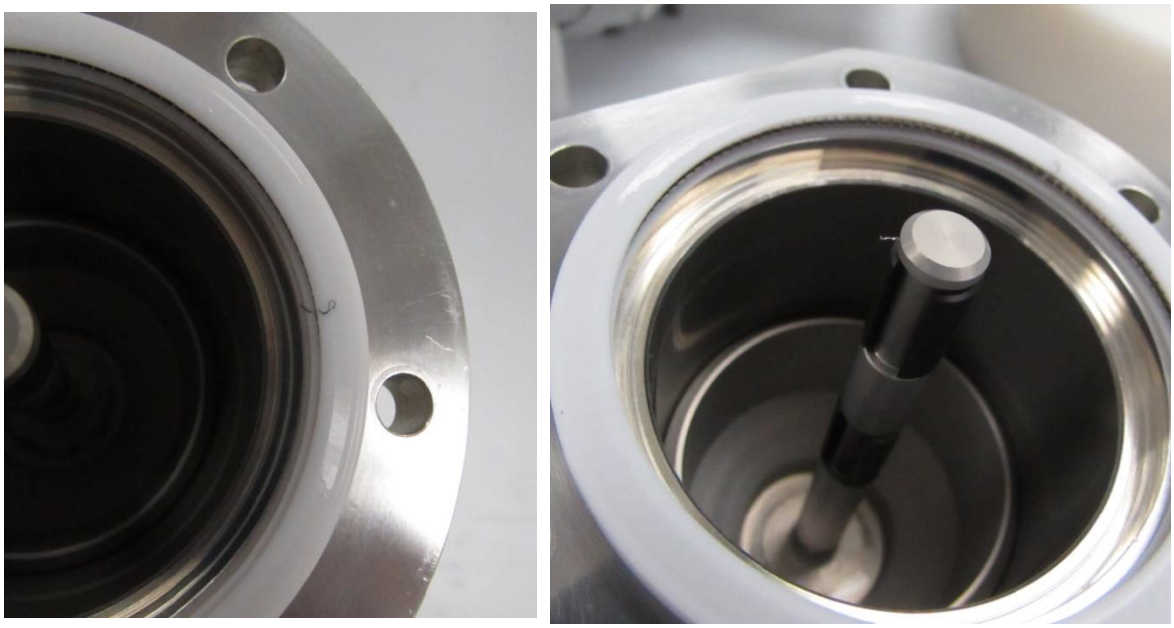


FIGURE 74
PARTICLES FOUND IN ACTUATOR

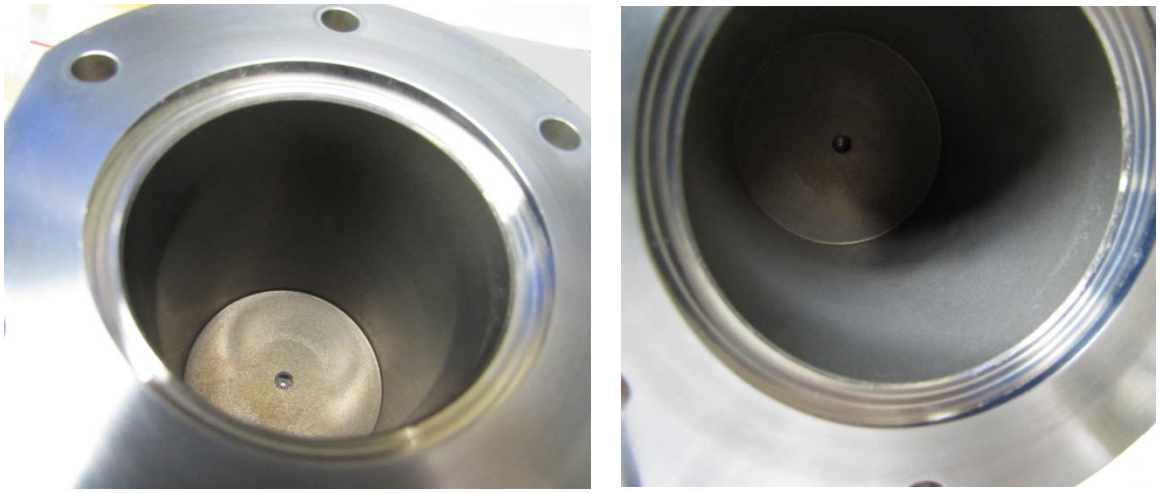


FIGURE 75
ACTUATOR HOUSING BORE

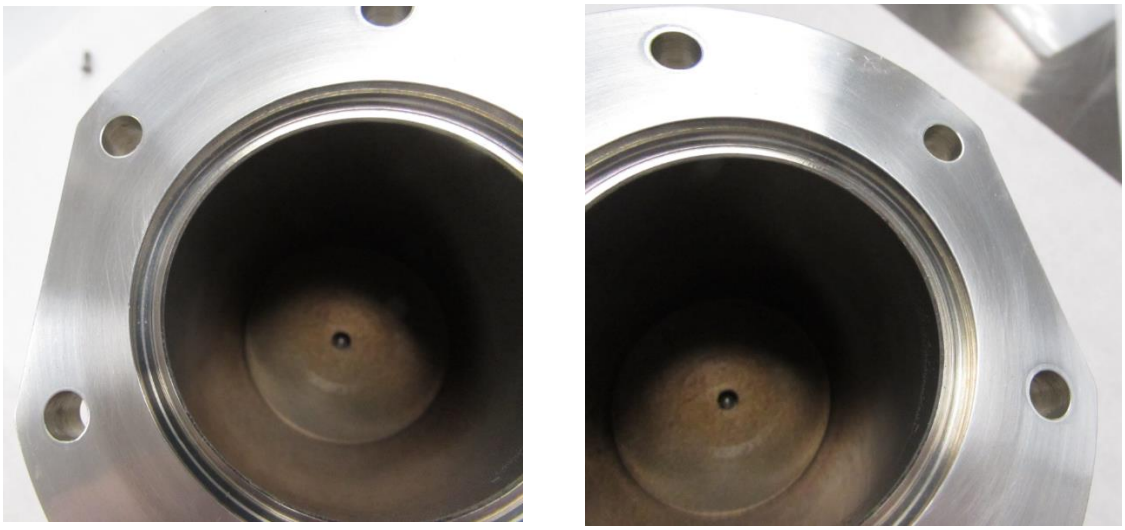


FIGURE 76
POST-TEST: SEAL GROOVE ON ACTUATOR HOUSING

Flow Control in Actuator Port **Flow Control from Inside Actuator Housing**

FIGURE 77
ACTUATOR FLOW CONTROL

FIGURE 78
PISTON WITH SEAL AND BUSHINGS

Piston

FIGURE 79
PISTON AND DYNAMIC SEALS, BUSHINGS & RETAINERS

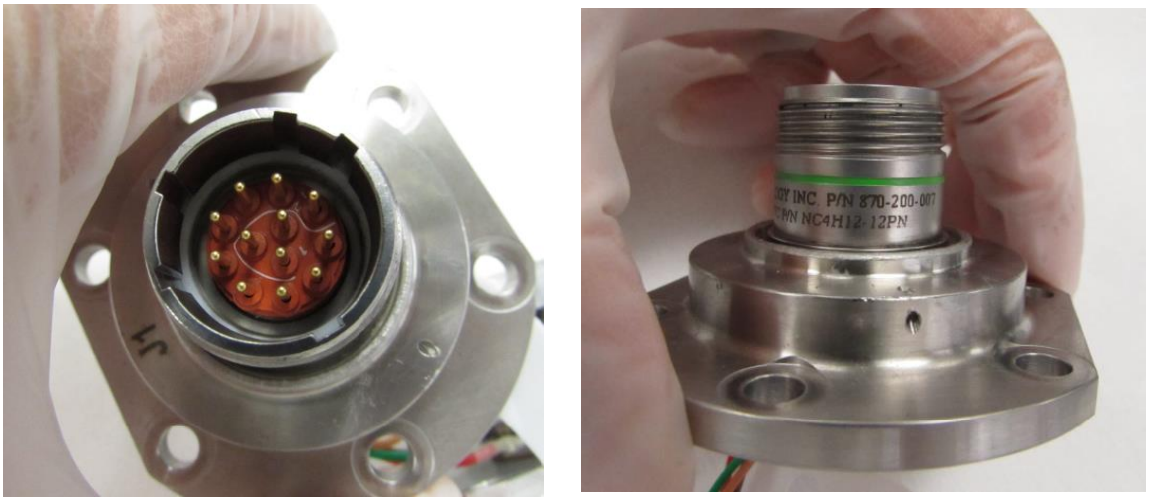


FIGURE 80
SWITCH CONNECTOR (J1)

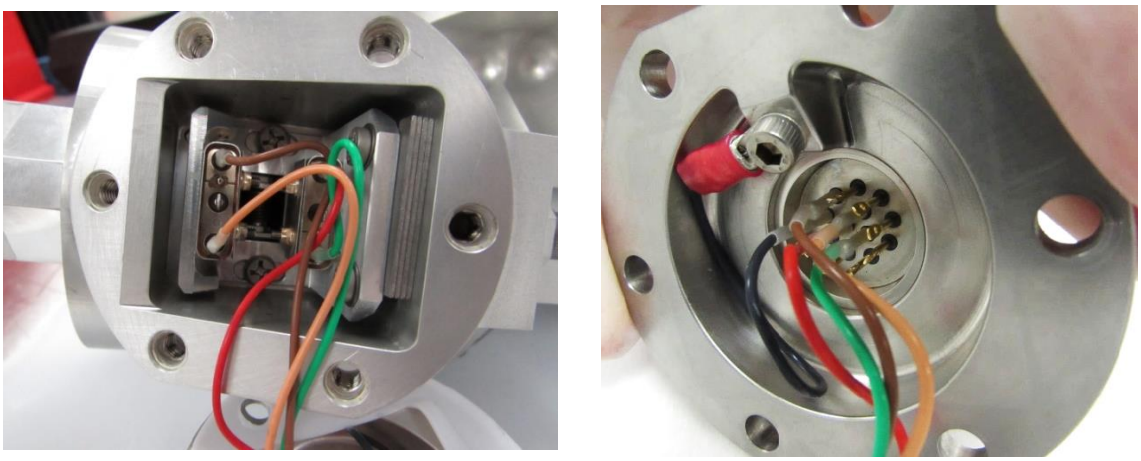
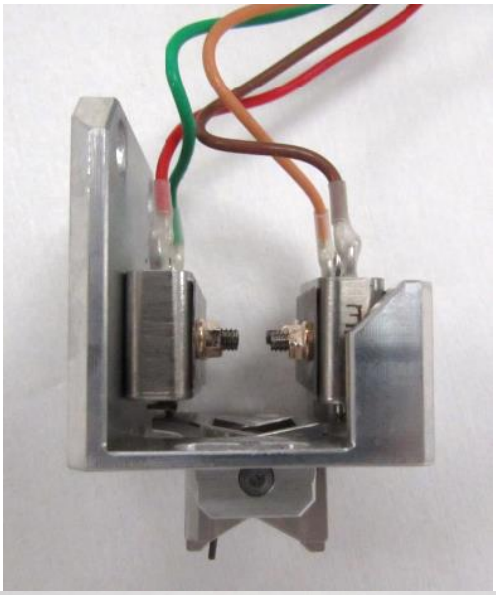
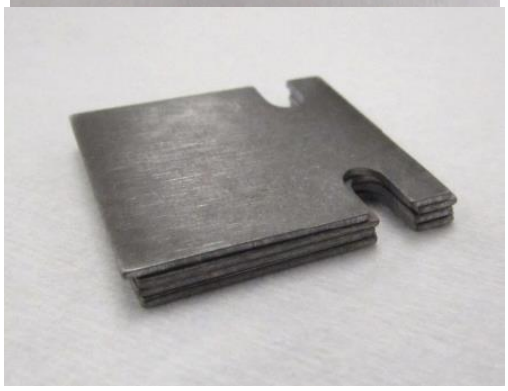


FIGURE 81
WIRES AND TERMINALS (J1)





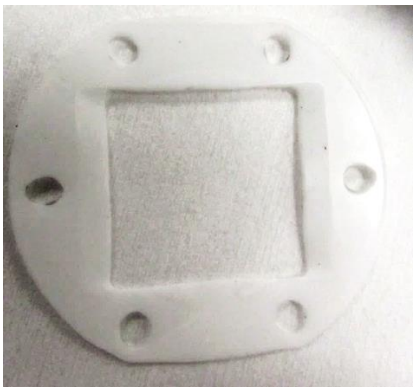
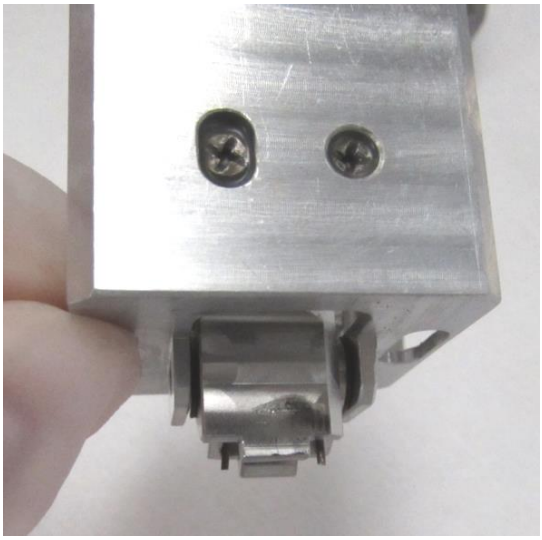
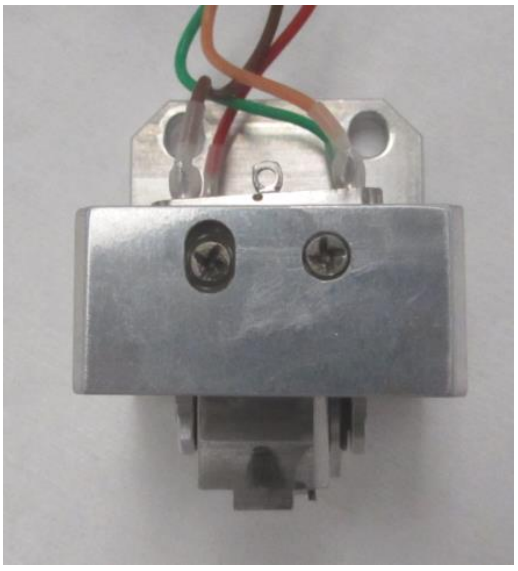


FIGURE 82
SWITCH ASSEMBLY (J1), SHIMS, AND GASKET

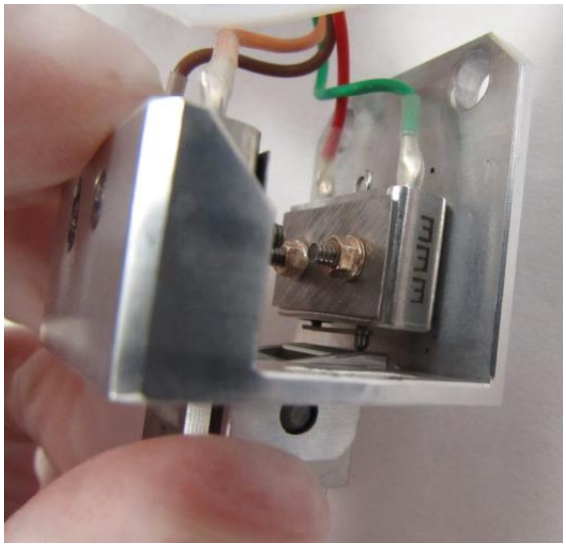


Close Switch Side

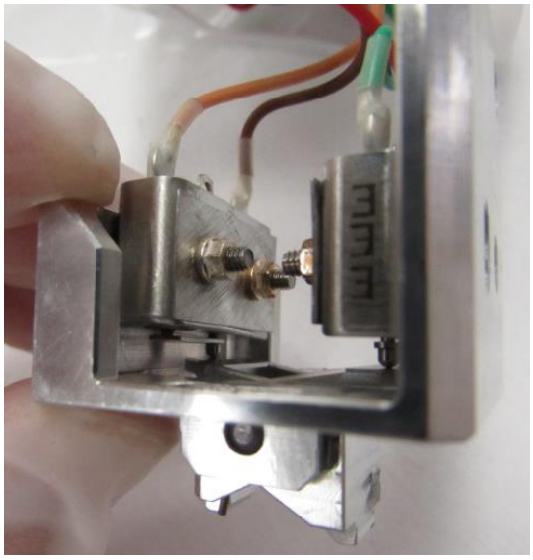


Open Switch Side

FIGURE 83
SWITCH ASSEMBLY (J1): OPEN AND CLOSE SIDES (TOP VIEW)



Close Switch Side



Open Switch Side

FIGURE 84
SWITCH ASSEMBLY (J1): OPEN AND CLOSE SIDES (SIDE VIEW)

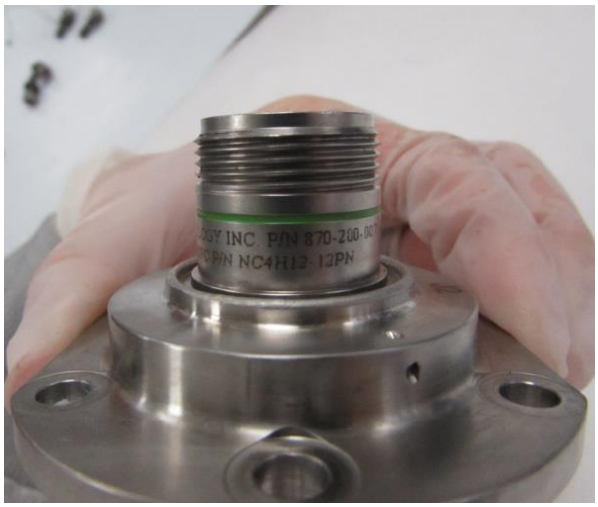


FIGURE 85
SWITCH CONNECTOR (J2)

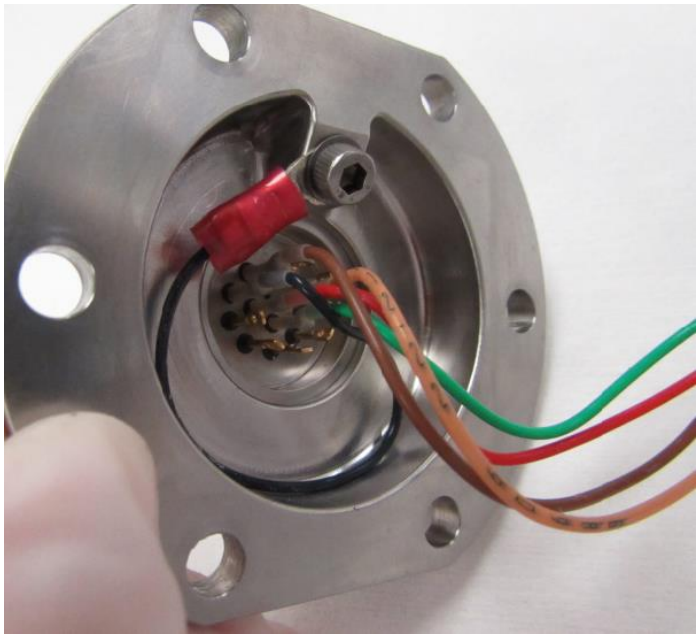
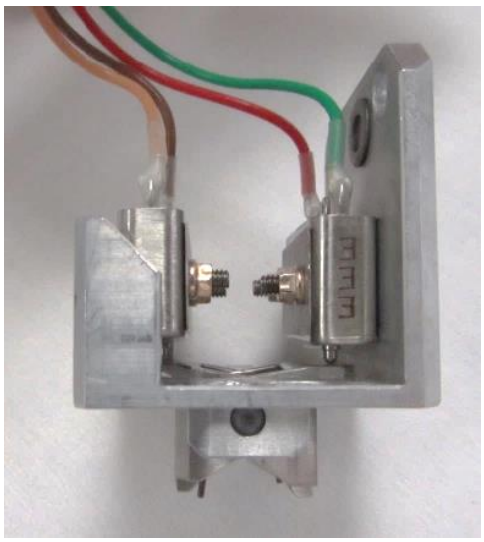
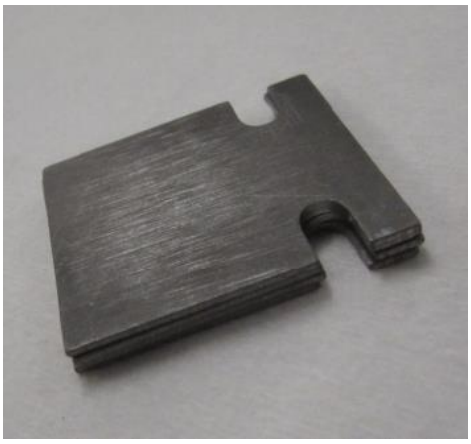


FIGURE 86
WIRES AND TERMINALS (J2)





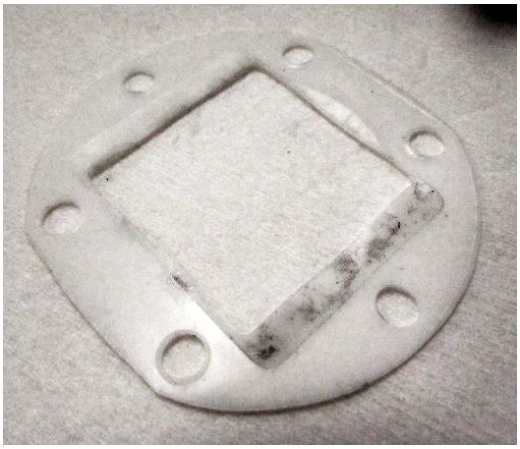
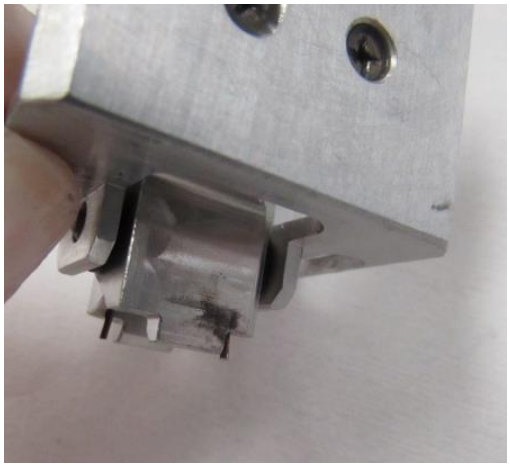
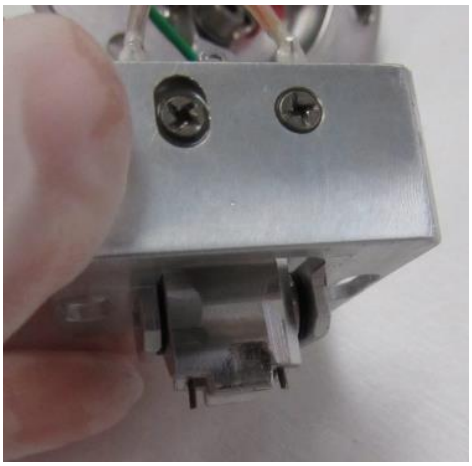


FIGURE 87
SWITCH ASSEMBLY (J2), SHIMS, AND GASKET

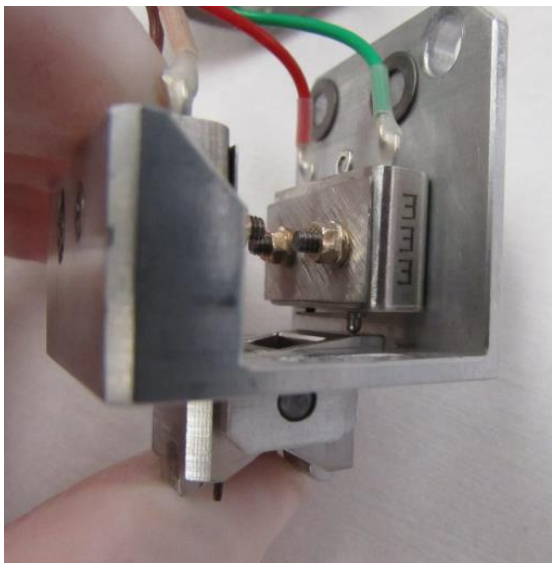


Close Switch Side

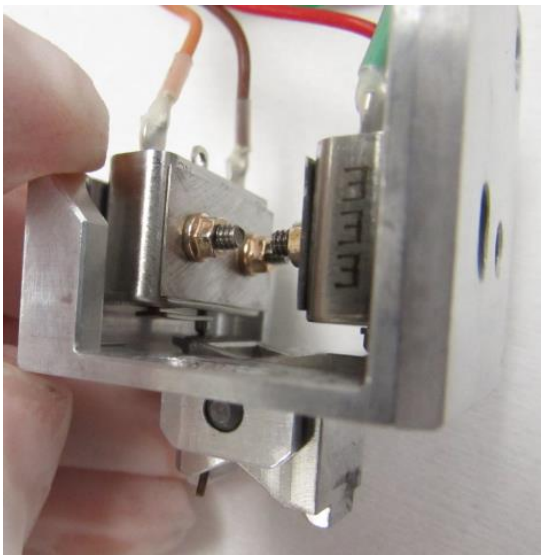


Open Switch Side

FIGURE 88
SWITCH ASSEMBLY (J2): OPEN AND CLOSE (TOP VIEW)



Close Switch Side



Open Switch Side

FIGURE 89
SWITCH ASSEMBLY (J2): OPEN AND CLOSE (SIDE VIEW)

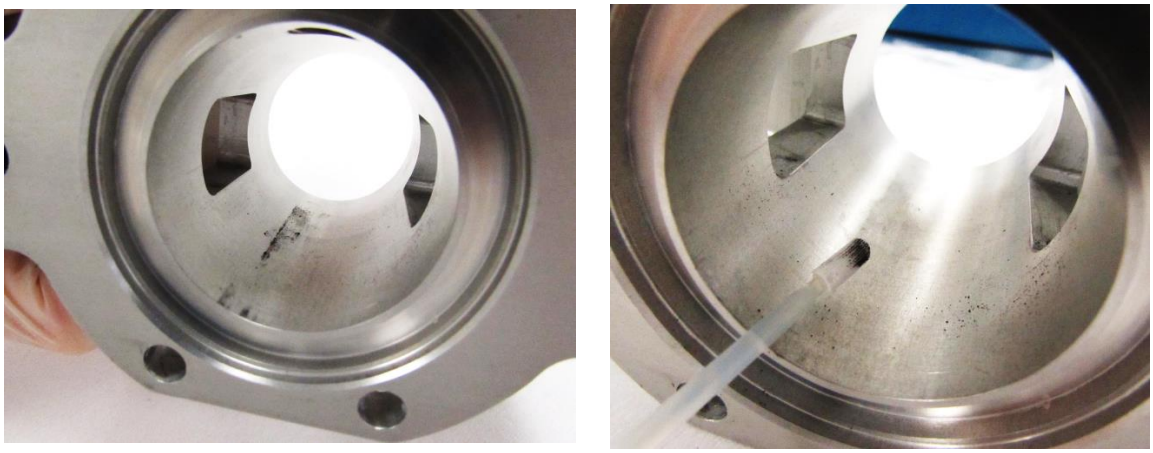
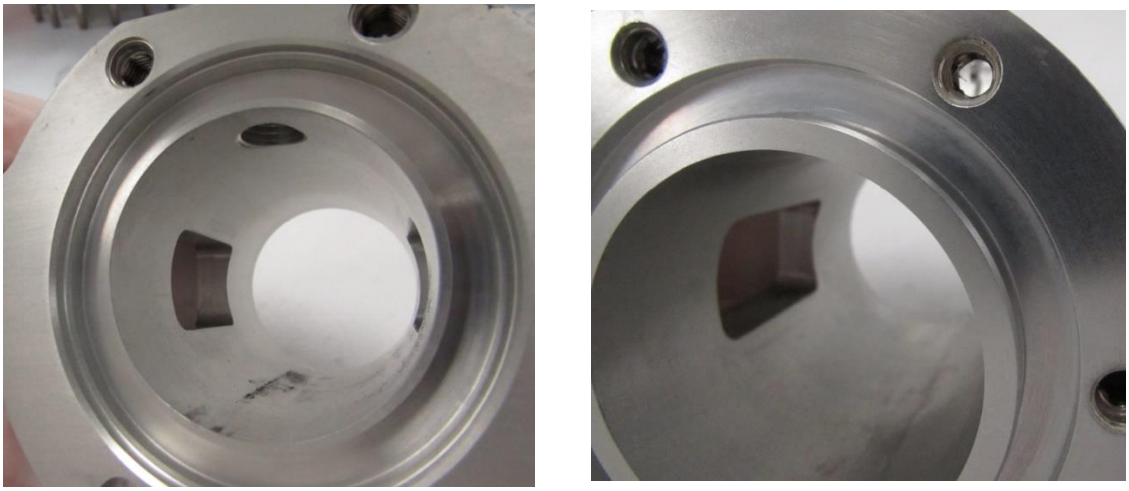
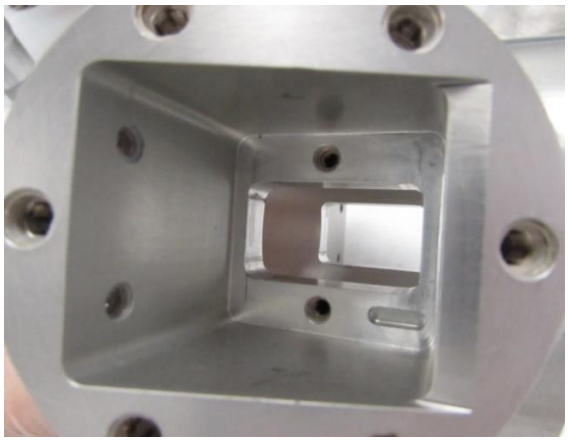


FIGURE 90
PARTICLES IN SWITCH HOUSING

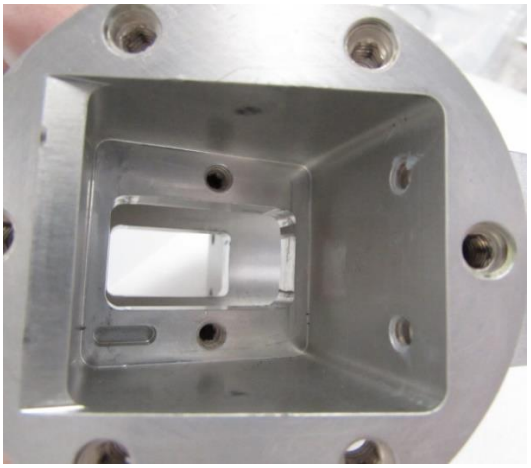


Body Side **Actuator Side**

FIGURE 91
SWITCH HOUSING: SEAL GROOVES



J1



J2

FIGURE 92
SWITCH HOUSING: SWITCH CAVITIES

Relief Valve Port

Relief Valve

FIGURE 93
SWITCH HOUSING: RELIEF VALVE PORT AND VALVE

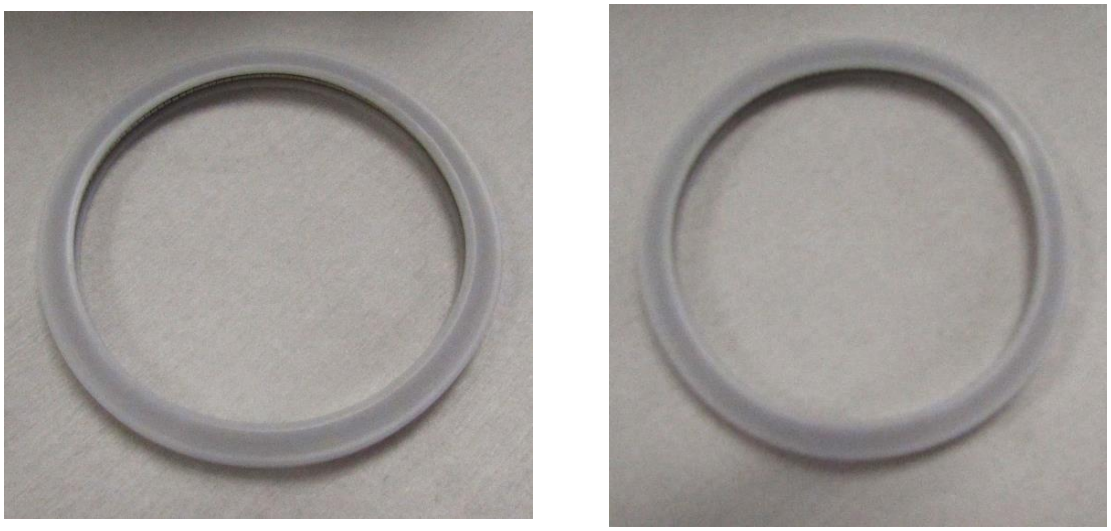


FIGURE 94
SWITCH HOUSING SEALS

FIGURE 95
ACTUATOR INTERNAL PARTS

FIGURE 96
PARTICLES ON SWITCH SKIRT OD

(Left to Right): Outer Nut, Inner Nut, Shims (Used In Between)

FIGURE 97
NUTS AND SHIMS

FIGURE 98
ACTUATOR SPRING

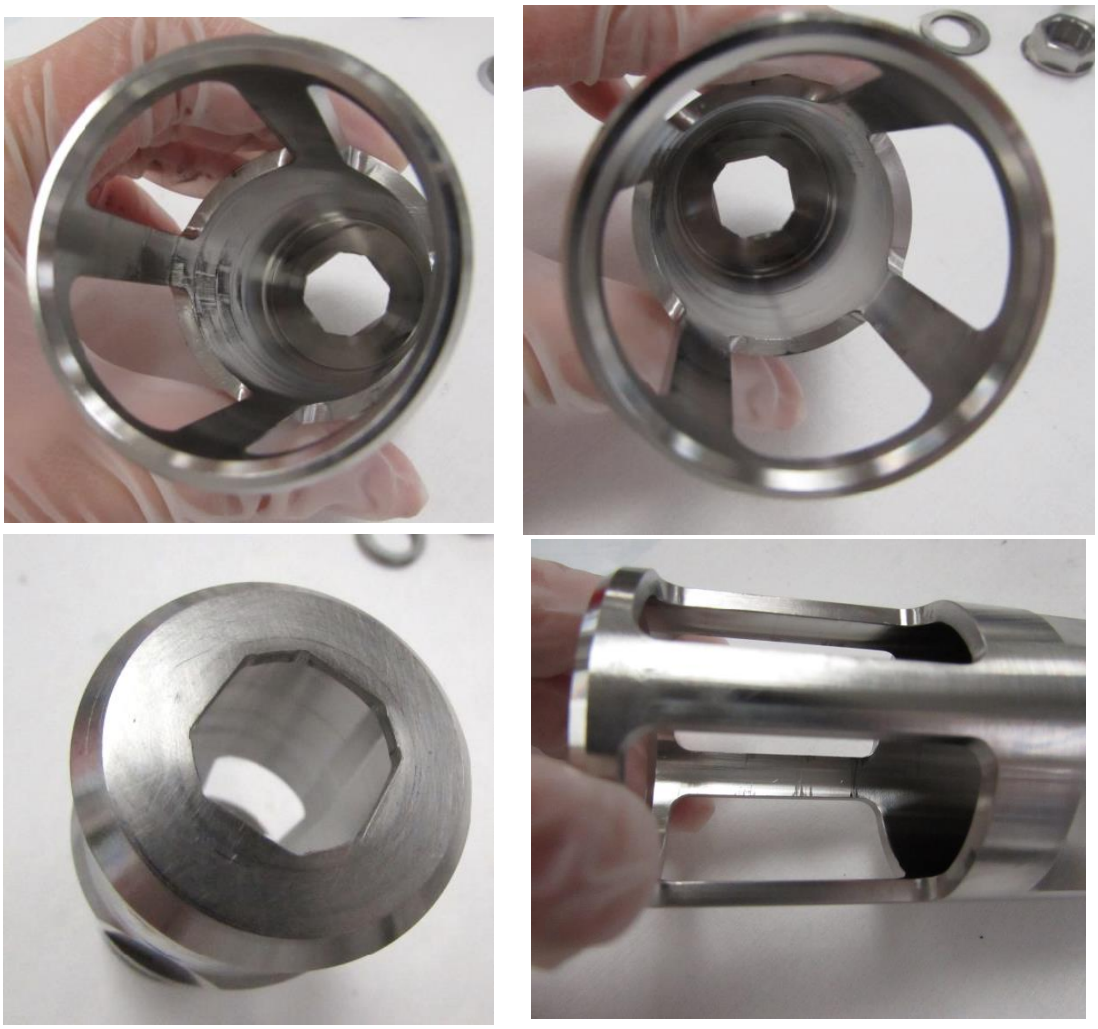


FIGURE 99
SWITCH SKIRT

FIGURE 100
BELLOWS WELDMENT ASSEMBLY

FIGURE 101
BELLOWS WELDMENT ASSY: THREADED END

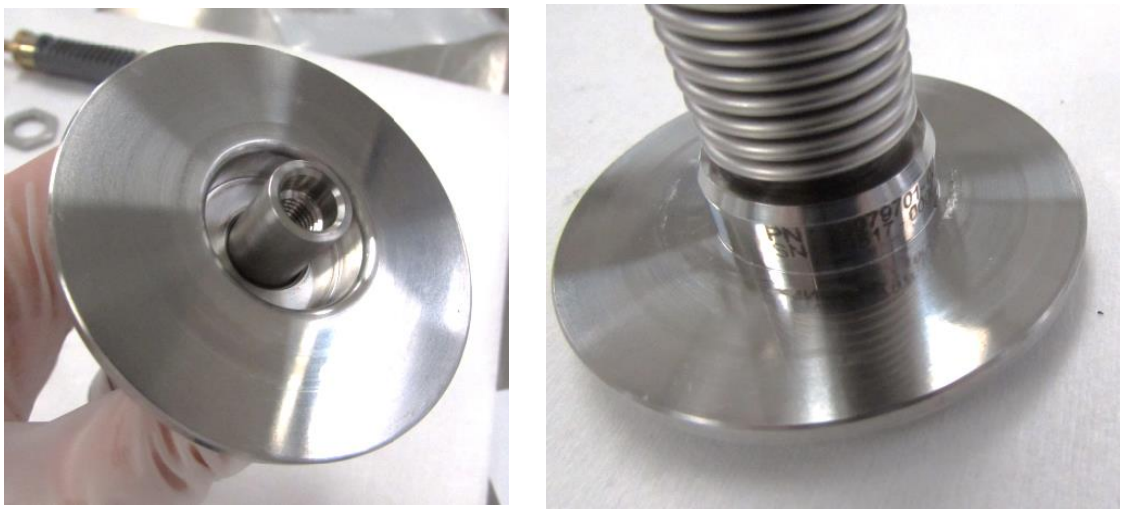


FIGURE 102
BELLOWS WELDMENT ASSY: DISC SIDE

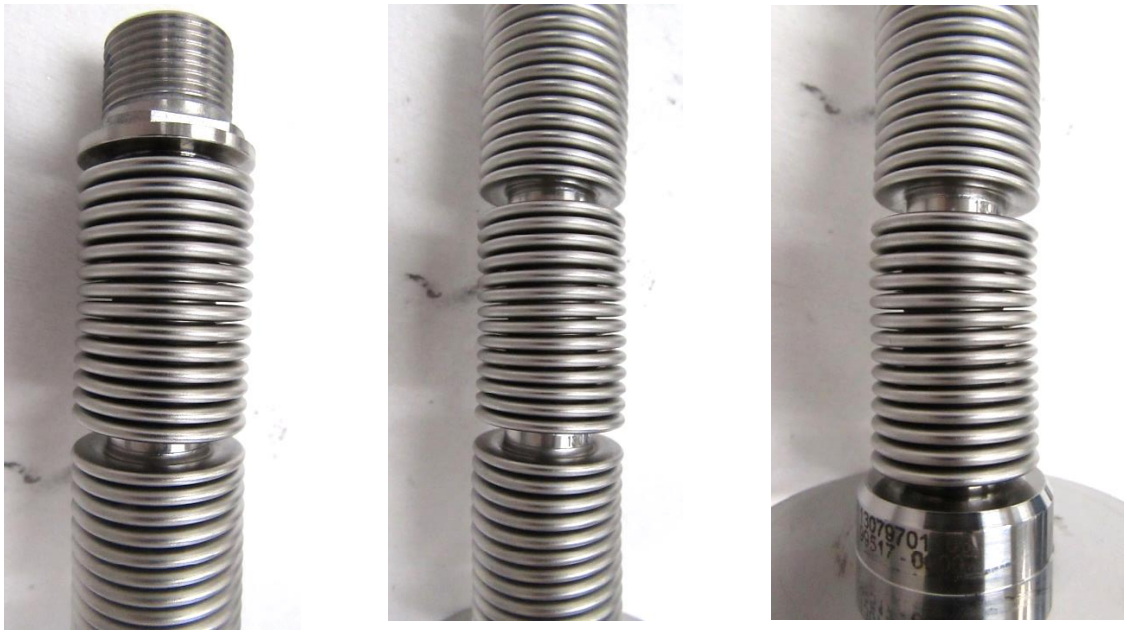


FIGURE 103
BELLOWS WELDMENT ASSY: BELLOWS AND WELDED JOINTS

FIGURE 104
RACK (TOP VIEW) AND BUSHINGS

FIGURE 105
RACK (SIDE VIEW) AND SHIMS

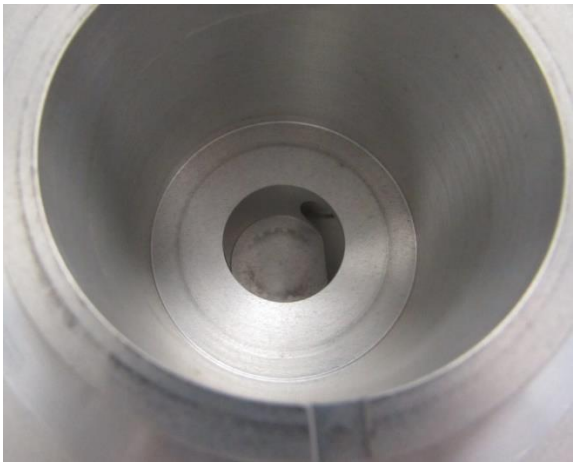


FIGURE 106
TOP COVER (INSIDE VIEW)

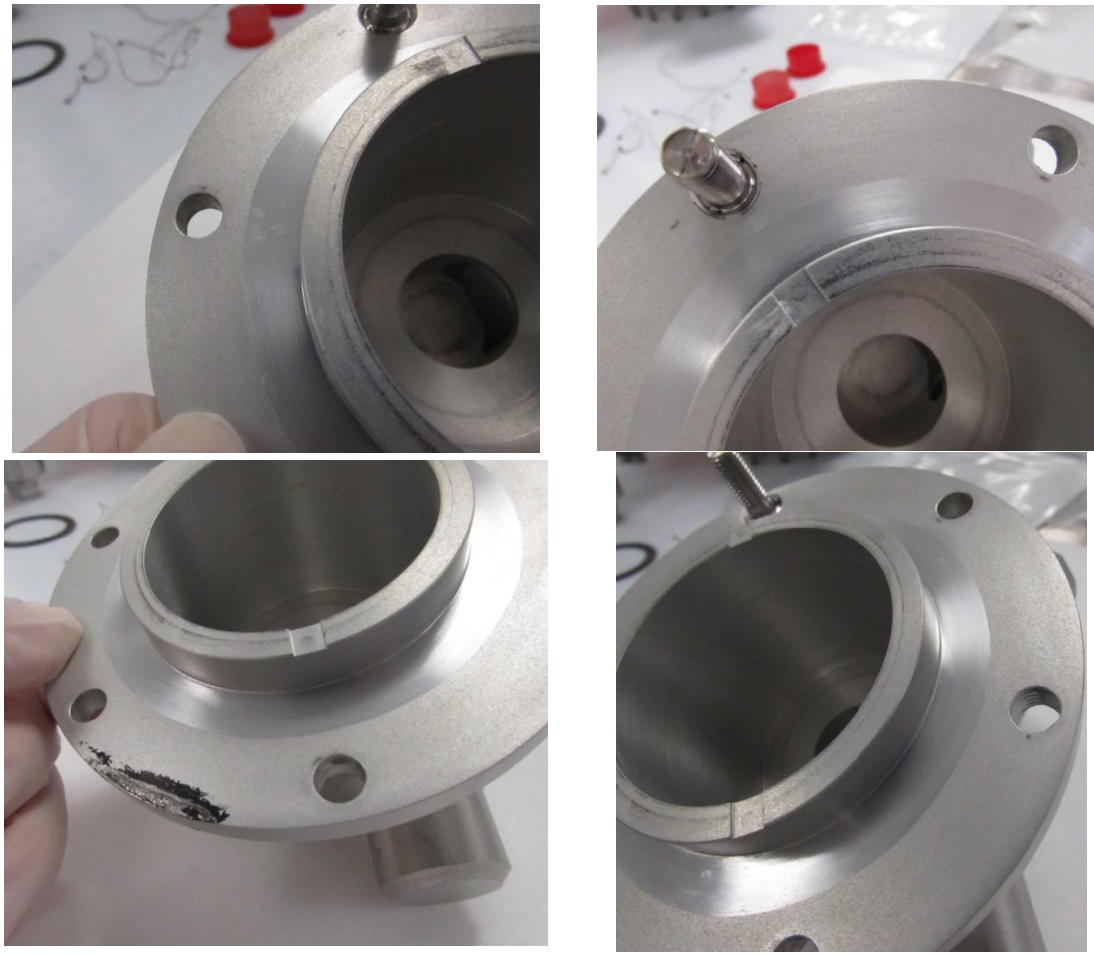


FIGURE 107
TOP COVER: SEALING SURFACE

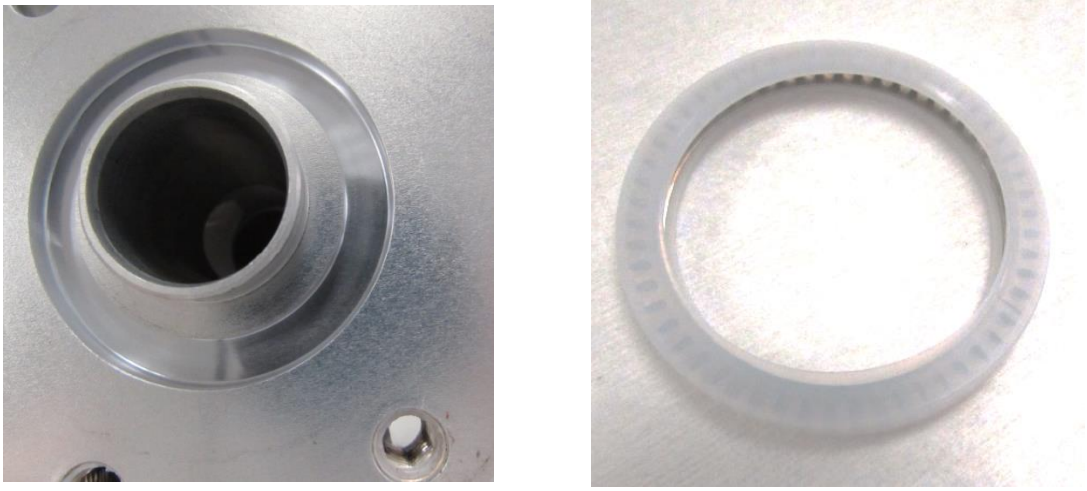


FIGURE 108
TOP COVER: SEAL GROOVE AND SEAL

FIGURE 109
BALL BEARINGS (S/N 15716)

FIGURE 110
BALL BEARINGS (S/N 15717)

Bearing Spacer

Spacer Washer

Thrust Washer

FIGURE 111
SPACERS AND WASHERS

FIGURE 112
SPACER WASHERS

FIGURE 113
PINION

FIGURE 114
PINION SPHERICAL BEARING WITH KEYING PIN

Pins

Translator Pins

FIGURE 115
PINS AND TRANSLATOR PINS

FIGURE 116
ROTATOR RING

FIGURE 117
ROTATOR RING: PIN GROOVES

FIGURE 118
ECCENTRIC RETAINER (INSIDE VIEW)

Groove for Pins **Pins**

FIGURE 119
ECCENTRIC RETAINER GROOVES & PINS

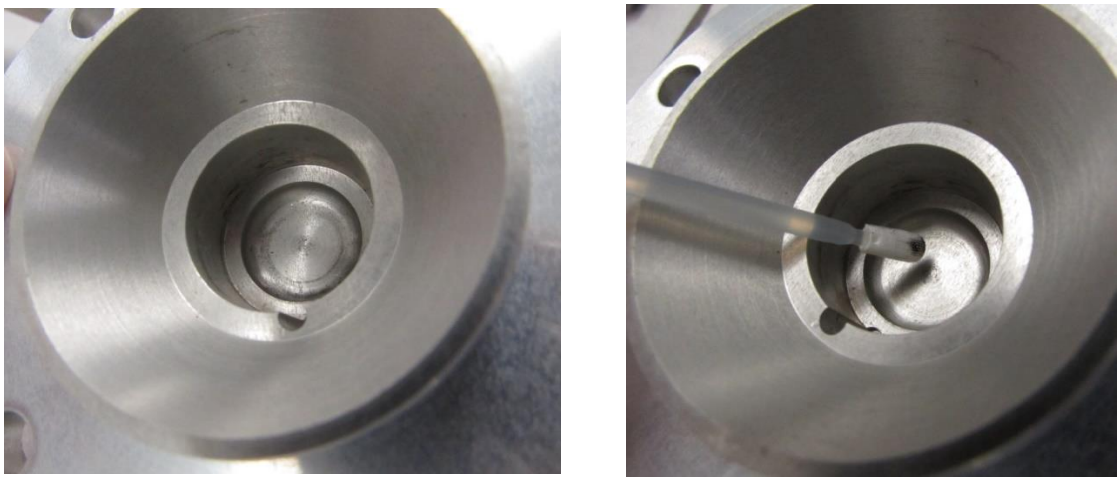


FIGURE 120
PARTICLES IN BOTTOM COVER (INSIDE)

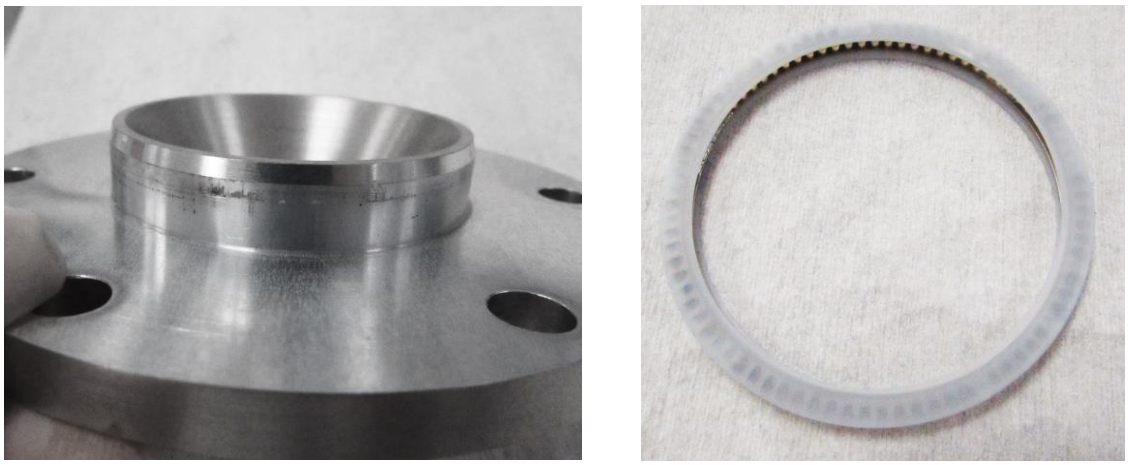


FIGURE 121
BOTTOM COVER SEALING SURFACE (FLAT SURFACE) AND SEAL

FIGURE 122
SPHERICAL BEARING AND KEYING PIN

Spacer **Shims**

FIGURE 123
BOTTOM SUPPORT SPACER AND SHIMS

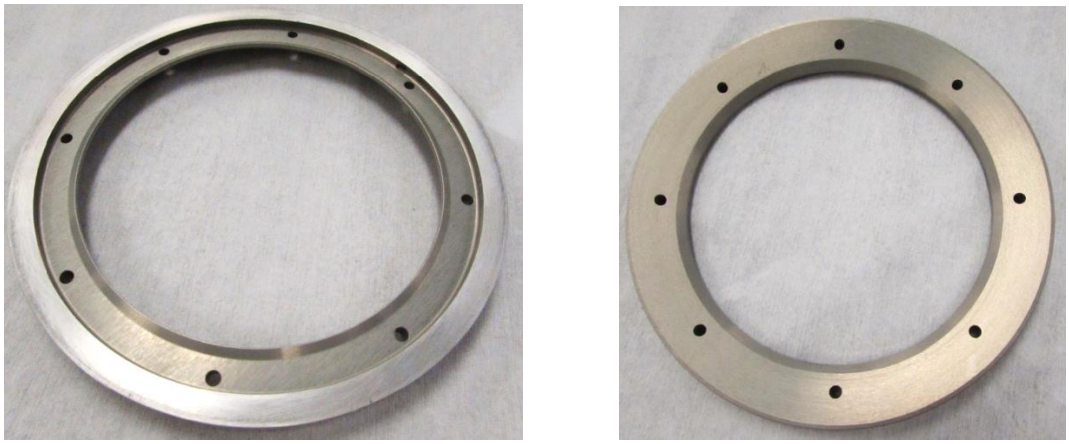


FIGURE 124
SEAL RETAINER

Top Stem **Bottom Stem**

FIGURE 125
FLOW GUIDE WELDMENT

FIGURE 126
FLOW GUIDE WELDMENT: WELDED LOCATIONS

FIGURE 127
VISOR: SEALING SURFACE

FIGURE 128
FLOW GUIDE WELDMENT: NOTCH (CONTACTS RING ROTATOR)

FIGURE 129
HOUSING: TOP-SEAL GROOVE

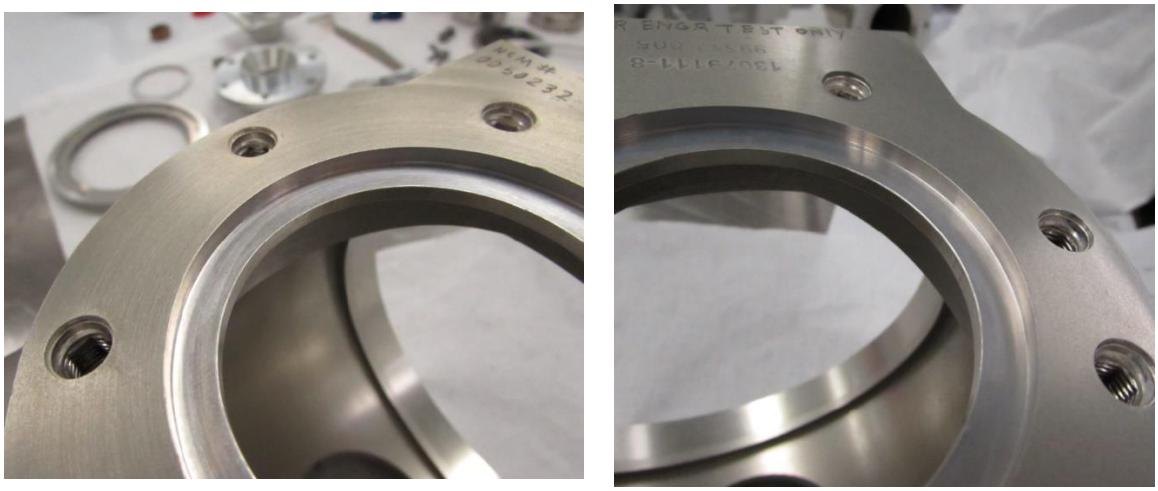


FIGURE 130
HOUSING: BOTTOM-SEAL GROOVE

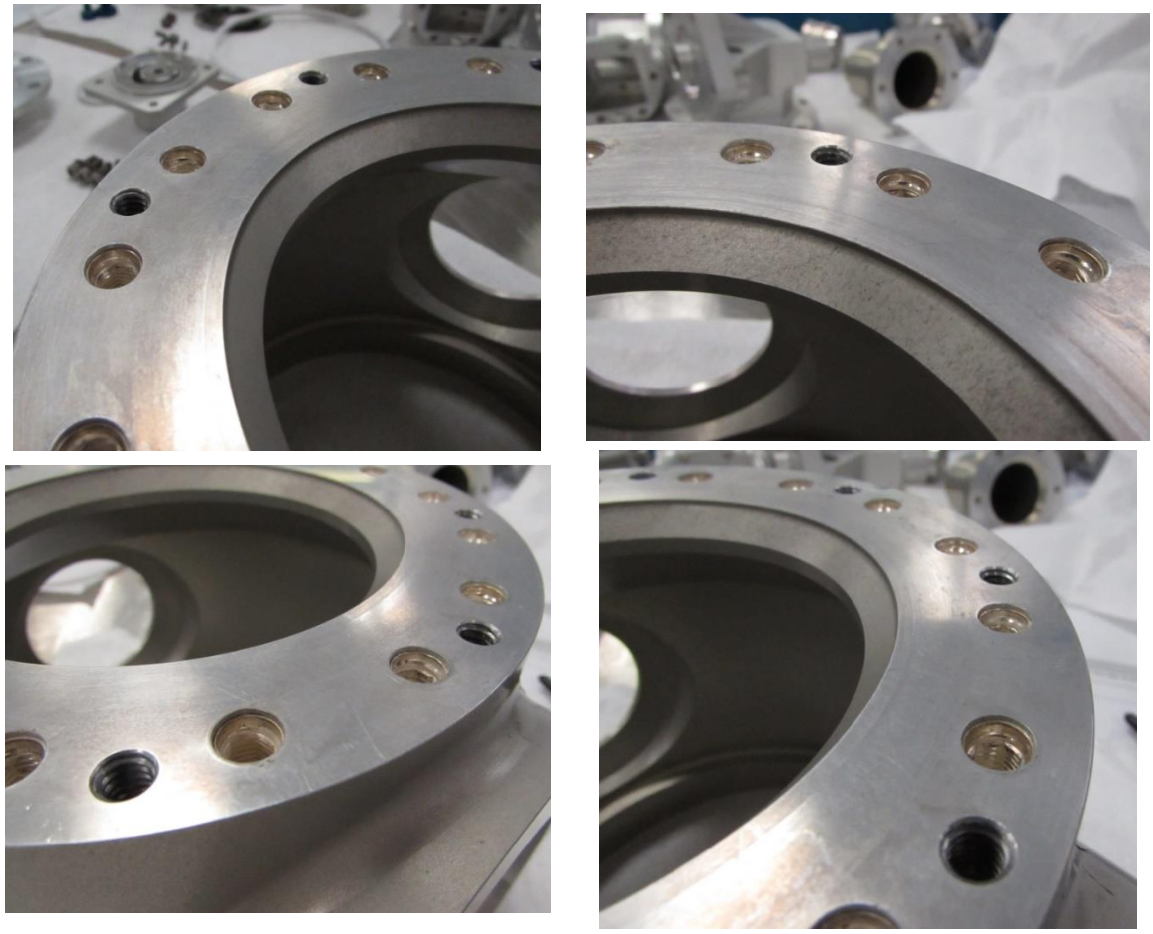


FIGURE 131
HOUSING: INLET SEALING SURFACE

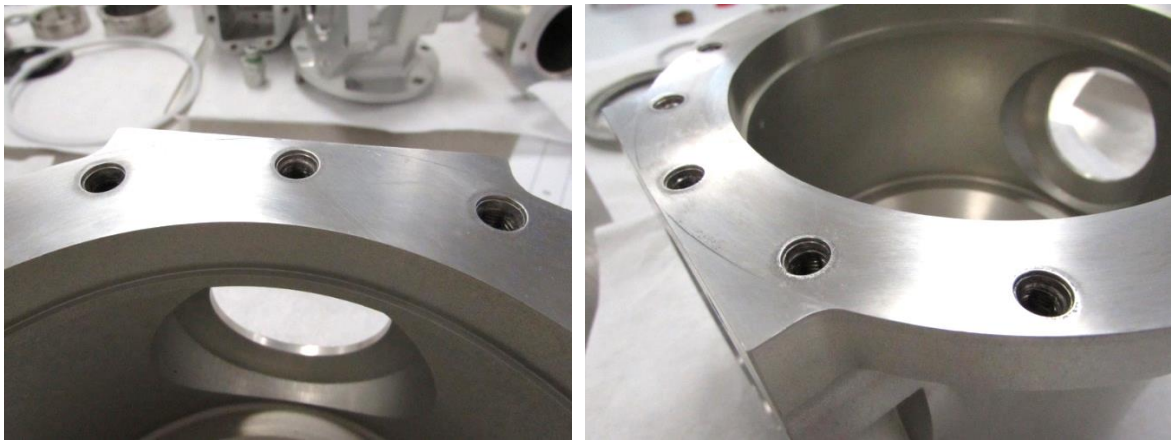


FIGURE 132
HOUSING: OUTLET SIDE (MATES WITH FLANGE)

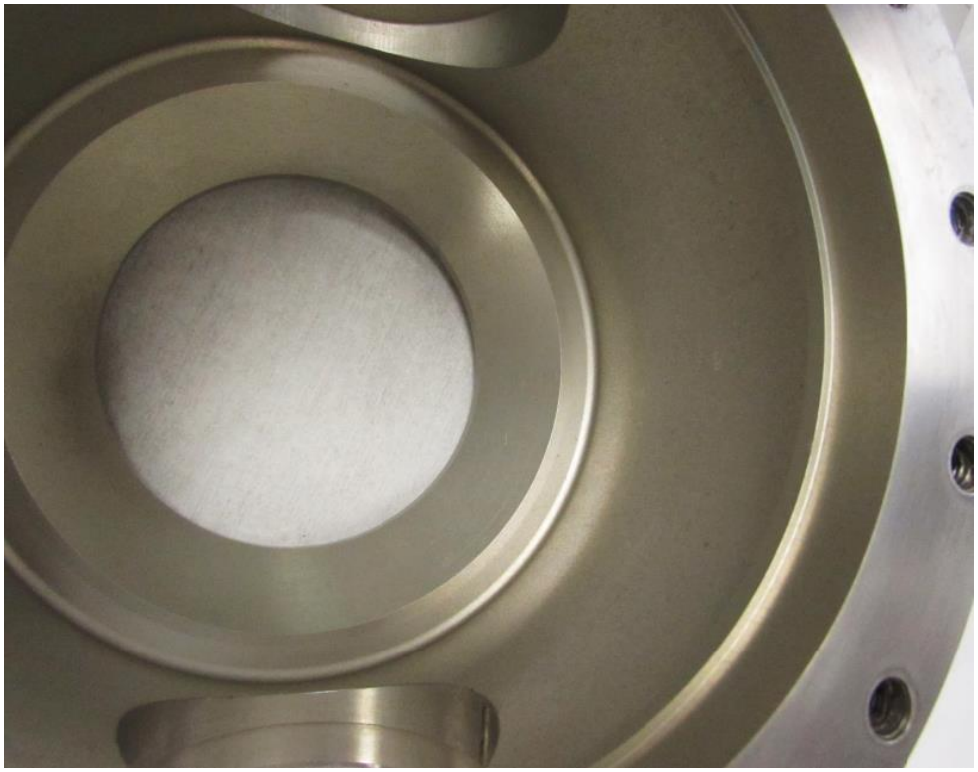


FIGURE 133
HOUSING: INSIDE

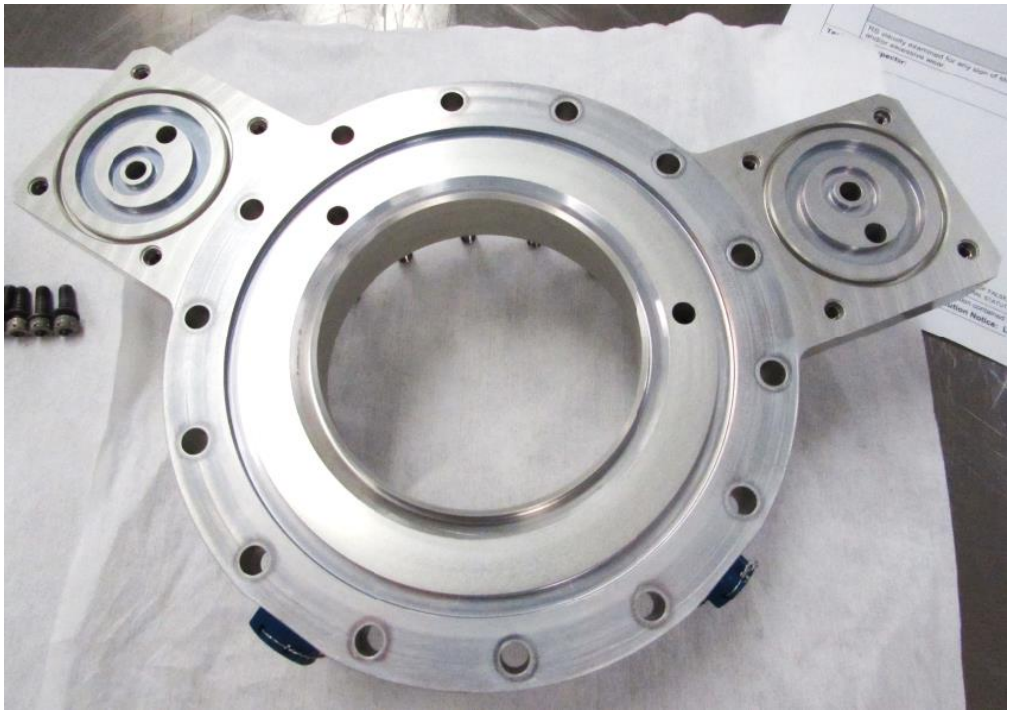


FIGURE 134
FLANGE (HOUSING SIDE)

FIGURE 135
FLANGE: (OUTLET SIDE)

FIGURE 136
FLANGE: SEAL GROOVES (HOUSING SIDE)

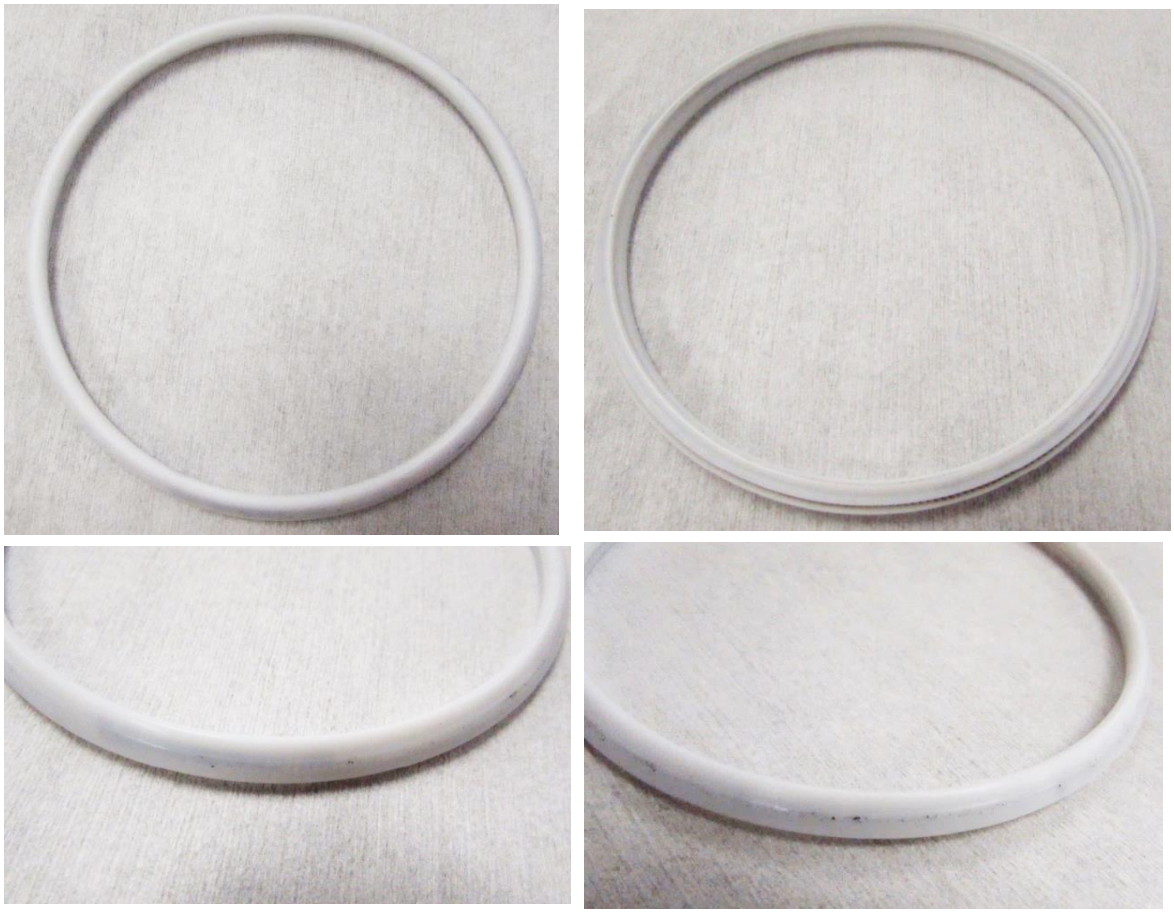


FIGURE 137
POPPET SEAL

FIGURE 138
FACE SEAL (FLANGE)

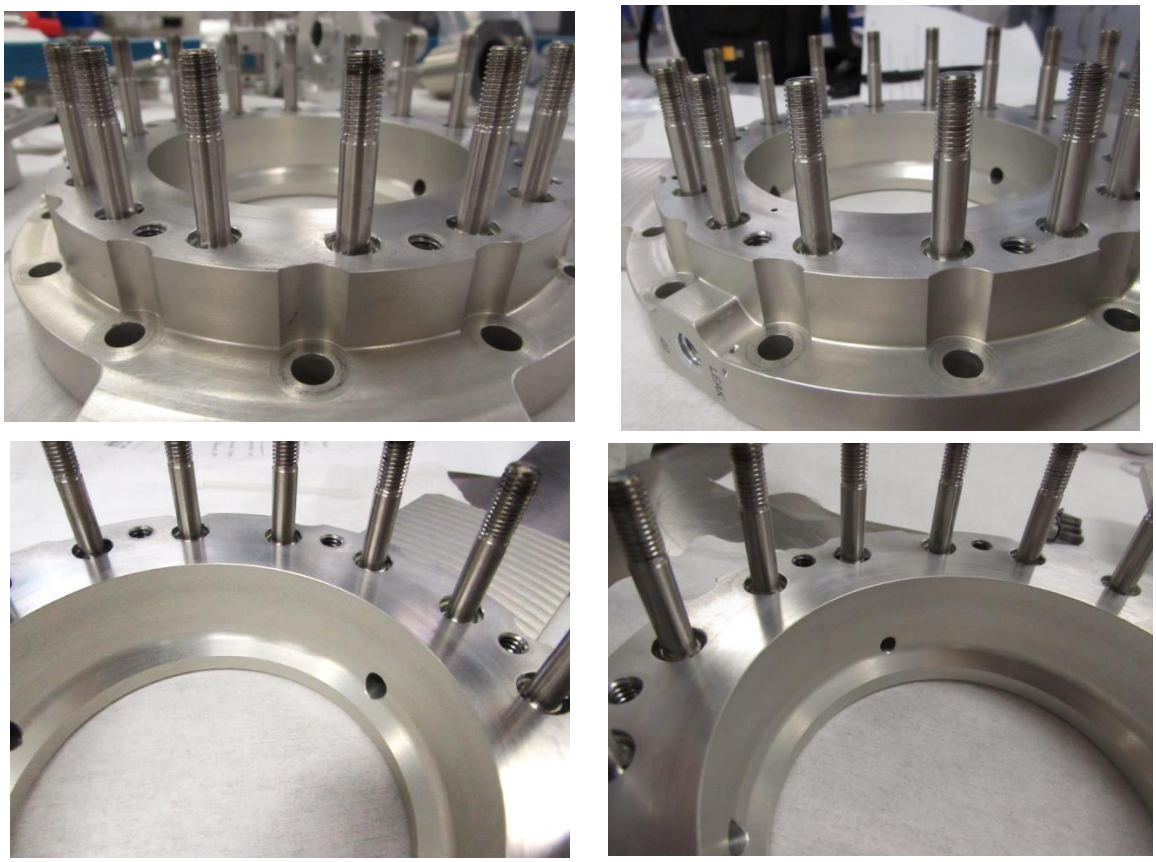


FIGURE 139
FLANGE: STUDS AND SEALING SURFACE (OUTLET SIDE)

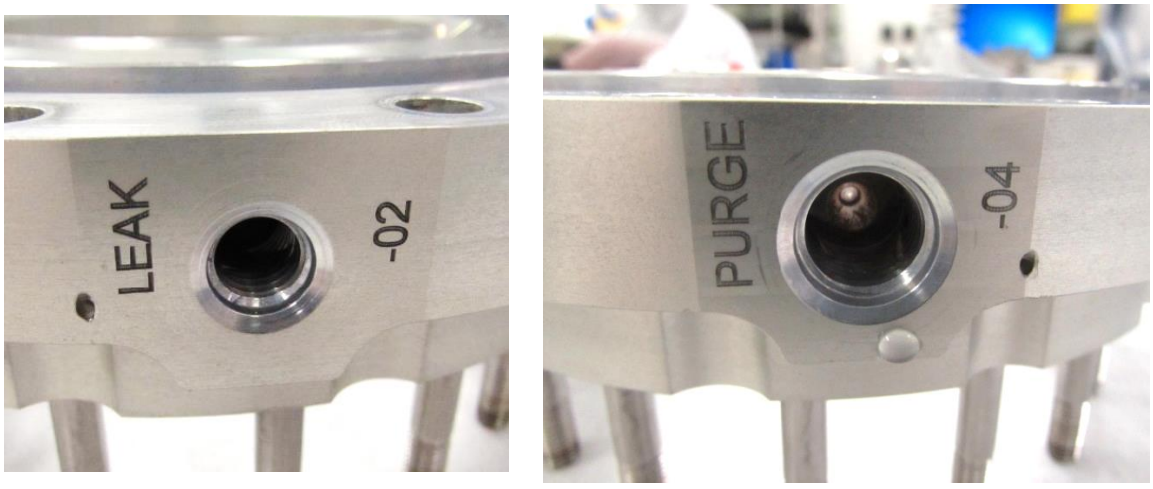


FIGURE 140
FLANGE: LEAK AND PURGE PORTS

Leak Port Plug

Purge Port Plug

FIGURE 141
FLANGE: LEAK AND PURGE PORT PLUGS

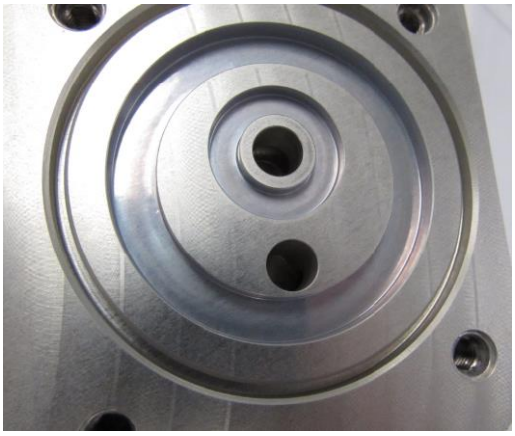


FIGURE 142
RELIEF VALVE SEAL GROOVES, S/N 00011 (LEFT) S/N 00005 (RIGHT)

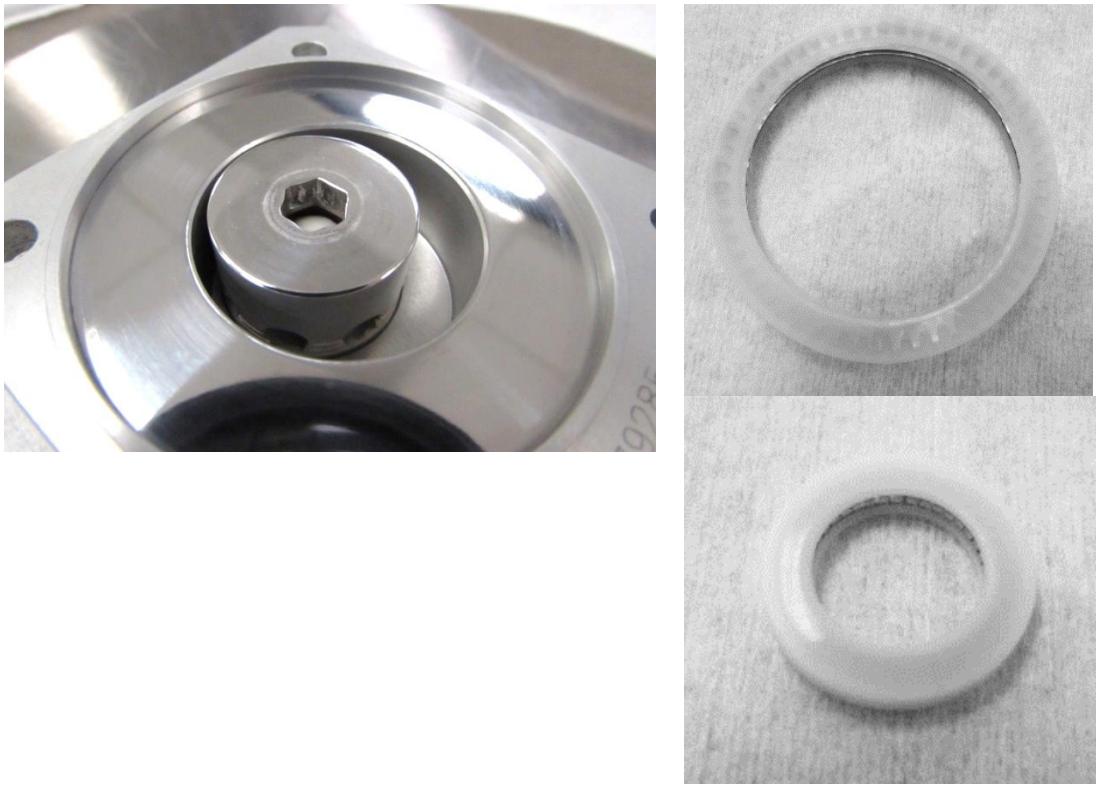


FIGURE 143
RELIEF VALVE S/N 00005 AND SEALS

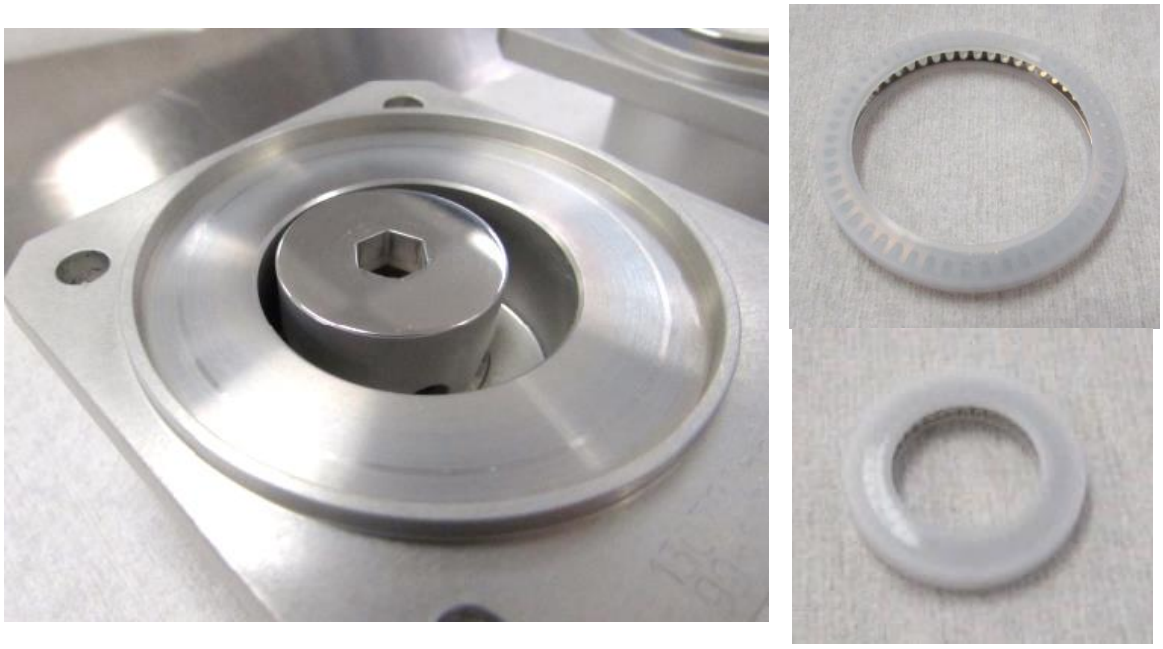


FIGURE 144
RELIEF VALVE S/N 00011 AND SEALS

7.0 CONCLUSION

TAERON's Redundant Seal, Shut-Off Valve, LH2 (P/N 13079-000-01) has completed all testing specified in the Qualification Test Procedure 13079-00-QTP1 and successfully demonstrated compliance with the performance requirements of ED 201-023702.

APPENDIX A

ACCETANCE TEST PROCEDURE DATA SHEETS (ATPDS)

APPENDIX B

QUALIICATION TEST PROCEDURE DATA SHEETS (QTPDS)

APPENDIX C

BENCH SHOCK, SHOCK, AND VIBRATION TESTS
NTS SANTA CLARITA
TEST REPORT NO. PR065733-00, REV. A

APPENDIX D

LH2 TESTS
NTS SAN BERNARDINO
TEST REPORT NO. TR065733, REV. 1

APPENDIX E

NON-CONFORMANCES & FAILURE INVESTIGATIONS

VACCO *Engineered Fluid Controls and Etched Products*

VACCO INDUSTRIES ESCO CAGE CODE: 99517	ENGINEERING CHANGE NOTICE	ECR NO. ECR009584 ECN NO. ECN008787

INITIATED BY:	DEPT.	DATE:	DOCUMENT NO.	REV.
Chung, Marilyn	Engineering	05/30/2019	13079-00-QTR1	-

END ITEM AFFECTED: 13079000-01

DOCUMENT TITLE: Qualification Test Report for Redundant Seal

CUSTOMER: BOEING HUNTSVILLE

CHARGE NO.. 501504AG58

DESCRIPTION OF CHANGE REQUEST: (For reference only, see red line document for changes)

(For Reference, see red line markup for changes)
Initial Release

REASON: Initial Release

JUSTIFICATION:

EFFECTIVITY: Upon release of ECN

SERIAL NUMBER: N/A

EFFECTIVITY DATE: 06/03/2019

OTHER DRAWING/DOCUMENT AFFECTED? No

AFFECTED ITEM LIST:

REVIEWERS	DATE	MATERIAL DISPOSITION	COMMENTS
CHECKER: Torres, Josie	06/03/2019	**ON ORDER:** Not Applicable	
DOCUMENT PREPARED BY: Not Applicable		**IN PROCESS:** Not Applicable	
PROJECT ENGINEER: Chung, Marilyn	06/12/2019	**IN STOCK:** Not Applicable	
ENGINEERING MANAGER: Cortez, Jose	06/12/2019	**IN ASSY'S:** Not Applicable	
QUALITY ASSURANCE: Korzen, Joe	06/12/2019	**IN SERVICE:** Not Applicable	
MANUFACTURING ENG: Not Applicable		**OTHER:**	
PRODUCTION CONTROL: Not Applicable			
M&P ENGINEERING: Not Applicable		**CUSTOMER APPROVAL:** Yes	
OPERATIONS: Not Applicable		**CHANGE CLASSIFICATION:** NA	
ELECTRICAL ENGINEER: Not Applicable		**CHANGE INITIATION:**	
CONTRACTS: Amador, Christina	06/12/2019	**INCORPORATED BY:**	
CHECKED BY: Torres, Josie			
PRJ. ENG. INCORP. APPROVAL: Chung, Marilyn			
ENG. INCORP. APPROVAL: Cortez, Jose			