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Modal Analysis and Vibration Test of NASA MSFC Shaker Table

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July 13, 2018

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National Aeronautics and Space Administration
George C. Marshall Space Flight Center
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July 13, 2018

To: ET40 Vibrations Team
From: Brian Mincks
Subject: Modal Analysis and Vibration of UD T4000-H Shaker

The Unholtz-Dickie T4000A horizontal shaker (UD T4000A-H) was subject to both a modal tap test and a subsequent vibration test. The modal test was completed on July 2, 2018 and the vibration test was completed on July 9, 2018. The FRF's from the modal test and the acceleration profiles and duration schedules from the vibration test are shown in the attached tests and procedures.

Please direct any questions or comments to Brian Mincks at (740) 348-6826, brian.mincks@nasa.gov, or b.d.mincks@wustl.edu.

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Unholtz-Dickie T4000A Modal Analysis & Vibration Test

Abstract

A shaker can be used to simulate launch vibrations and check responses of structures forced at different frequencies. When vibrating at certain frequencies during tests, structural modes of the shaker table itself can cause the test to abort by accelerating too much or by pushing too much electrical gain through the system. Furthermore, structural modes can produce misleading data at these modal frequencies and cause the test article to be under-tested or over-tested. A modal roving hammer test of the horizontal shaker table is conducted to characterize these modes of the shaker table. Two cases were tested in an attempt to simulate the boundary condition of the table on the shaker: free-free and free-fixed. The free-free case revealed a stretching mode at 1334.2Hz while free-fixed showed two stretching modes at 576.7Hz and 1372.3Hz. A subsequent vibration test revealed controlling 20in from the shaker attachment point best controls these modes without drastically over-testing or under-testing.

Introduction

The goal of this experiment is to characterize the structural modes of the UD T4000A horizontal shaker in an effort to better understand how to control it at these resonances. A control accelerometer is attached to the shake table and relays how many g's the test article is feeling to the control system. The control system adjusts power to the shaker in an attempt to shake the control accelerometer at a specified level. Due to the continuity in the shaker table structure and the finite location at which a control accelerometer can sense, the control accelerometer can be subject to more or less g's relative to the rest of the structure depending on where it is in the mode shape. If the control accelerometer is in a resonance of the mode shape, it will not take much power to shake the control accelerometer at the specified level and the rest of the mode shape will feel less g's (under testing). Conversely, if the control accelerometer is in a node, the control system will push the shaker harder than necessary. This causes the rest of the mode shape to feel more g's (over testing). Furthermore, the control system may be forced to abort the test in this case because it puts too much gain through the amps in an attempt to push the control accelerometer to the specified levels.

Damage and test abort problems usually occur in the axis of vibration so the in-axis component of the modes is all that is considered in this report. The plate stretching mode responds completely in axis and usually causes the most problems. The stretching modal frequency in Hz of any structure is calculated as in Eq. 1 [1].

$$f = \frac{V}{AL} \tag{1}$$

Here, *V* is the speed of sound of the material defined as $V = \sqrt{\frac{E}{\rho}}$ where *E* is the elastic modulus of the material and ρ is the density. *L* is the length of the structure in the axis of stretching. *A* is a constant dependent on the boundary condition and is defined in Eq. 2.

$$A = \begin{cases} 2, & Free - Free \\ 4, & Free - Fixed \end{cases} \tag{2}$$

A modal roving hammer test is performed to reveal the stretching modes that Eq. 1-2 predict. The table has a free-forced boundary condition on the table itself. A forced boundary condition cannot be simulated in the modal tap test so the plate will be simulated as both free-free and free-fixed to reveal all frequencies around which the stretching mode might appear. A subsequent vibration test is performed to sweep through the modal frequencies discovered in the modal tests. The swept sine test will be repeated, but controlled at various locations along the length of plate. This should reveal how much vibration gain or attenuation is being felt around the plate

Apparatus & Procedures

<u>Part 1: Modal Analysis</u>

The experiment starts with the free-free modal test. The equipment list for the modal tests is seen below in Table 1.

Table 1 Equipment List

	Item	NEMS/SN	Cal Date	Cal Due
R1	Accelerometer	LW147719	9/20/14	9/20/15
R2	Accelerometer	LW147963	2/28/15	2/28/16
	Hammer/Load Cell	LW40109	N/A	N/A
	20g hammer mass	N/A	N/A	N/A
	Plastic hammer tip	N/A	N/A	N/A
	Data Acquisition Front End	45034708	N/A	N/A
	Dell M6400 Computer	TL13A	N/A	N/A
	Free Shaker Table	N/A	N/A	N/A
	Fixed Shaker Table	N/A	N/A	N/A

Accompanying, relevant calibration documents are available in Appendix A.1. A schematic showing the equipment setup is seen below in Figure 1.

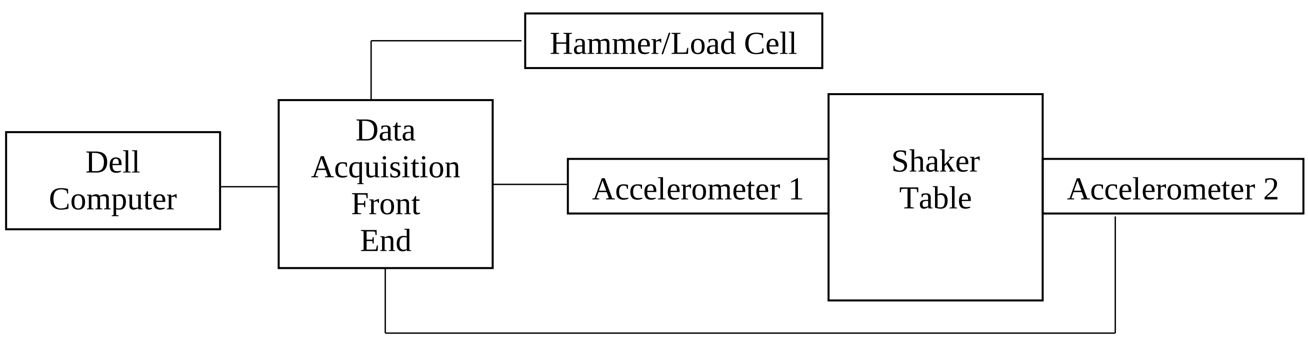


Figure 1 Modal test setup

To simulate the free-free boundary condition, the shaker is setup on foam blocks. Simple, checkout tests revealed the first structural mode was more than ten times that of the first rigid body mode signifying the free-free simulation is valid [1]. Figure 2 shows this setup of the shaker table on foam.

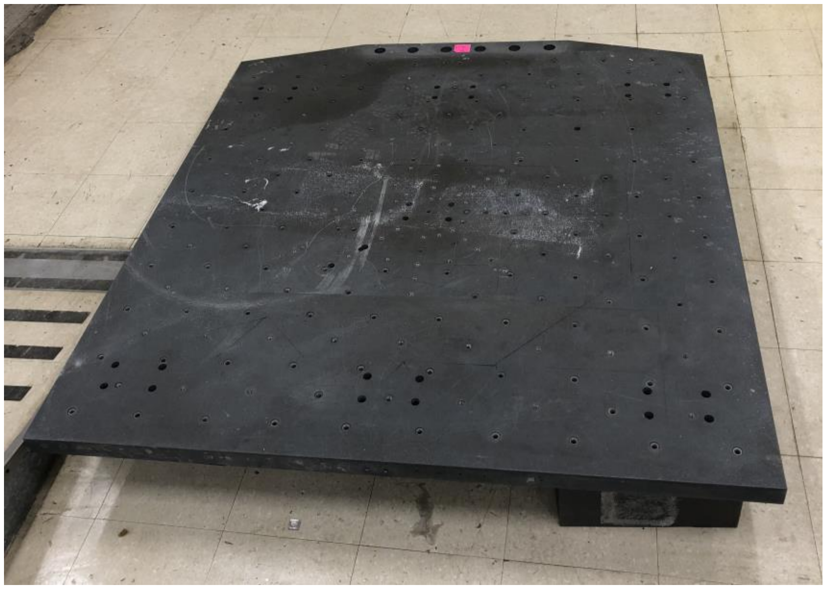


Figure 2 Free-Free test setup

To simulate a free-fixed boundary condition, the table is left on the shaker. Lubricating oil that flows during shaker operation is pumped in between the table and its support structure to create the free boundary condition. The shaker is left locked to fix the other end. Figure 3 shows the free-fixed configuration.

Figure 3 Free-fixed test setup

The tap test utilized two response accelerometers and six tap locations. The plate geometry, accelerometer locations, and hammer tap locations are seen below in Figure 4.

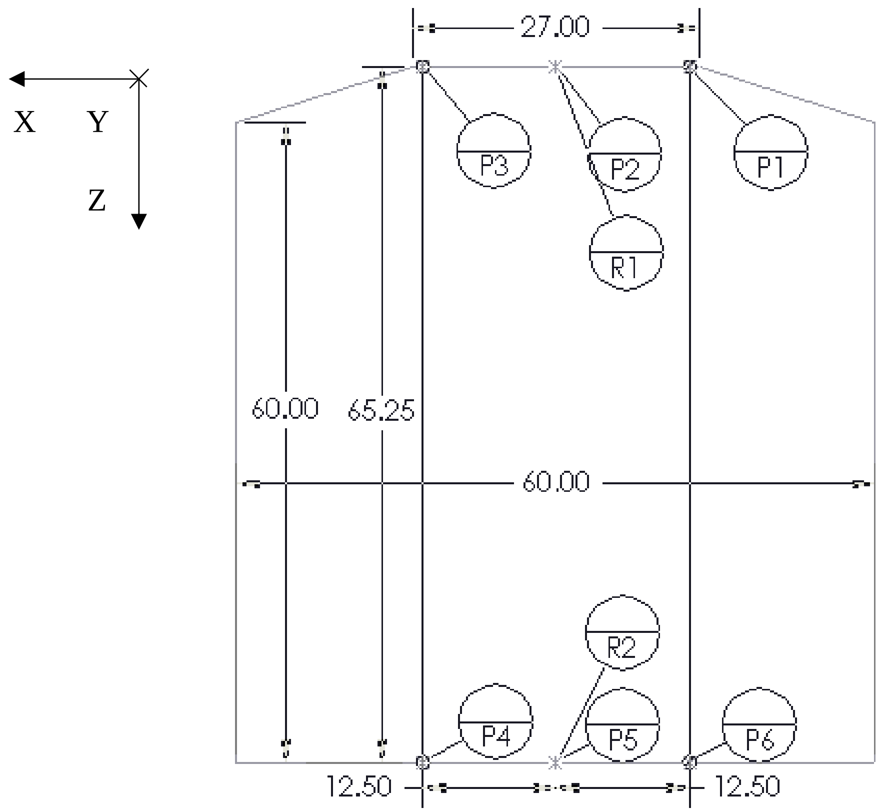


Figure 4 Geometry and tap locations on shaker table (dimensions in inches)

Here P1 – P6 signify the tap locations of the hammer and R1 and R2 are the accelerometer locations. The accelerometers are glued onto the table using Cyanoacrylate. The test excites frequencies over 1000Hz so glue must be used to ensure good energy transfer. Taps on point P1-P3 happen along the thickness of the plate in the +Z direction while taps on points P4-P6 happen in the -Z direction.

All of the data is taken using LMS Impact Testing 13A software. Table 2 shows all of the test setup parameters. The impact scope parameters are all codependent. Once two are defined, the other two are calculated. Bandwidth is set to 1600Hz because tests usually abort around what is suspected to be the stretching mode at 700Hz. In order to prevent leakage in the data, 1600Hz is chosen to ensure at least twice the frequency of interest is measured [1]. Acquisition time was set next at 5.12s. The plate rang for approximately three seconds in the free-free case when struck with the hammer. In order to observe the entire impact with a margin of safety, 5.12s is chosen. Once the Impact scope parameters are chosen, the tip and hammer masses has to be addressed. A 10 – 20 dB drop in impact energy is desired across the bandwidth of interests. This prevents the introduction of leakage through non negligible energy being input at a frequency that's not being measured [1]. This can be accomplished with many different hammer mass and tip configurations. For this experiment, a hard plastic tip and two 20g masses were used. All the trigger settings were chosen from what the software suggests. A few test taps will yield suggested values similar to those seen below in Table 2. The data is slightly windowed to ensure the entire impact is observed without having lengthy acquisition time. If excluded from the table below, use the default settings.

Table 2 LMS parameters

Software Section	Software Subsection	Field	Value
Impact Scope	N/A	Bandwidth	1600Hz
		Spectral Lines	8192
		Resolution	0.1953125Hz
		Acquisition Time	5.12s
Impact Setup	Trigger	Input Range	10V
		Trigger level	0.0916
		Pretrigger	0.0028s
	Windowing	Input	Force-Exponential (0.1403%)
		Response	Uniform (100%)
Measure	N/A	Averages	5

Part 2: Vibration Test

Once the modes have been found and characterized, a vibration test is conducted to sweep across the modal frequencies. The test uses 4 accelerometers at varying lengths from the shaker attachment point. The same test will be run 4 times with the exception of changing the control accelerometer. This should reveal what the rest of the structure is feeling compared to what the control accelerometer feels. The test equipment list is seen below in Table3.

Table 3 Vibration test equipment

	Item	NEMS/SN	Cal Date	Cal Due
P1	Accelerometer	LW129160	2/26/18	1/26/2019
P1	Charge Amp	M667358	7/1/17	7/1/18
P2	Accelerometer	LW189436	11/13/17	11/13/18
P2	Charge Amp	M666781	7/1/17	7/1/18
P3	Accelerometer	LW189425	11/13/17	11/13/18
P3	Charge Amp	M654005	11/16/17	11/16/18
P4	Accelerometer	LW189432	11/13/17	11/13/18
P4	Charge Amp	M665526	10/23/17	9/23/18
	Shaker	UD T4000A-H	N/A	N/A
	Control System Ch 1-4	VR9500 M671477	N/A	N/A
	Control System Ch 5-8	VR9500 M671481	N/A	N/A
	Control System Ch 9-12	VR9500 M671484	N/A	N/A

Accompanying, relevant calibration documents are available in Appendix A.2. A schematic of the test setup is seen in Figure 5.

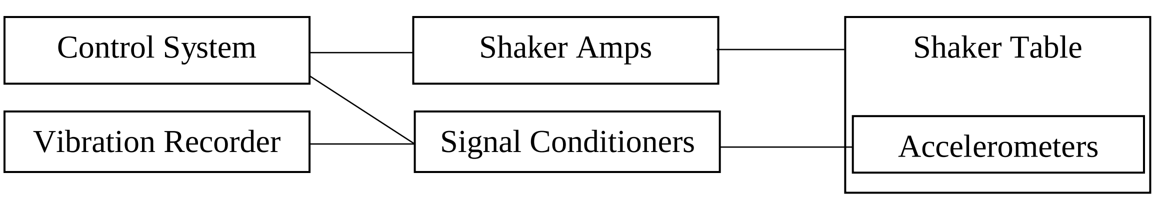


Figure 5 Vibration test setup schematic

Figures 6 shows a detailed drawing of the accelerometer locations on the table.

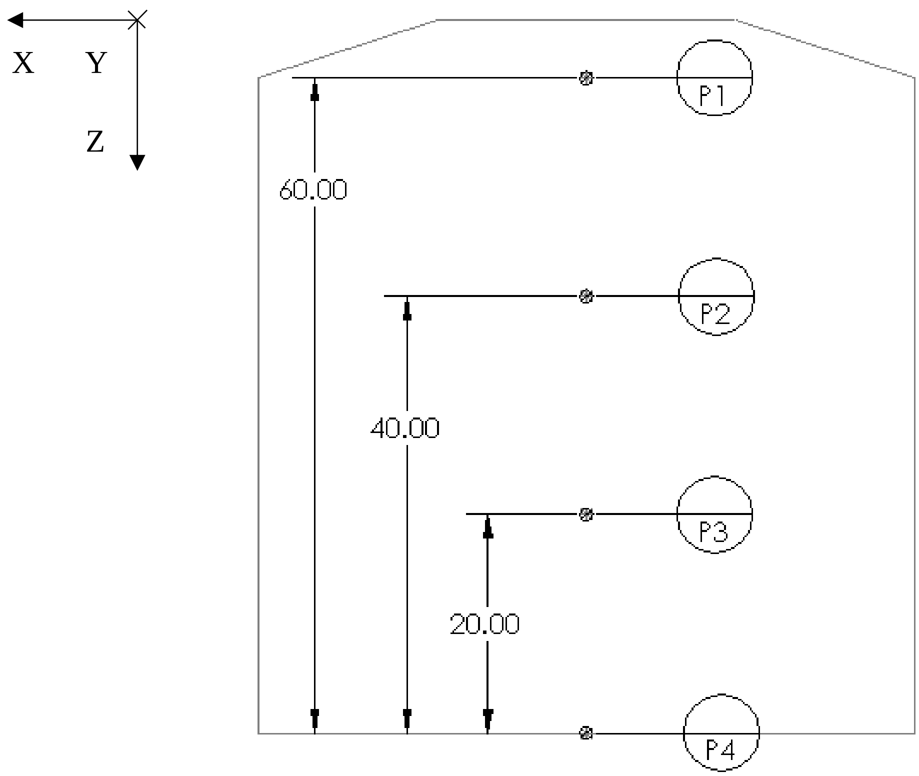


Figure 6 Accelerometer locations for vibration test (dimensions in inches)

Figure 7 shows a picture of the actual test setup.

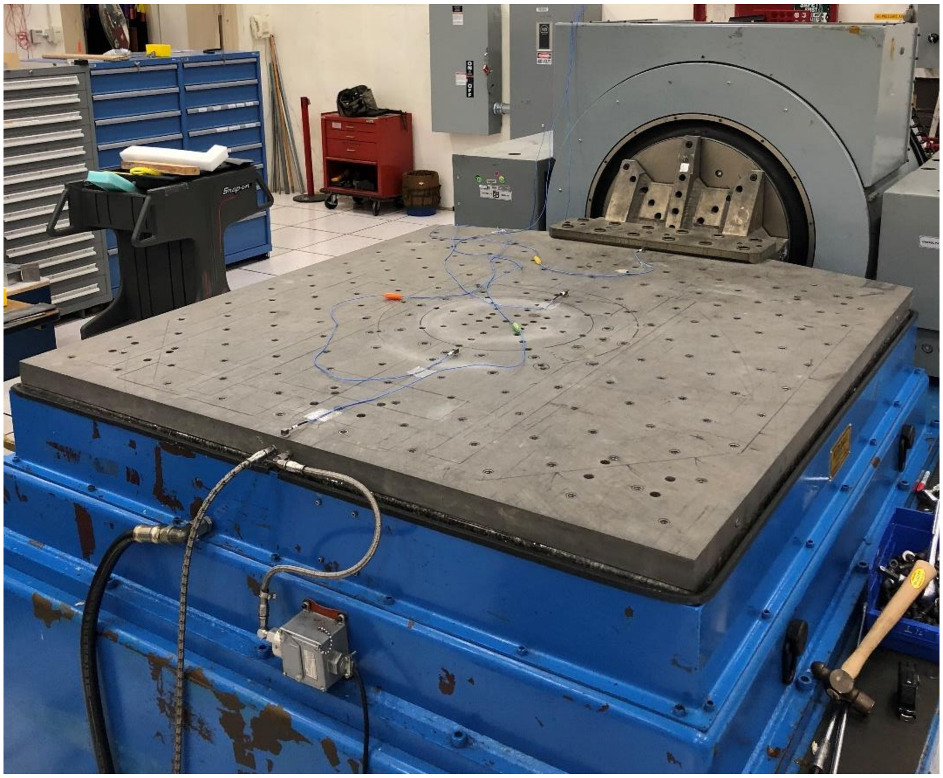


Figure 7 Vibration test setup

The test is controlled and recorded with the VibrationVIEW software. The test sweeps from 40Hz – 2000Hz at 0.5g. The test sweeps through the frequencies at 5 octaves/min with an abort range of $\pm 50dB$. All of the other settings are default. The first test controls with an accelerometer at P1, the second test controls with an accelerometer at P2, etc. All the other accelerometers in these tests simply record the response.

Results

Part 1: Modal Analysis

The frequency response functions (FRF's) at each tap location of the free-free tap test are seen below in Figure 8. The free-fixed FRF's are seen in Figure 9. Both Figures 8 and 9 are obtained directly from LMS.

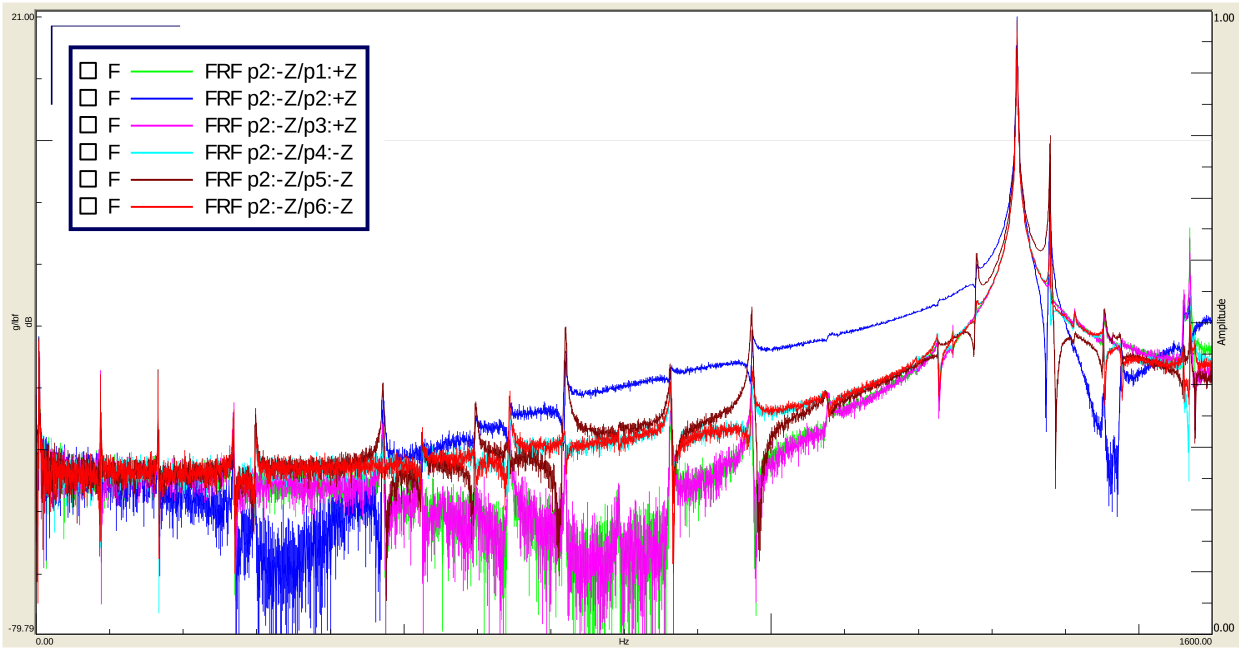


Figure 8 FRF's of free-free modal tap test

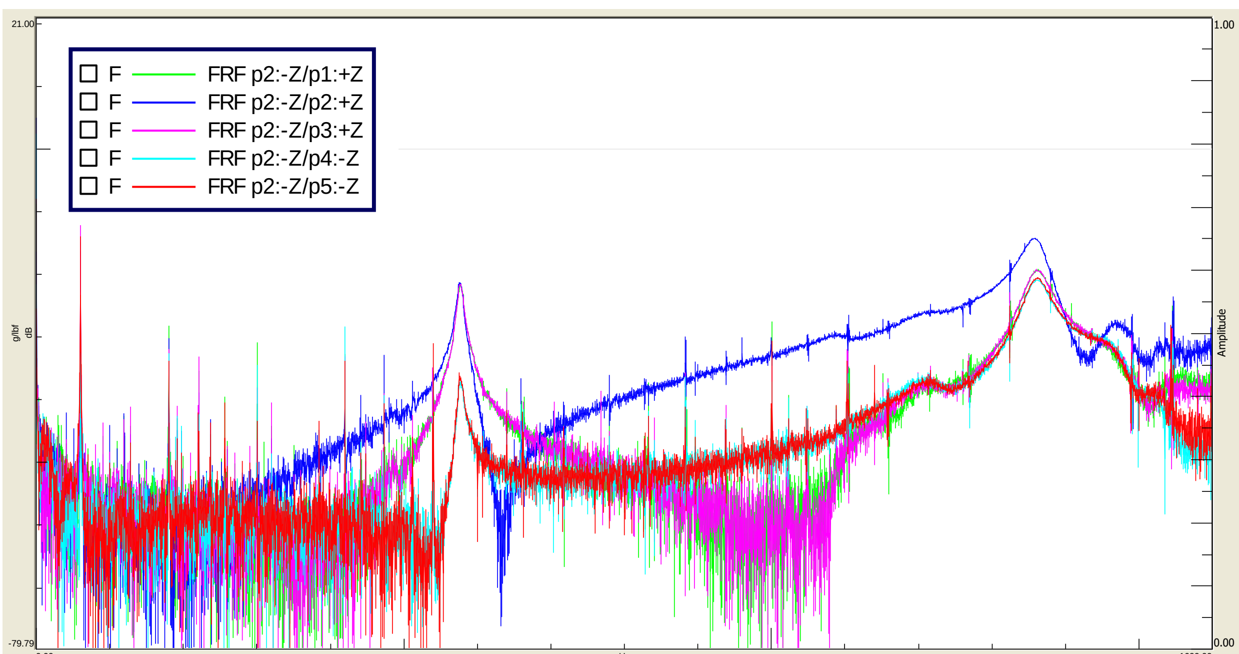
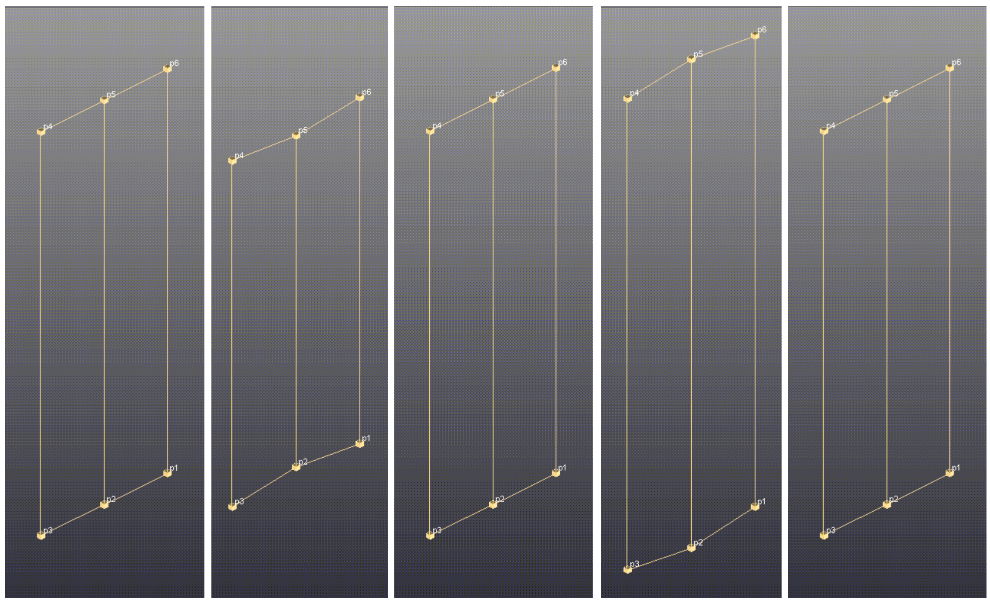


Figure 9 FRF's of free-fixed modal tap test

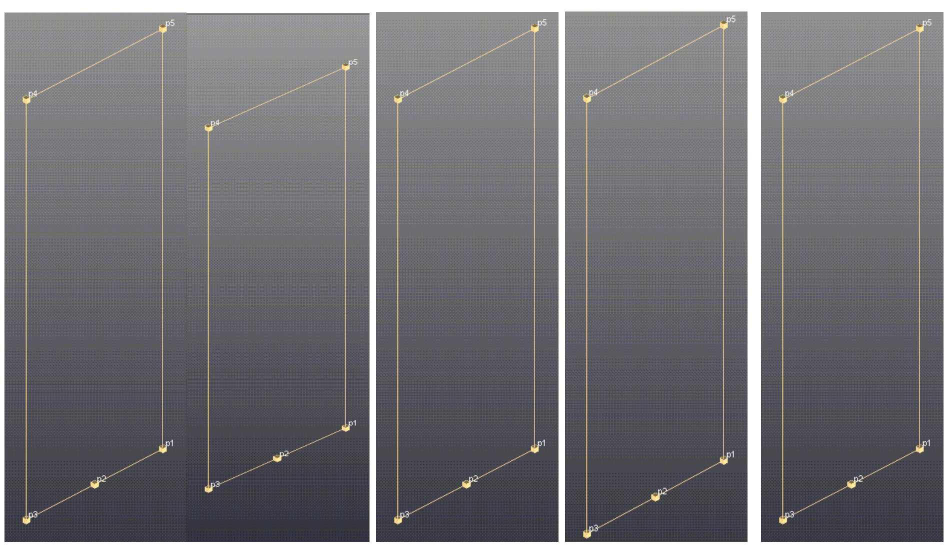
The quality of the data appears to be good. There is some noise in the data but it's all relatively small compared to the modal peaks.

All the peaks in all the test configurations correspond to a stretching mode. LMS directly animates the mode shapes that it is recording. The free-free stretching mode at 1334.2 Hz is seen below in Figure 10. The first and second modes of the free-fixed case at 576.7 Hz and 1360.6 Hz are seen in Figures 11 and 12, respectively.



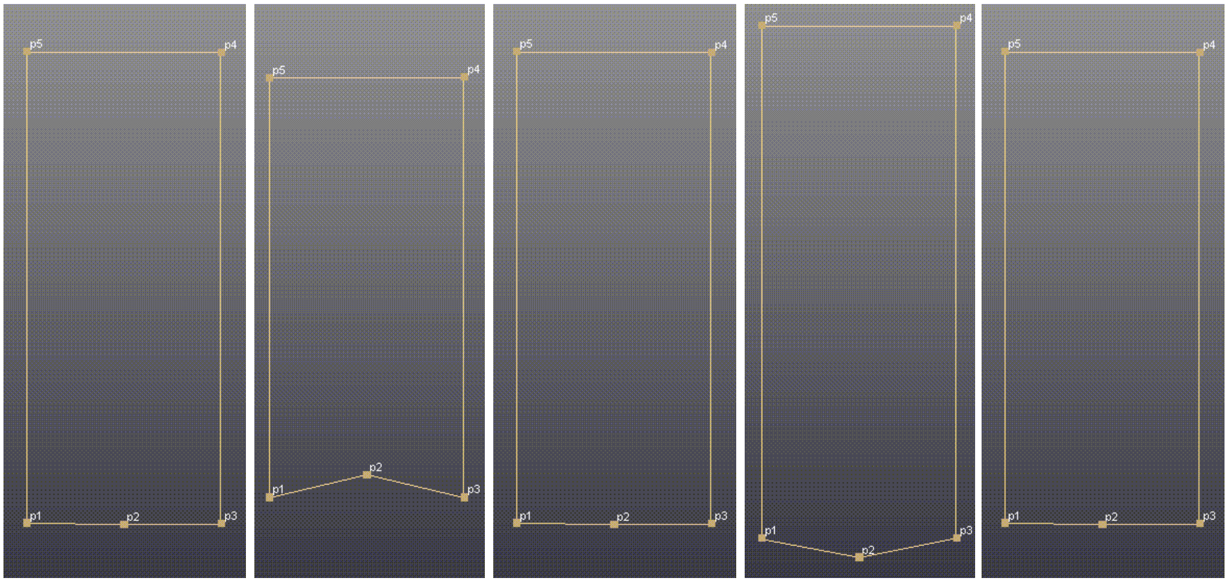
Initial Compressed Initial Stretched Initial

Figure 10 Free-free stretching mode at 1334.2 Hz, 0.02% damping



Initial Compressed Initial Stretched Initial

Figure 11 Free-fixed stretching mode at 576.7 Hz, 0.67% damping



Initial Compressed Initial Stretched Initial

Figure 12 Free-fixed stretching mode at 1360.6 Hz, 1.19% damping

Part 2: Vibration Test

Figure 13 shows the vibration profile controlling at P1. Figure 14 shows the vibration profile controlling at P2. Figure 15 shows the acceleration profile controlling at P3. Figure 16 shows the vibration profile controlling at P4. All of the acceleration profiles are exported directly from VibrationView

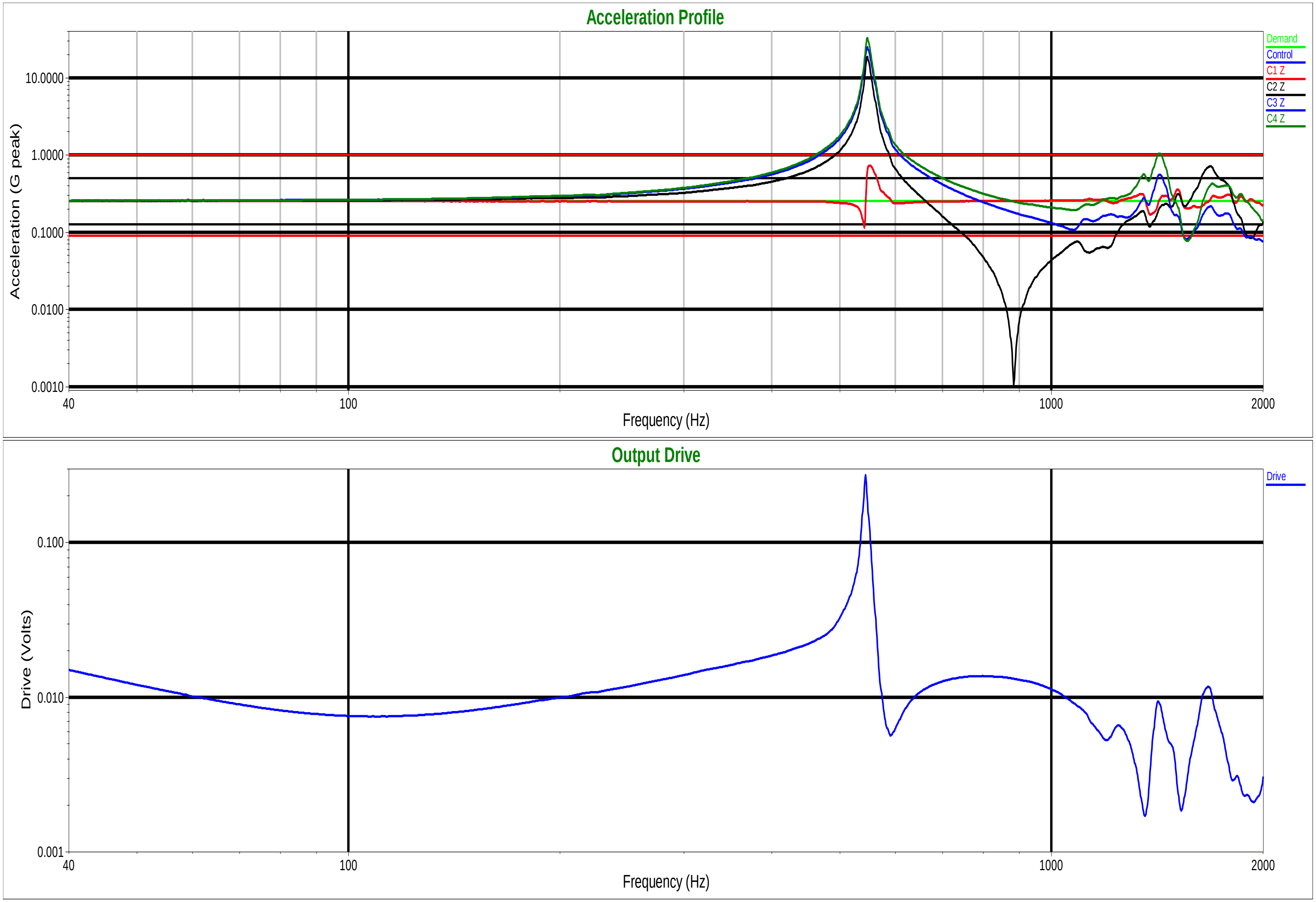


Figure 13 Vibration profile controlling at P1

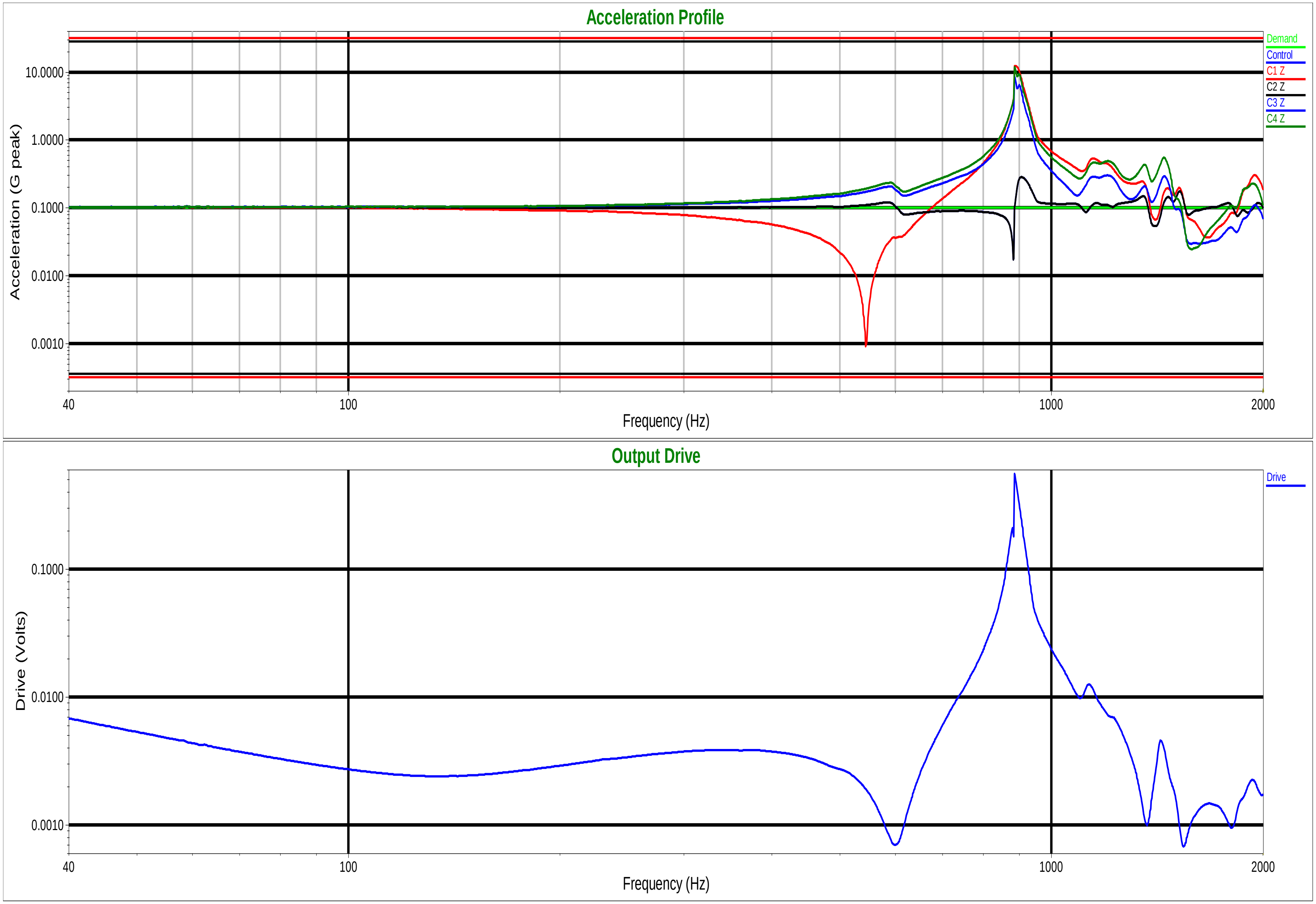


Figure 14 Vibration profile controlling at P2

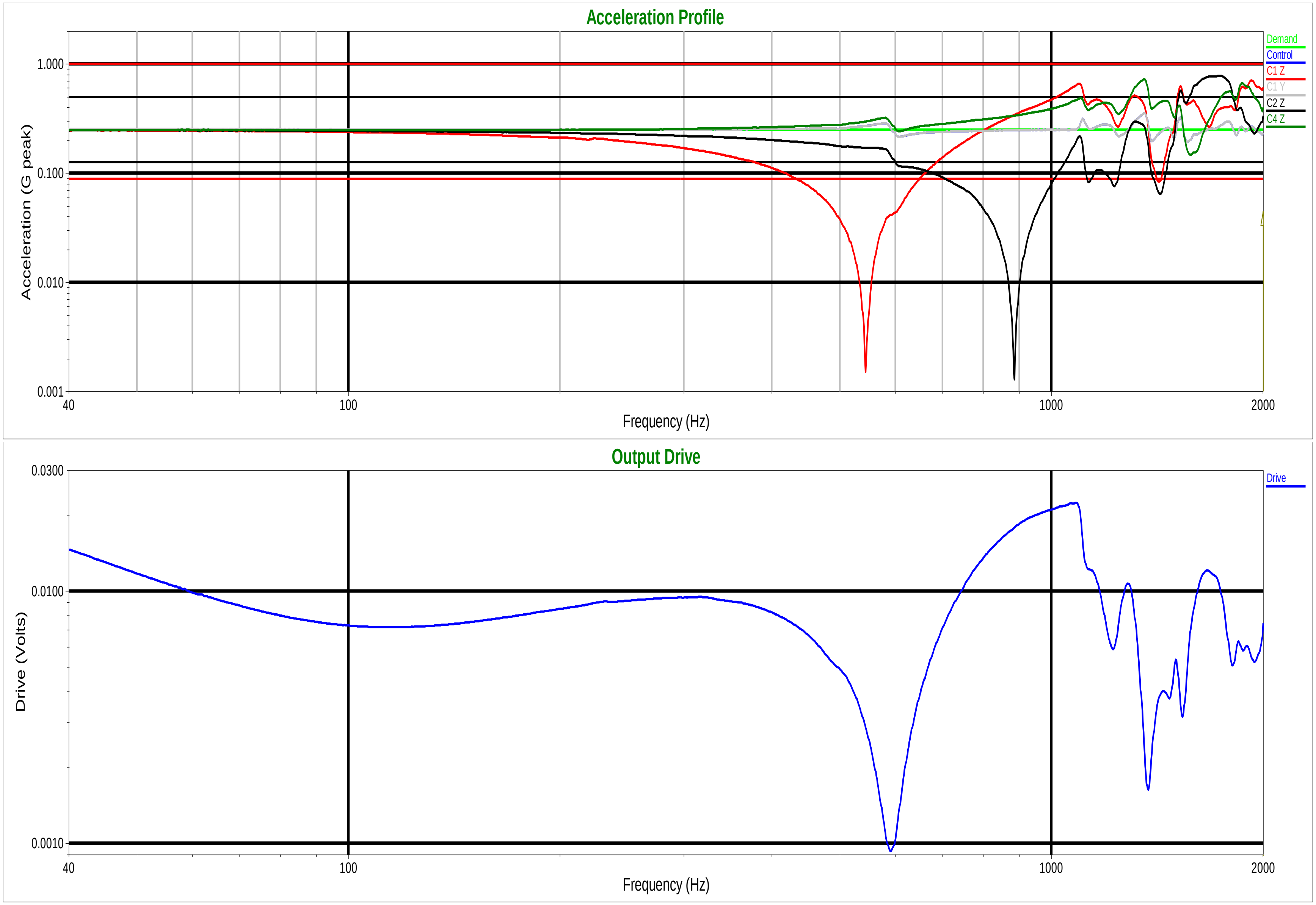


Figure 15 Vibration profile controlling at P3

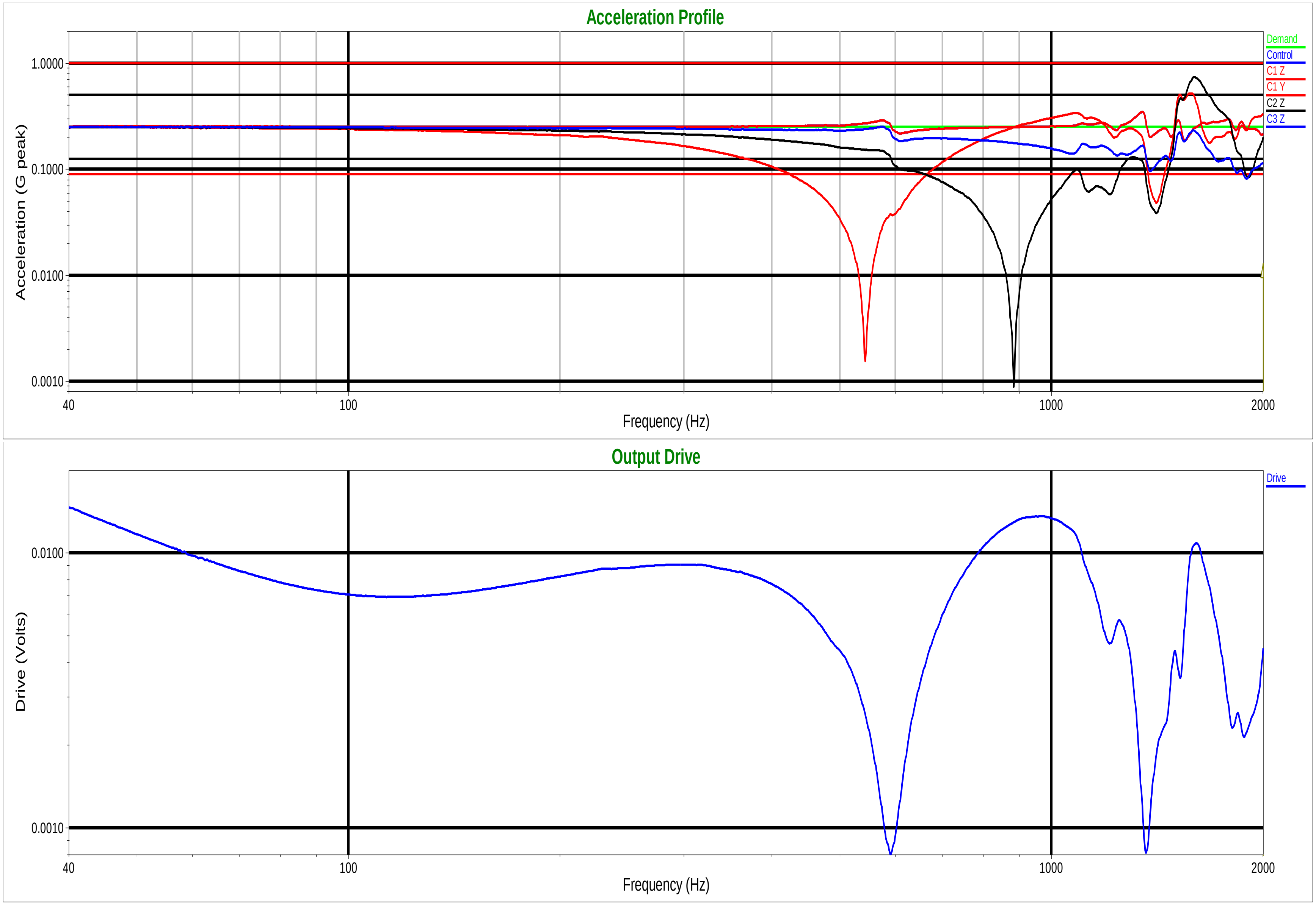


Figure 16 Vibration profile controlling at P4

The data looks good in quality. There doesn't appear to be any outliers that signify something went wrong in the tests.

Discussion

Part 1: Modal Analysis

The FRF peaks denote the modal stretching frequencies and align well with the predicted analytical first stretching mode frequencies as seen in Table 3.

Table 4 Experimental-analytical comparison of modal frequencies

Test Configuration	Measured Frequency [Hz]	Analytical Frequency [Hz]	Percent Error
Free-Free	1334.2	1446.9	7.78
Free-Fixed	576.7	723.5	20.3

The discrepancies in the data can be accredited to the irregular plate geometry. Equations 1 and 2 model a fixed-length uniform plate. The plate is not of fixed length and is riddled with mounting and bearing holes which both directly contradict the assumptions that are necessary to use Equations 1 and 2 accurately. The exaggerated error in the free-fixed case is due to an imperfect fixed boundary condition. While the plate is locked in the shaker, the whole shaker/plate system can still move because the shaker sits on airbags.

Part 2: Vibration Test

Point 1 appears to be a node. Figure 13 shows the acceleration profile controlling at point 1. While it stays on its 0.5g line through the frequency, all the other points have vibration gains over 20 at the first stretching mode. The control system has to push the shaker hard to get this node up to a 0.5g while the others are resonating. Point 2 appears to be approaching a resonance. Figure 14 shows the control system doesn't have to push the shaker too hard to get Point 2 up to the specified acceleration. It's also seen that the Point 1 node is barely moving and Points 3 and 4 are resonating a little harder at the first stretching mode. Figures 15 and 16 show similar trends with points 3 and 4. It appears that point 4 resonates the hardest followed by point 3 and then point 2. This was analyzed by exporting all the vibration view data to Excel.

At each control location, the acceleration gains were analyzed by comparing the responses to the control. Table 5 shows these trends.

Table 5 Vibration gains across table at varying control points

Control Point	Vibration Gain			
---	P1	P2	P3	P4
P1	1	34.59554	45.88156	60.12159
P2	0.009636	1	1.573561	1.753507
P3	0.010218	0.628204	1	1.10232
P4	0.010724	0.559686	0.878997	1

This makes sense from the results from the modal test. The animations in Figures 11 and 12 show both ends moving like an accordion. However, that is for a free fixed boundary condition. Since the 'fixed' end is actually forced in the actual vibration test, a Galilean transformation must be applied to the frame of reference so that the free-fixed mode shapes can be applied. In this transformed reference frame, the mode shape is viewed from the perspective of the shaker head and the end (P4) will be resonating the most while the attachment point (P1) will be fixed.

Conclusion

Stretching modes exist in the shaker table. The free-free configuration has a stretching mode at 1334.2 Hz and the free-fixed configuration has two modes at 576.7 Hz and 1360.6 Hz. The free-free test aligns quite well with the analytical solution while the free-fixed case test setup could be improved to make a more fixed end. These results can be used to help control the shaker through the stretching modal frequencies. A Galilean transformation of the reference frame is conducted to the accordion-like mode shape from the free-fixed test so it is viewed from the perspective of the shaker. In this reference frame the accordion mode will be stationary at the attachment point to the shaker and be resonating at the full length. Table 5 concisely depicts how this length dependent resonance affects the vibration gain in the structure. To best control the shaker table and to provide an accurate, safe, abort free test through the stretching modes, control around 20 inches from the attachment head. The vibration gains felt throughout the rest of the structure only get as big as 1.75. This should prevent the test from aborting and ensure the test article is not being damagingly over-tested.

References

1. Rost, Robert, Allemong, Randal. (2018, May 15-17). *Practical Data Acquisition and Experimental Modal Analysis Theory and Applications*.

Appendix A.1 Modal Test accelerometer calibration information

CH2/Free Side

Calibration Certificate

Marshall Space Flight Center

AS FOUND CALIBRATION

Certificate #: 278353

Calibration Performed By:	Calibration Performed For:
MSFC METROLOGY & CALIBRATION LABORATORY BLDG 4650S DODD ROAD MARSHALL SPACE FLIGHT CENTER, AL 35812 (256) 544-4900	Department: ET40-E Requested By: STEVE RODGERS Owner: STEVE RODGERS User Location: 4619RM 151

Equipment Information

ECN (ID):	M667029	Calibration Interval Adjustment Method:	EOPR
Manufacturer:	PCB PIEZONTRONICS	Effective EOPR: 100 %	Cals In Tolerance: 1
Model Number:	356B21	Previous EOPR: 0 %	Total Cals: 1
Description:	ACCELEROMETER	CIAM Comments:	
Serial Number:	LW147719	Minimum EOPR Target:	89 %
Range(if applicable):	500GPK	Maximum EOPR Target:	95 %
Recall Category:	2	Interval Suggested:	12 Months

Current Calibration Information

Work Order Number:	20140904002	Condition Received:	A IN TOLERANCE
Priority:	3 - LOW	Action Taken:	C CALIBRATED
Calibration Date:	09/20/14	Calibration Result:	PASS
Calibration Interval:	12 MONTHS	Found/Left*	FOUND/LEFT
Calibration Due Date:	09/20/15	Quality Requirement:	ANSI/NCSL Z540-1-1994(2002)
Performed By:	THOMAS MAGRUDER	Ratio Descr / Ratio:	TAR / 3.16:1
Performed By Email:	thomas.v.magruder@nasa.gov	Lab Temperature/Relative Humidity:	24C / 41 %

Limitations (if applicable):

Calibration Notes (if applicable): **Note: Unless otherwise indicated, the condition of the item was left in the same state as which it was received.*

Traceable Standards Used During Calibration

ECN	Manufacturer	Model	Description	Cal Date	Due Date
2195390	MB DYNAMICS	405L	SIGNAL CONDITIONER	07/25/14	07/25/15
M656450	PCB PIEZOTRONICS	301M15	ACCELEROMETER	06/17/14	06/17/15
M656502	NATIONAL INSTRUMENTS	PCI-MIO-16E-1	DAC BOARD	07/24/14	07/24/15

End of Traceable Standards

Procedures Used In This Event

Procedure By	Procedure Number	Description	Revision	Revision Date
MSFC	2-0142	ACCELEROMETERS AND VIBRATION PICKUPS	3	02/07/2011

This instrument was calibrated to laboratory standards which are traceable through an unbroken chain of comparisons to the National Institute of Standards and Technology (NIST), laboratories recognized by the same, intrinsic standards, fundamental constants of nature, or mutual consent standards. This report may not be reproduced, except in full, without written permission from the organization issuing this report. The results of this calibration apply only to the item identified above, at the time of test, and under the conditions reported.

Generation Date:09/20/14 Page 1 of 1 *MSFC CERT REV 2 (08-06-2014)* cn3 / shaker side

Calibration Certificate

Marshall Space Flight Center

AS FOUND CALIBRATION

Certificate #: 301600

Calibration Performed By:	Calibration Performed For:
MSFC METROLOGY & CALIBRATION LABORATORY BLDG 4650S DODD ROAD MARSHALL SPACE FLIGHT CENTER, AL 35812 (256) 544-4900	Department: ET40-E Requested By: STEVE RODGERS Owner: STEVE RODGERS User Location: 4619RM151

Equipment Information

ECN (ID):	M667671	Calibration Interval Adjustment Method:	EOPR
Manufacturer:	PCB PIEZONTRONICS	Effective EOPR: 100 %	Minimum EOPR Target: 89 %
Model Number:	356B21	Interval Suggested: 12 Mon.	Maximum EOPR Target: 95 %
Description:	ACCELEROMETER	CIAM Comments:	12 month interval per EOPR of others in database with this
Serial Number:	LW147963	Calibrations Found In Tolerance:	1
Range(if applicable):	500G	Calibrations Found Inoperative/Other:	0
Recall Category:	2	Total Calibrations:	1

Current Calibration Information

Work Order Number:	20150212065	Condition Received:	A IN TOLERANCE
Priority:	3 - LOW	Action Taken:	C CALIBRATED
Calibration Date:	02/28/15	Calibration Result:	PASS
Calibration Interval:	12 MONTHS	Found/Left*:	FOUND/LEFT
Calibration Due Date:	02/28/16	Quality Requirement:	ANSI/NCSL Z540-1-1994(2002)
Performed By:	THOMAS MAGRUDER	Ratio Descr / Ratio:	TAR / 3.16:1
Performed By Email:	thomas.v.magruder@nasa.gov	Lab Temperature/Relative Humidity:	23 C / 44 %

Limitations (if applicable):

Calibration Notes (if applicable):

Note: Unless otherwise indicated, the condition of the item was left in the same state as which it was received.

Traceable Standards Used During Calibration

ECN	Manufacturer	Model	Description	Cal Date	Due Date
2195390	MB DYNAMICS	405L	SIGNAL CONDITIONER	07/25/14	07/25/15
M656450	PCB PIEZOTRONICS	301M15	ACCELEROMETER	06/17/14	06/17/15
M656502	NATIONAL INSTRUMENTS	PCI-MIO-16E-1	DAC BOARD	07/24/14	07/24/15

End of Traceable Standards

Procedures Used In This Event

Procedure By	Procedure Number	Description	Revision	Revision Date
MSFC	2-0142	ACCELEROMETERS AND VIBRATION PICKUPS	3	02/07/2011

This instrument was calibrated to laboratory standards which are traceable through an unbroken chain of comparisons to the National Institute of Standards and Technology (NIST), laboratories recognized by the same, intrinsic standards, fundamental constants of nature, or mutual consent standards. This report may not be reproduced, except in full, without written permission from the organization issuing this report. The results of this calibration apply only to the item identified above, at the time of test, and under the conditions reported.

Appendix A.2 Vibration Test accelerometer calibration information

Calibration Certificate

Marshall Space Flight Center

AS FOUND CALIBRATION

Certificate #: 554787

Calibration Performed By:	Calibration Performed For:
MSFC METROLOGY & CALIBRATION LABORATORY BLDG 4650S DODD ROAD MARSHALL SPACE FLIGHT CENTER, AL 35812 (256) 544-4900	Department: ET40-E Requested By: STEVE RODGERS Owner: STEVE RODGERS User Location: 4619RM 151

Equipment Information

ECN (ID):	**M668560**	Calibration Interval Adjustment Method:	EOPR
Manufacturer:	PCB PIEZOTRONICS	Effective EOPR: 100 %	Minimum EOPR Target: 89 %
Model Number:	356B21	Interval Suggested: 12 Mon.	Maximum EOPR Target: 95 %
Description:	ACCELEROMETER	CIAM Comments:	
Serial Number:	LW189425	Calibrations Found In Tolerance:	3
Range(if applicable):	500G PK	Calibrations Found Inoperative/Other:	0
Recall Category:	2	Total Calibrations:	3

Current Calibration Information

Work Order Number:	20171109183	Condition Received:	A IN TOLERANCE
Priority:	1 - HIGH	Action Taken:	C CALIBRATED
Calibration Date:	11/13/17	Calibration Result:	PASS
Calibration Interval:	12 MONTHS	Found/Left*	AS FOUND
Calibration Due Date:	11/13/18	Quality Requirement:	NPD 8730.1C
Performed By:	NATE GONZALES	Ratio Descr / Ratio:	TUR / 2.94:1
Performed By Email:	nathaniel.s.gonzales@nasa.gov	Lab Temperature/Relative Humidity:	20.7 C / 45.3 %

Limitations (if applicable):

Calibration Notes (if applicable): **Note: Unless otherwise indicated, the condition of the item was left in the same state as which it was received.*

See data.

Traceable Standards Used During Calibration

ECN	Manufacturer	Model	Description	Cal Date	Due Date
M666865	PCB PIEZOTRONICS	443B101	DUAL MODE SIGNAL CONDITIONI	12/12/16	12/12/17
M666866	PCB PIEZOTRONICS	080A200	SHAKER REFERENCE ACCELERO	12/07/16	12/07/17
M666867	PCB PIEZOTRONICS	442A102	SENSOR SIGNAL CONDITIONER	12/07/16	12/07/17
M667153	NATIONAL INSTRUMENTS	NI PC-4461	24 BIT DATA ACQUISITION MODU	12/05/16	12/05/17

End of Traceable Standards

Procedures Used In This Event

Procedure By	Procedure Number	Description	Revision	Revision Date
MSFC	2-0142	ACCELEROMETERS AND VIBRATION PICKUPS	3	02/07/2011

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Calibration Certificate

Marshall Space Flight Center

AS FOUND CALIBRATION

Certificate #: **583623**

Calibration Performed By:	Calibration Performed For:
MSFC METROLOGY & CALIBRATION LABORATORY BLDG 4650S DODD ROAD MARSHALL SPACE FLIGHT CENTER, AL 35812 (256) 544-4900	Department: ET40-E Requested By: STEVE RODGERS Owner: STEVE RODGERS User Location: 4619RM151

Equipment Information

ECN (ID): **M668960**	Calibration Interval Adjustment Method: EOPR
Manufacturer: PCB PIEZOTRONICS	Effective EOPR: 75 % Minimum EOPR Target: 89 %
Model Number: 356B21	Interval Suggested: 11 Mon. Maximum EOPR Target: 95 %
Description: TRIAXIAL ACCELEROMETER	CIAM Comments:
Serial Number: LW129160	Calibrations Found In Tolerance: 3
Range(if applicable): 500G PK	Calibrations Found Inoperative/Other: 0
Recall Category: 2	Total Calibrations: 4

Current Calibration Information

Work Order Number: 20180220007	Condition Received: A IN TOLERANCE
Priority: 3 - LOW	Action Taken: C CALIBRATED
Calibration Date: 02/26/18	Calibration Result: PASS
Calibration Interval: 11 MONTHS	Found/Left*: AS FOUND
Calibration Due Date: 01/26/19	Quality Requirement: NPD 8730.1C
Performed By: NATE GONZALES	Ratio Descr / Ratio: TUR / 2.94:1
Performed By Email: nathaniel.s.gonzales@nasa.gov	Lab Temperature/Relative Humidity: 21.8 C / 50.7 %

Limitations (if applicable):

Calibration Notes (if applicable): **Note: Unless otherwise indicated, the condition of the item was left in the same state as which it was received.*

See data.

Traceable Standards Used During Calibration

ECN	Manufacturer	Model	Description	Cal Date	Due Date
M666866	PCB PIEZOTRONICS	080A200	SHAKER REFERENCE ACCELERO	12/13/17	12/13/18
M666867	PCB PIEZOTRONICS	442A102	SENSOR SIGNAL CONDITIONER	12/13/17	12/13/18
M667153	NATIONAL INSTRUMENTS	NI PC-4461	24 BIT DATA ACQUISITION MODU	12/15/17	12/15/18
PCB-539	PCB PIEZOTRONICS	443B101	DUAL MODE SIGNAL CONDITIONE	11/17/17	11/17/18

End of Traceable Standards

Procedures Used In This Event

Procedure By	Procedure Number	Description	Revision	Revision Date
MSFC	2-0142	ACCELEROMETERS AND VIBRATION PICKUPS	3	02/07/2011

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Calibration Certificate

Marshall Space Flight Center

AS FOUND CALIBRATION

Certificate #: **554775**

Calibration Performed By:	Calibration Performed For:
MSFC METROLOGY & CALIBRATION LABORATORY BLDG 4650S DODD ROAD MARSHALL SPACE FLIGHT CENTER, AL 35812 (256) 544-4900	Department: ET40-E Requested By: STEVE RODGERS Owner: STEVE RODGERS User Location: 4619RM 151

Equipment Information

ECN (ID):	**M668543**	Calibration Interval Adjustment Method:	EOPR
Manufacturer:	PCB PIEZOTRONICS	Effective EOPR: 100 %	Minimum EOPR Target: 89 %
Model Number:	356B21	Interval Suggested: 12 Mon.	Maximum EOPR Target: 95 %
Description:	ACCELEROMETER	CIAM Comments:	
Serial Number:	LW189432	Calibrations Found In Tolerance:	3
Range(if applicable):	500G PK	Calibrations Found Inoperative/Other:	0
Recall Category:	2	Total Calibrations:	3

Current Calibration Information

Work Order Number:	20171109178	Condition Received:	A IN TOLERANCE
Priority:	1 - HIGH	Action Taken:	C CALIBRATED
Calibration Date:	11/13/17	Calibration Result:	PASS
Calibration Interval:	12 MONTHS	Found/Left*	AS FOUND
Calibration Due Date:	11/13/18	Quality Requirement:	NPD 8730.1C
Performed By:	NATE GONZALES	Ratio Descr / Ratio:	TUR / 2.94:1
Performed By Email:	nathaniel.s.gonzales@nasa.gov	Lab Temperature/Relative Humidity:	20.7 C / 45.2 %

Limitations (if applicable):

Calibration Notes (if applicable): **Note: Unless otherwise indicated, the condition of the item was left in the same state as which it was received.*

See data.

Traceable Standards Used During Calibration

ECN	Manufacturer	Model	Description	Cal Date	Due Date
M666865	PCB PIEZOTRONICS	443B101	DUAL MODE SIGNAL CONDITIONI	12/12/16	12/12/17
M666866	PCB PIEZOTRONICS	080A200	SHAKER REFERENCE ACCELERC	12/07/16	12/07/17
M666867	PCB PIEZOTRONICS	442A102	SENSOR SIGNAL CONDITIONER	12/07/16	12/07/17
M667153	NATIONAL INSTRUMENTS	NI PC-4461	24 BIT DATA ACQUISITION MODU	12/05/16	12/05/17

End of Traceable Standards

Procedures Used In This Event

Procedure By	Procedure Number	Description	Revision	Revision Date
MSFC	2-0142	ACCELEROMETERS AND VIBRATION PICKUPS	3	02/07/2011

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Calibration Certificate

Marshall Space Flight Center

AS FOUND CALIBRATION

Certificate #: **555120**

Calibration Performed By:	Calibration Performed For:
MSFC METROLOGY & CALIBRATION LABORATORY BLDG 4650S DODD ROAD MARSHALL SPACE FLIGHT CENTER, AL 35812 (256) 544-4900	Department: ET40-E Requested By: STEVE RODGERS Owner: STEVE RODGERS User Location: 4619RM 151

Equipment Information

ECN (ID):	**M668549**	Calibration Interval Adjustment Method:	EOPR
Manufacturer:	PCB PIEZOTRONICS	Effective EOPR: 100 %	Minimum EOPR Target: 89 %
Model Number:	356B21	Interval Suggested: 12 Mon.	Maximum EOPR Target: 95 %
Description:	ACCELEROMETER	CIAM Comments:	
Serial Number:	LW189436	Calibrations Found In Tolerance:	3
Range(if applicable):	500G PK	Calibrations Found Inoperative/Other:	0
Recall Category:	2	Total Calibrations:	3

Current Calibration Information

Work Order Number:	20171109180	Condition Received:	A IN TOLERANCE
Priority:	1 - HIGH	Action Taken:	C CALIBRATED
Calibration Date:	11/13/17	Calibration Result:	PASS
Calibration Interval:	12 MONTHS	Found/Left*	AS FOUND
Calibration Due Date:	11/13/18	Quality Requirement:	NPD 8730.1C
Performed By:	NATE GONZALES	Ratio Descr / Ratio:	TUR / 2.94:1
Performed By Email:	nathaniel.s.gonzales@nasa.gov	Lab Temperature/Relative Humidity:	21.2 C / 44.4 %

Limitations (if applicable):

Calibration Notes (if applicable): **Note: Unless otherwise indicated, the condition of the item was left in the same state as which it was received.*

See data.

Traceable Standards Used During Calibration

ECN	Manufacturer	Model	Description	Cal Date	Due Date
M666865	PCB PIEZOTRONICS	443B101	DUAL MODE SIGNAL CONDITIONI	12/12/16	12/12/17
M666866	PCB PIEZOTRONICS	080A200	SHAKER REFERENCE ACCELERC	12/07/16	12/07/17
M666867	PCB PIEZOTRONICS	442A102	SENSOR SIGNAL CONDITIONER	12/07/16	12/07/17
M667153	NATIONAL INSTRUMENTS	NI PC-4461	24 BIT DATA ACQUISITION MODU	12/05/16	12/05/17

End of Traceable Standards

Procedures Used In This Event

Procedure By	Procedure Number	Description	Revision	Revision Date
MSFC	2-0142	ACCELEROMETERS AND VIBRATION PICKUPS	3	02/07/2011

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