SPD 10006 – FM KHUSAT-03

Vibration Testing

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Revision History

Revision	Description	Author	Date
00	Draft Document	Jehyuck Shin	11/20/15
01	Revision Update	Seongwhan Lee	11/20/15
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2.5	Revision Update	Jehyuck Shin	11/26/15
3.0	Revision Update	Seongwhan Lee	11/26/15
3.1	Revision Update	Jehyuck Shin	11/26/15
3.2	TEPC Additional Test	Seongwhan Lee	01/27/16

List of Abbreviations and Acronyms

SIGMA – Scientific cubesat with Instruments for Global Magnetic field and rAdiation
KHUSAT – Kyung Hee University SATellite
KHU – Kyung Hee Univeristy
SSR – School of Space Research
YU – York University, Canada
UNH – University of New Hampshire, USA
VT – Virginia Tech, USA
TestPOD - Test Picosatellite Orbital Deployer
P-POD – Poly-Picosatellite Orbital Deployer
UUT – Unit Under Test
TEPC – Tissue Equivalent Proportional Counter
MAG – miniaturized fluxgate MAGnetometer
IIB – Instrument Interface Board
OBC – On Board Computer
RBF – Remove Before Flight
P/N – Part Number
QM – Qualifying Model
FM – Flight Model
BRF – Body Reference Frame
LRF – Launcher Reference Frame
PRS – PRe Sine sweep vibration test
RV – Random Vibration test
POS – POst Sine sweep vibration test
CMD – CoMmanD
N/A - Not Applicable
P - Pass
F - Fail
NF – Natural Frequency
FRF – Frequency Response Function

Special Notes

CAUTION

Note: CAUTION notes identify situations where flight hardware may be damaged without proper attention.

DANGER

Note: DANGER notes identify situations where bodily harm may occur without proper attention.

Table of Contents

1. Introduction

This document provides the vibration test procedure of SIGMA FM (Acceqtance Model) by falcon 9 environment data. The sine sweep vibration test and random vibration test will be conducted at KAIST Satellite Research Center in Korea as SIGMA FM vibration test.

1.1 Characteristics of SIGMA

Table 1. Specification of the SIGMA

	Characteristics	
Size	3-unit CubeSat (100 mm x 100 mm x 340.5 mm)	
Weight and power	3.6 kg, 4 W	
ACS (Attitude Control System)	Nadir mode (Focus on earth)	
	Rod	1-unit torque rod
	Actuator	2-axis magnetic torque coil
Communication	Uplink	VHF
	Downlink	UHF, S-band
Life time	3 months	
Payload	TEPC	Effect with human skin tissue and radiation exposure
	MAG	Research of Electro Magnetic Ion Cyclotron (EMIC)

2. Equipment for the vibration test

2.1. Shaker

- Model 1216VH Electrodynamics shaker, Ling electronics

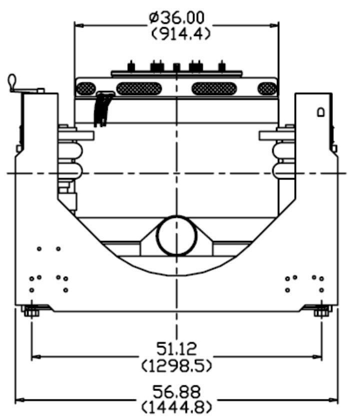


Figure 1. Front side of shaker 1216VH

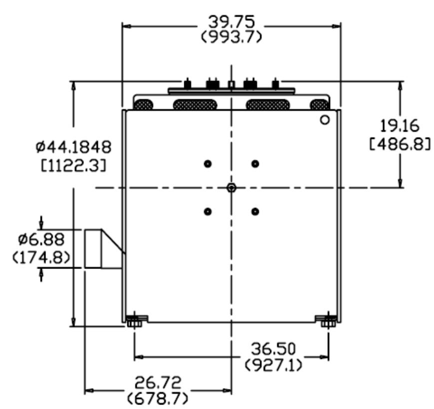


Figure 2. Left side of shaker 1216VH

Table 2. Specification of shaker 1216VH

Axial stiffness	77 kN/m
Armature diameter	438 mm
Armature mass	54.43 kg
Armature suspension	Half-loop metallic flexures
Static load support	454 kg
Maximum velocity	1.78 m/s
Frequency range	4 to 3000 Hz
Maximum acceleration	100 g sine vector
Utility power	123 kVA
Force rating	53.4 peak sine
	53.4 rms random
	106.8 kN Shock

- Model V964 Electrodynamics shaker, Brüel & Kjaer

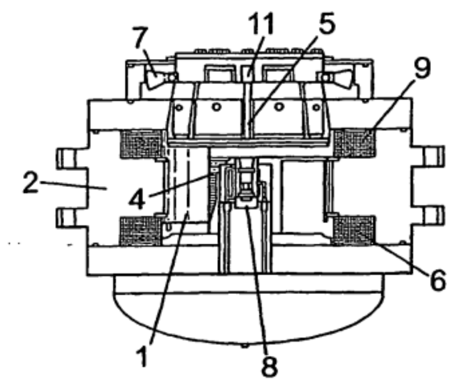


Figure 3. Inner structure of shaker V964

Table 3. Specification of shaker V964

System sine force peak	89 kN
System max random force rms	89 kN
Max acceleration sine peak	100 g
System velocity sine peak	2.0 m/s
Displacement continuous pk-pk	38.1 mm
Armature diameter	432 mm
Cooling system	LDS's water cooling
Usable frequency range	5 to 2500 Hz
Moving element mass	59.0 kg

2.2. Accelerometer

- < P/N: 8763A500, KISTLER>

Figure 4. KISTLER accelerometer(3 axis)

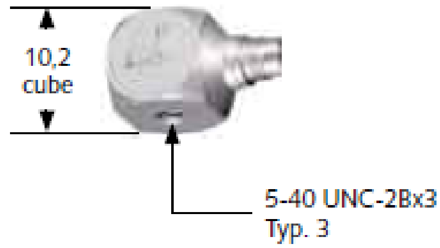


Figure 5. KISTLER accelerometer(1 axis)

Table 4. Specification of KISTLER accelerometer(3 axis)

Range	g	± 50
Sensitivity, ± 10%	mV/g	100
Frequency response, ± 5 %	Hz	0.5 to 7000
Threshold, nom	grms	0.0003
Transverse sensitivity, typ.	%	2.5
Non-linearity	%FSO	± 1
Temp. coeff.: sensitivity	%/℃	-0.06
Operating temperature	℃	-55 to 90
Mass	grams	4.5

3. Test procedure

Prior to arrival at the test facility shakedown test will be conducted using mass dummy (1 to 2kg) in order to validate the acceptance level random noise. This shall be conducted in lateral directions.

The test sequence for each of the three orthogonal axes is normally as follows:

I. Spacecraft functional checkout
II. Qualification random noise
III. Spacecraft functional checkout

Note: The test pod should not exhibit significant resonant frequencies below 2000Hz.
The order in which the axis tests are carried out may vary due to the initial configuration of the shaker.

Accelerometer readings will be inspected after each test in order to identify possible anomalies. Visual Inspection of the FM spacecraft shall be performed after the test sequence.

Table 5. Work flow of SIGMA FM vibration test

Run #	Test Description	Comments
Run 1	Function Test	Spacecraft functional checkout
Run 2	X_axis vibration test	Sine sweep vibration test → Random vibration test → Sine sweep vibration test
Run 3	Function Test	Check by Eye and check the CMD
Run 4	Y_ axis vibration test	Sine sweep vibration test → Random vibration test → Sine sweep vibration test
Run 5	Function Test	Check by Eye and check the CMD
Run 6	Z_ axis vibration test	Sine sweep vibration test → Random vibration test → Sine sweep vibration test
Run 7	Function Test	Spacecraft functional checkout

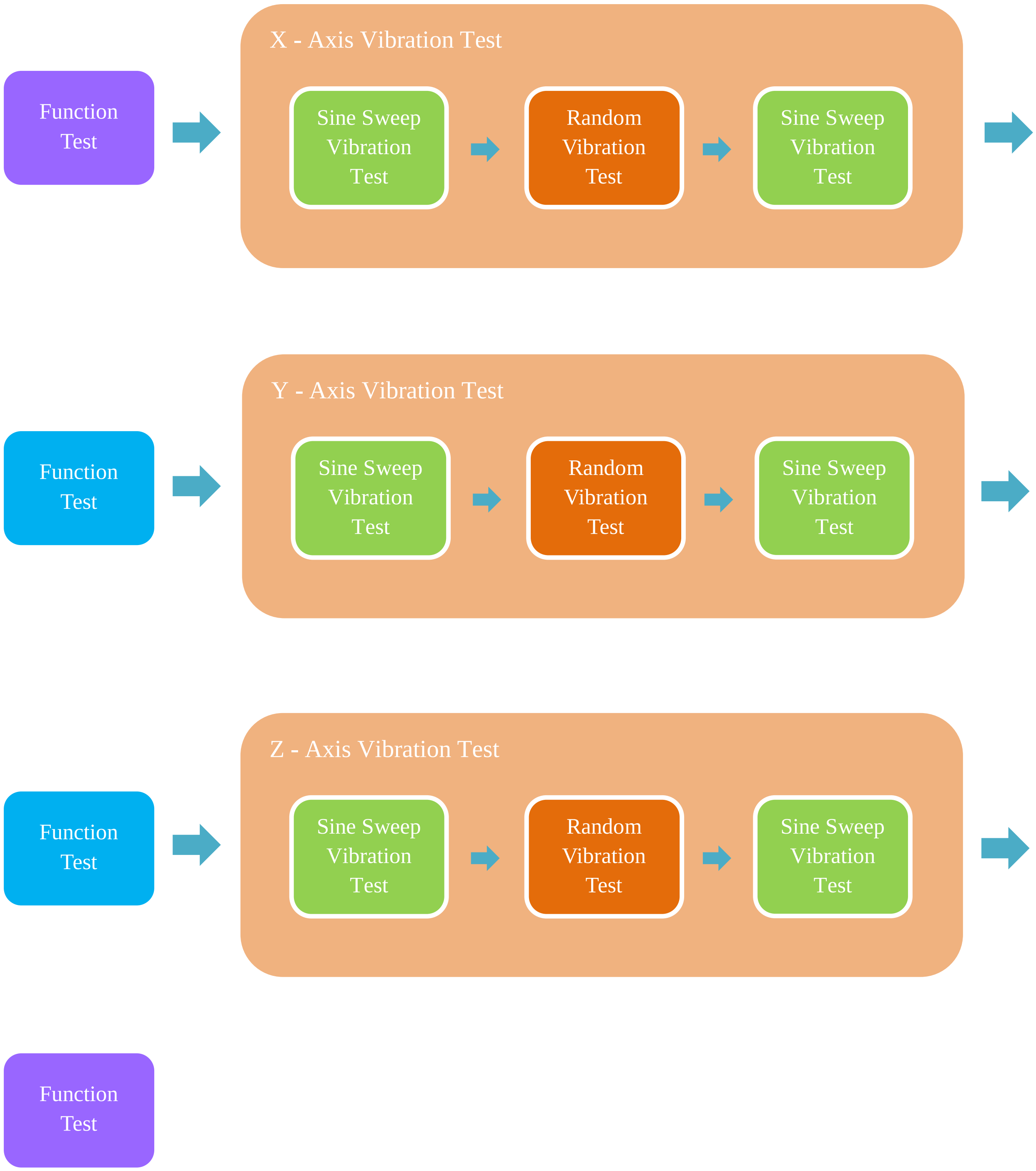


Figure 6. Block diagram of SIGMA FM vibration test work flow

3.1. Test requirement

Vibration test requirement based on ISL document(*ISL.ISILaunch09.EL - Environment Levels ISILaunch09 v1.2_07JUL2015MB.pdf*). According as document, vibration test was conducted as sine sweep vibration test and random vibration test with acceptance level of each test requirements.

3.1.1 Sine sweep vibration test characteristics

Table 6. Test characteristics of sine sweep vibration

Characteristic		Qualification	Acceptance
Test		Required	**Required**
Directions	{BRF}	X, Y, Z	**X, Y, Z**
Type		Harmonic	**Harmonic**
Amplitude		0.4 g	**0.4 g**
Frequency range		5 – 2000 [Hz]	**5 – 2000 [Hz]**
Sweep Rate		2 [oct/min]	**2 [oct/min]**

**** First natural frequency: > 90 Hz**

3.1.2 Random vibration test characteristics

Table 7. Test characteristics of random vibration test

Characteristic		Qualification	Acceptance
Test		Required	**Required**
Directions	{BRF}	X, Y, Z	**X, Y, Z**
Profile	Frequency range [Hz]	Amplitude [g^2/Hz]	**Amplitude [g^2/Hz]**
	20	0.026	**0.013**
	50	0.16	**0.08**
	800	0.16	**0.08**
	2000	0.026	**0.013**
RMS acceleration		14.1 [g]	**10.0 [g]**
Duration		180 [sec/axis]	**60 [sec/axis]**

3.2 Accelerometer points

Accelerometer and control sensors are used for vibration test as triaxis measurable snesor. Sensors are mounted to three points such as on CubeSat, Test POD and Fixture. Details of accelerometer points and information of channels are shown below.

Table 8. Test point location

Test Point Location				
Equipment	ID	Axis	Location	Remarks
Chassis	A	X, Y, Z	Near patch antena (-Z)	External
POD	B	X, Y, Z	Top plate	External
Fixture	C	X, Y, Z	Top plate	External

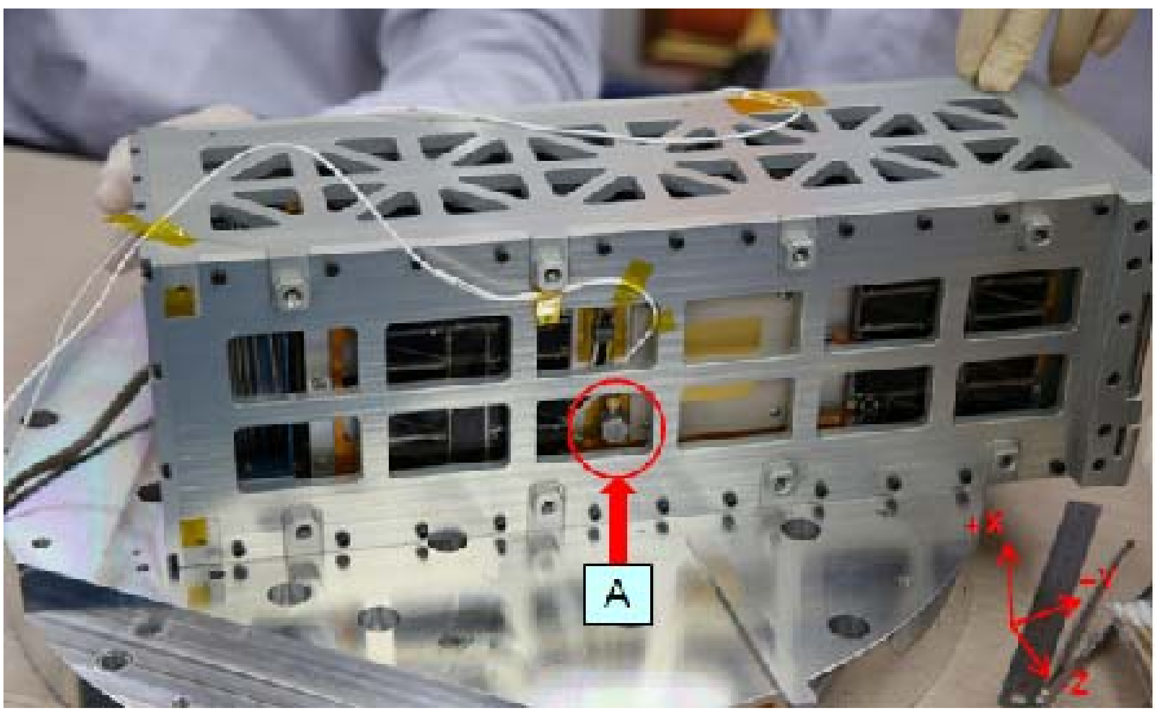


Figure 7. Location of external accelerometer points (A)

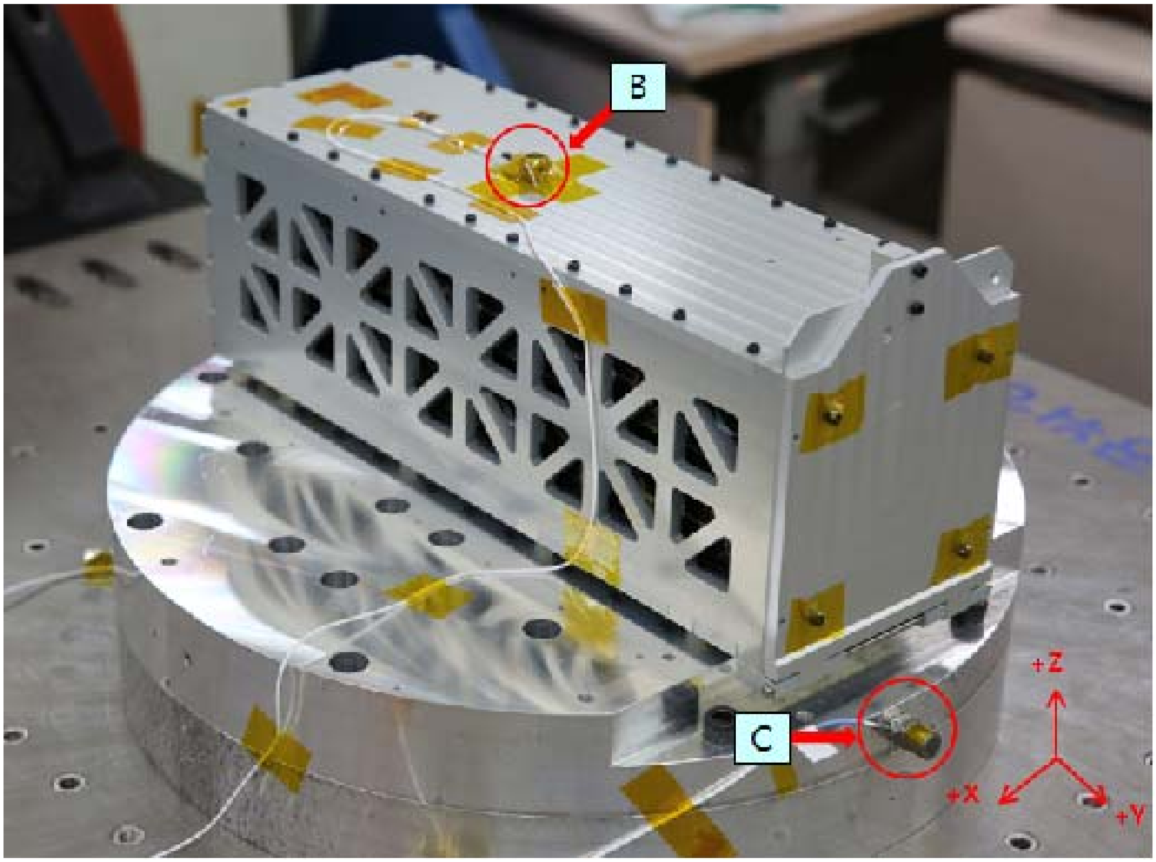


Figure 8. Location of external accelerometer points (B, C)

Table 9. Information of accelerometer sensors

Position	Sensor ID	Seosor direction	Ch	Asix of SIGMA	Sensitivity (mV/g)
On CubeSat (-Z Chassis: near patch antena)	TA788	X	5	X	52.01
		Y	6	Z	46.07
		Z	7	Y	48.72
On POD (+Z)	TA925	X	8	Y	54.55
		Y	9	X	53.54
		Z	10	Z	52.14

Table 10. Information of control sensors

Control	Sensor ID	Ch	Asix of SIGMA	Sensitivity (mV/g)	Remark
Lateral control (fixture)	S1004	1	Lateral (X, Y)	101.5	Ch 1 of S1004 was replaced to Ch 11 at POS of Y axis.
Vertical Control (fixture)	SA458	11	Vertical (Z)	104.1	

Table 11. Channel information of each axis

Body Reference Frame	Measurement channel information
X axis	Ch5, Ch9
Y axis	Ch7, Ch8
Z axis	Ch6, Ch10

4. Vibration test

4.1 Issues of vibration test

Table 12. Issue items of vibration test

Run #	Test Description	Remarks
Run 0	Test preparation	Insertion problem between P-POD and the SIGMA was found. Problem of P-POD was checked, then we decided to replace P-POD of new verssion.
Run 1	Function Test	N/A
Run 2	PRS (X axis)	N/A
	RV (X axis)	N/A
	POS (X axis)	N/A
Run 3	Check	Weak noise was checked inside the SIGMA. Same noise was reproduced when the SIGMA position was changed.
	Inspection work	Inspection of inside was conducted after + Z chassis of SIGMA was disassembled. Then, cause of noise was checked as it of inside TEPC. We decided this issue is not effect other systems, so conduceted remaining proceed of vibration test after re-assemble from next day.
Run 4	Check	N/A
Run 5	PRS (Y axis)	N/A
	RV (Y axis)	N/A
	POS (Y axis)	Control ch 1 of accelerometer control sensors (S1004) was replaced to ch 11.
Run 6	Check	N/A
Run 7	PRS (Z axis)	N/A
	RV (Z axis)	N/A
	POS (Z axis)	N/A
Run 8	Function Test	N/A

4.2 X axis of SIGMA

Table 13. Channel informations of accelerometer sensors (X axis)

Sensor	Position	Asix of SIGMA	Ch
Accelerometer sensors	Chassis (-Z)	X	5
	Top on POD	X	9
Control sensor	On fixture	X, Y (Lateral)	1

4.2.1 Response data

4.2.1.1 Pre sine sweep vibration test (X axis)

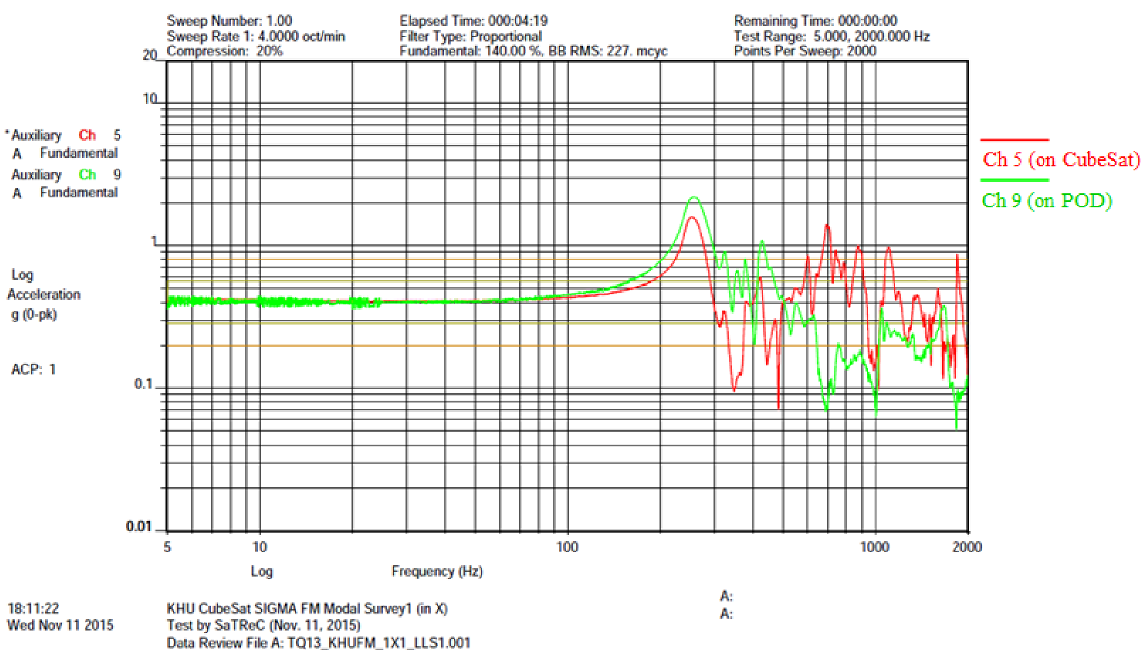


Figure 9. Pre sine sweep vibration test result (X axis)

4.2.1.2 Random vibration test (X axis)

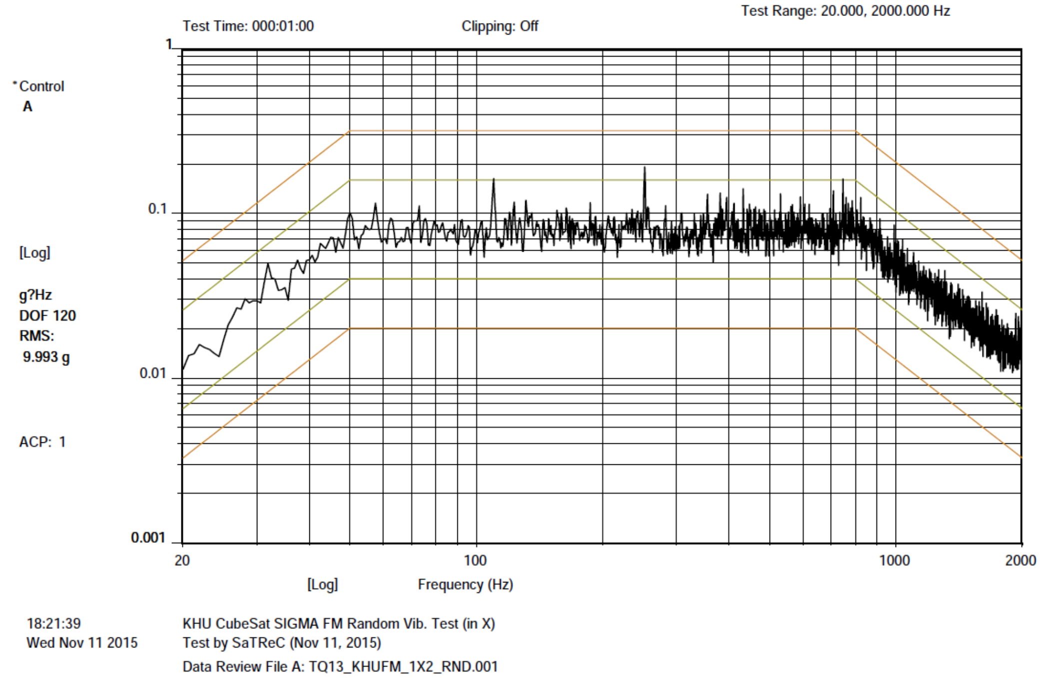


Figure 10. Random vibration test result of accelerometer control sensor (X axis)

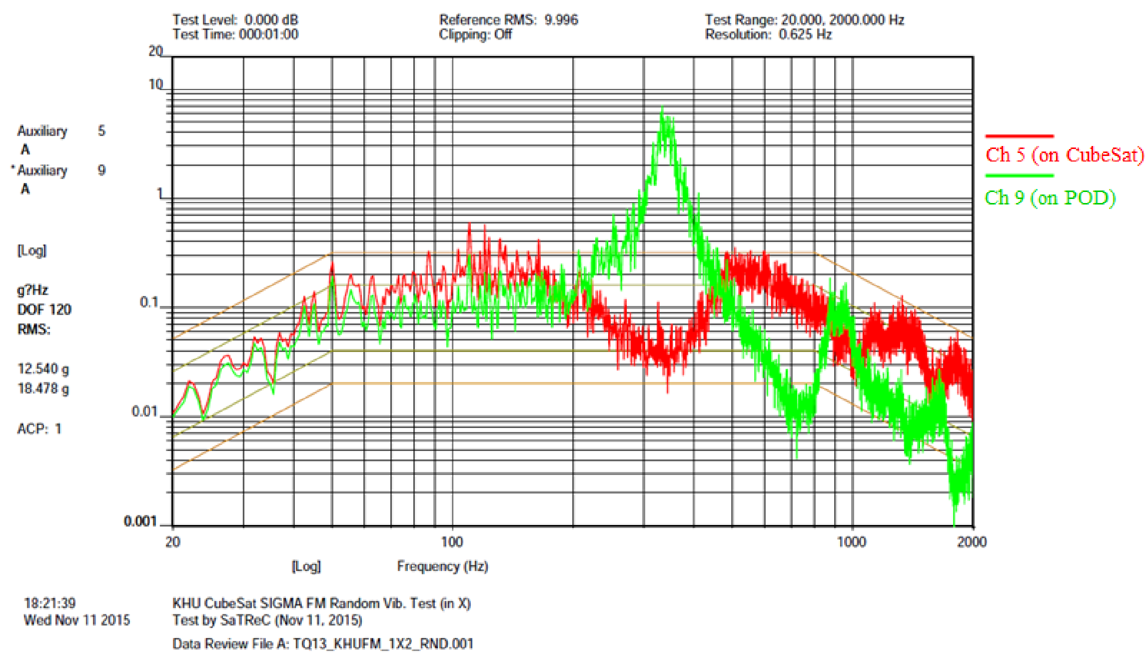


Figure 11. Random vibration test result (X axis)

4.2.1.3 Post sine sweep vibration test (X axis)

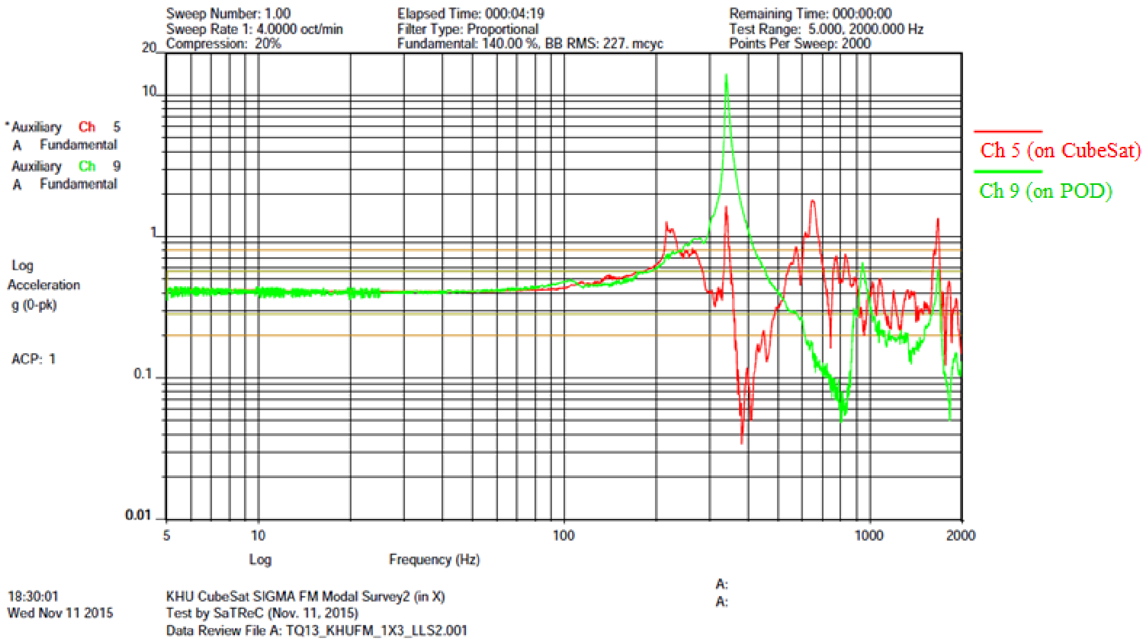


Figure 12. Post sine sweep vibration test result (X axis)

4.2.2 Result

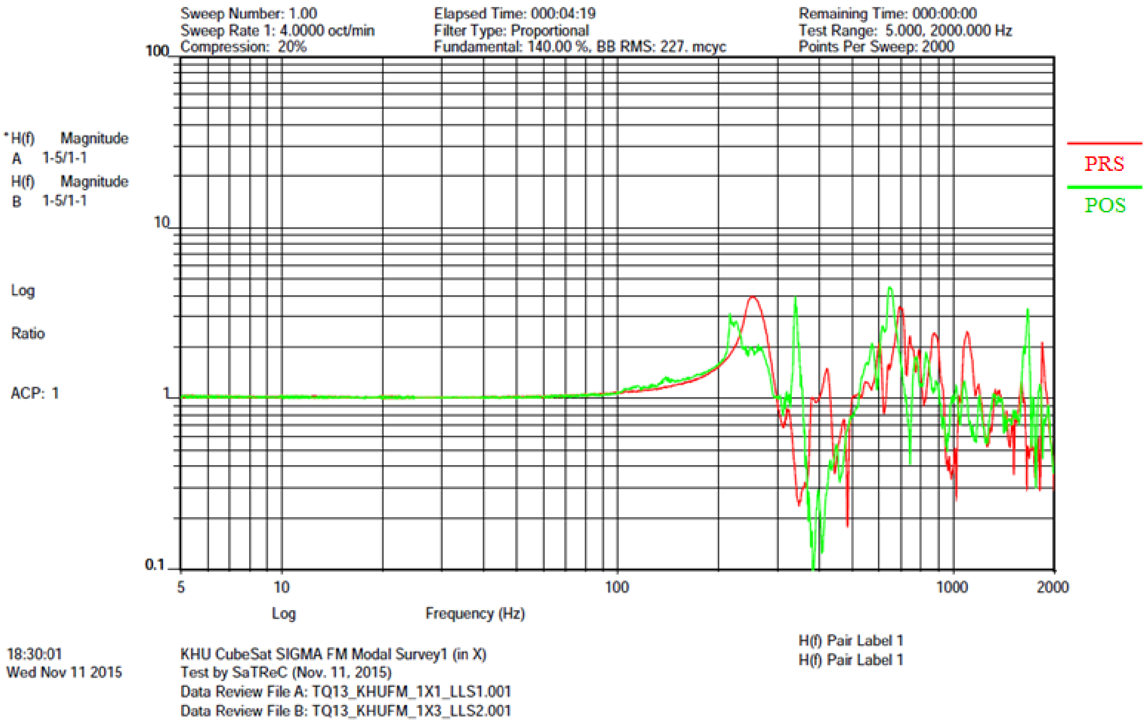


Figure 13. Comparison of natural frequency about pre sine sweep vibration and post sine sweep vibration test on ch 5 (X axis)

After vibration test of X axis, weak noise was checked inside the SIGMA during function test. Same noise was reproduced when the SIGMA position was changed for several times. Inspection of inside was conducted after + Z chassis of SIGMA was disassembled. Then, cause of noise was checked as it of inside TEPC. We decided this issue is not effects other systems, so conduceted remaining proceed of vibration test after re-assemble from next day.

By comparing response data of PRS and POS, change of their natural frequencies was checked. During random vibration test of X axis, mechanical problem of TEPC was happen and that problem caused to generate differentness with PRS and POS. For more details about TEPC issue refer to Appendix A.

Table 14. Comparison of X axis natural frequency (X axis)

Axis	Test type	Natural frequency	Remarks
X	PRS	250.6 Hz	N/A
	RV	N/A	
	POS	215.7 Hz	

4.3 Y axis of SIGMA

Table 15. Channel informations of accelerometer sensors (Y axis)

Sensor	Position	Asix of SIGMA	Ch
Accelerometer sensors	Chassis (-Z)	Y	7
	Top on POD	Y	8
Control sensor	On fixture	X, Y (Lateral)	1 → 11

* Ch 1 of lateral control sensor was replaced to Ch 11 at POS of Y axis due to data acquisition problem of ch 1.

4.3.1 Response data

4.3.1.1 Pre sine sweep vibration test (Y axis)

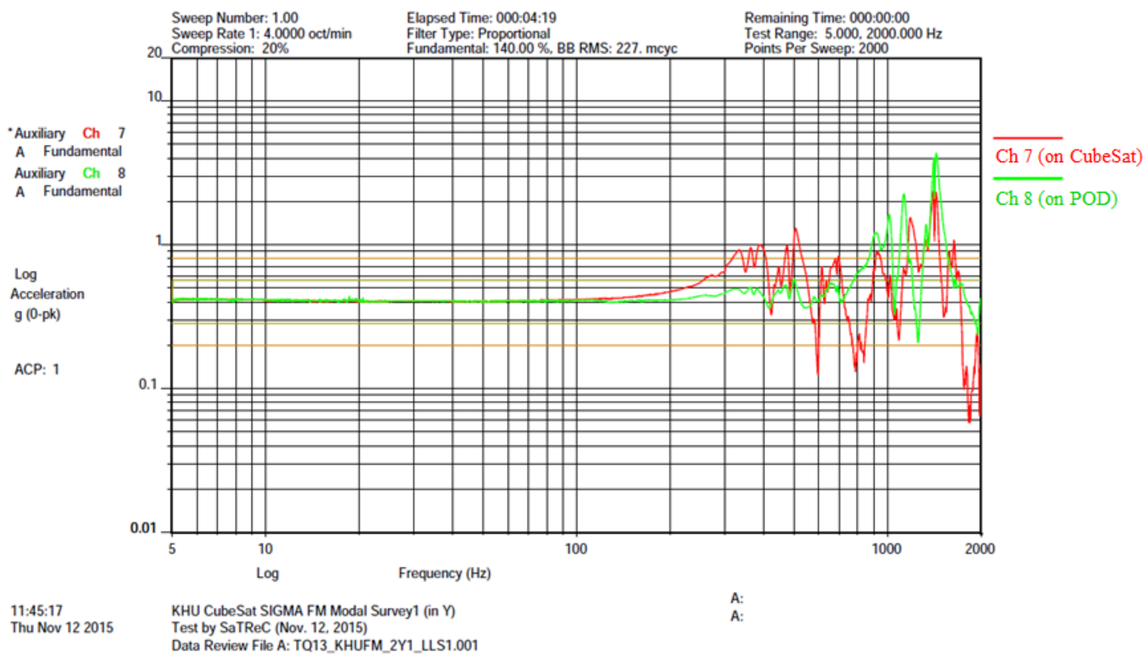


Figure 14. Pre sine sweep vibration test result (Y axis)

4.3.1.2 Random vibration test (Y axis)

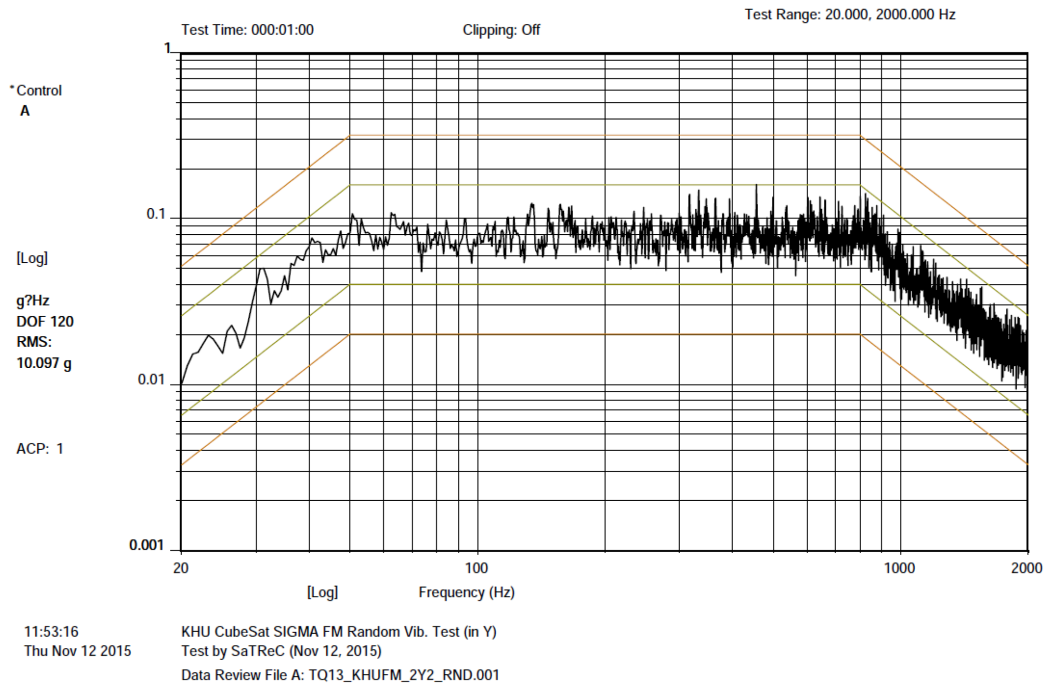


Figure 15. Random vibration test result of accelerometer control sensor (Y axis)

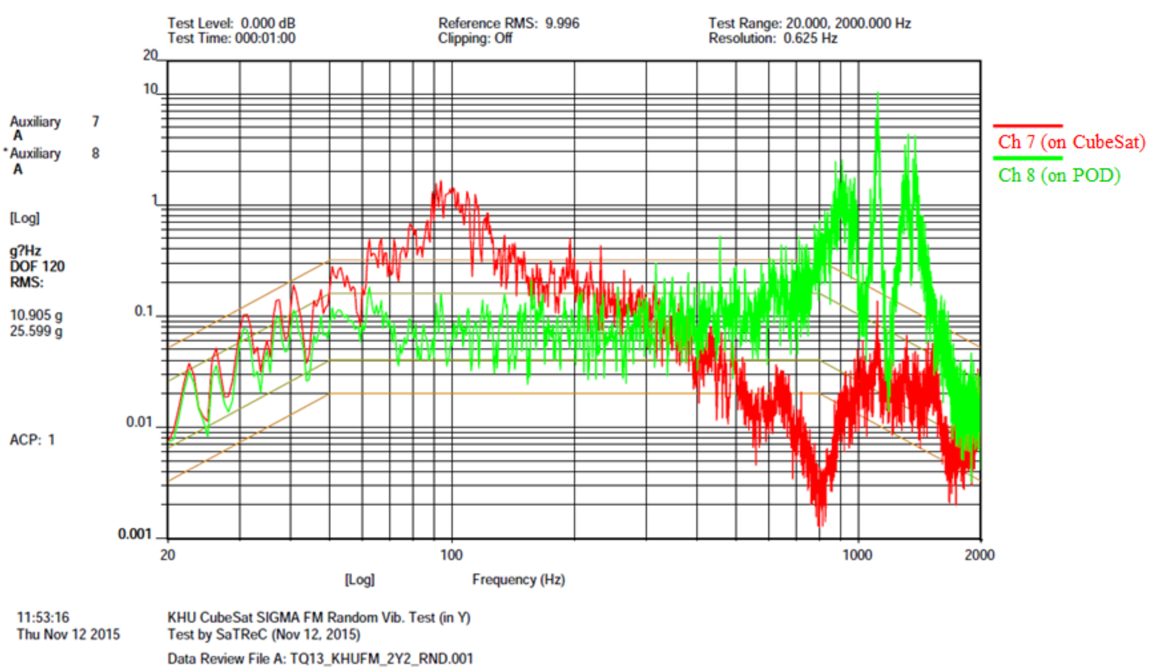


Figure 16. Random vibration test result (Y axis)

4.3.1.3 Post sine sweep vibration test_1 (Y axis)

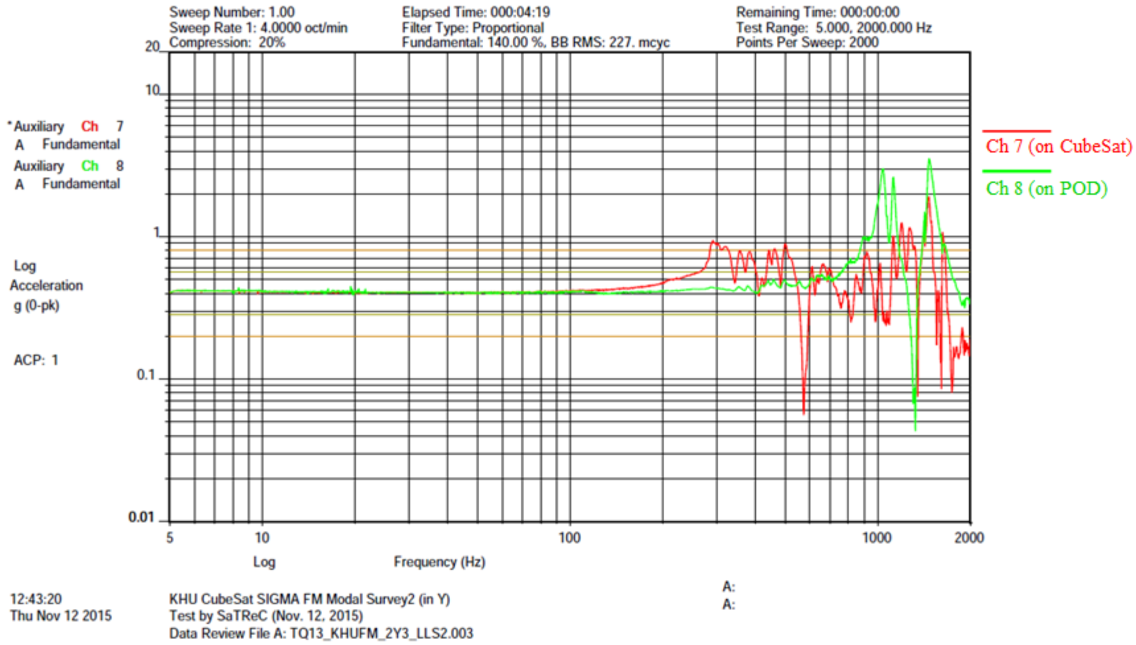


Figure 17. Post sine sweep vibration test result (Y axis)

4.3.2 Result

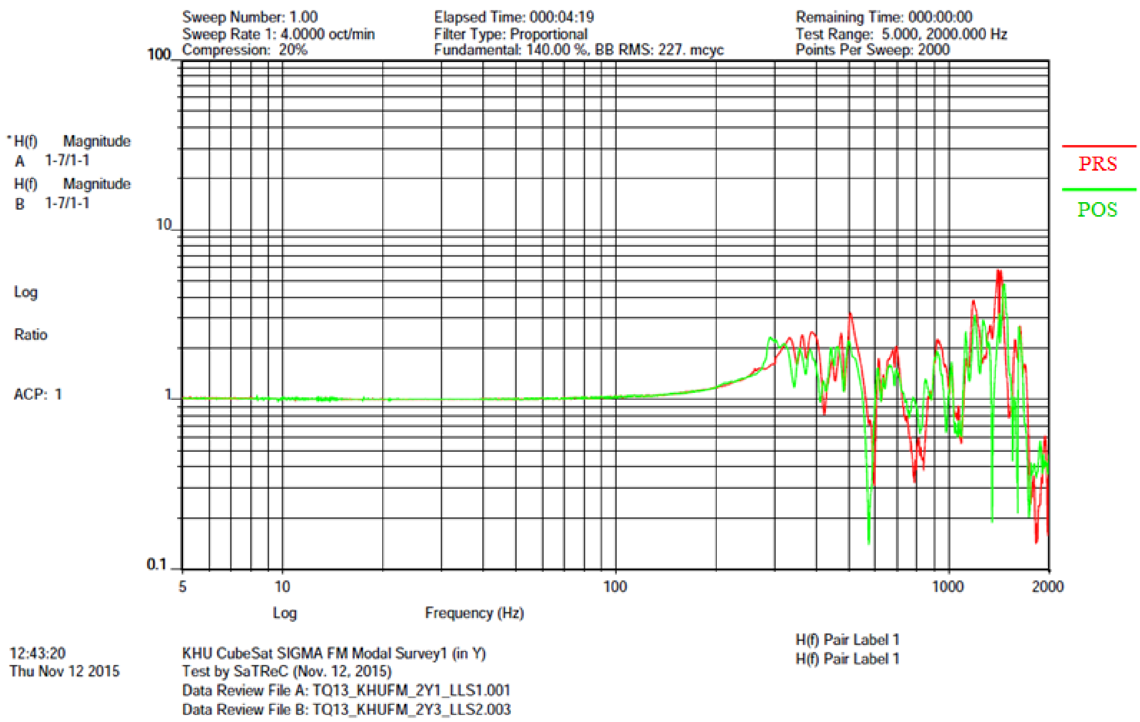


Figure 18. Comparison of natural frequency about pre sine sweep vibration and post sine sweep vibration test on ch 7 (Y axis)

Also PRS and POS of Y axis are effected by TEPC issue. By comparing response data of each test, change of their natural frequencies was checked. On the other hand, overall graph shape was similar with PRS and POS than other test results due to BRF of Y axis.

Table 16. Comparison of natural frequency (Y axis)

Axis	Test type	Natural frequency	Remarks
Y	PRS	332 Hz	N/A
	RV	N/A	
	POS	291 Hz	

4.4 Z axis of SIGMA

Table 17. Channel informations of accelerometer sensors (Z axis)

Sensor	Position	Asix of SIGMA	Ch
Accelerometer sensors	Chassis (-Z)	Z	6
	Top on POD	Z	10
Control sensor	On fixture	Z (Vertical)	11

4.4.1 Response data

4.4.1.1 Pre sine sweep vibration test (Z axis)

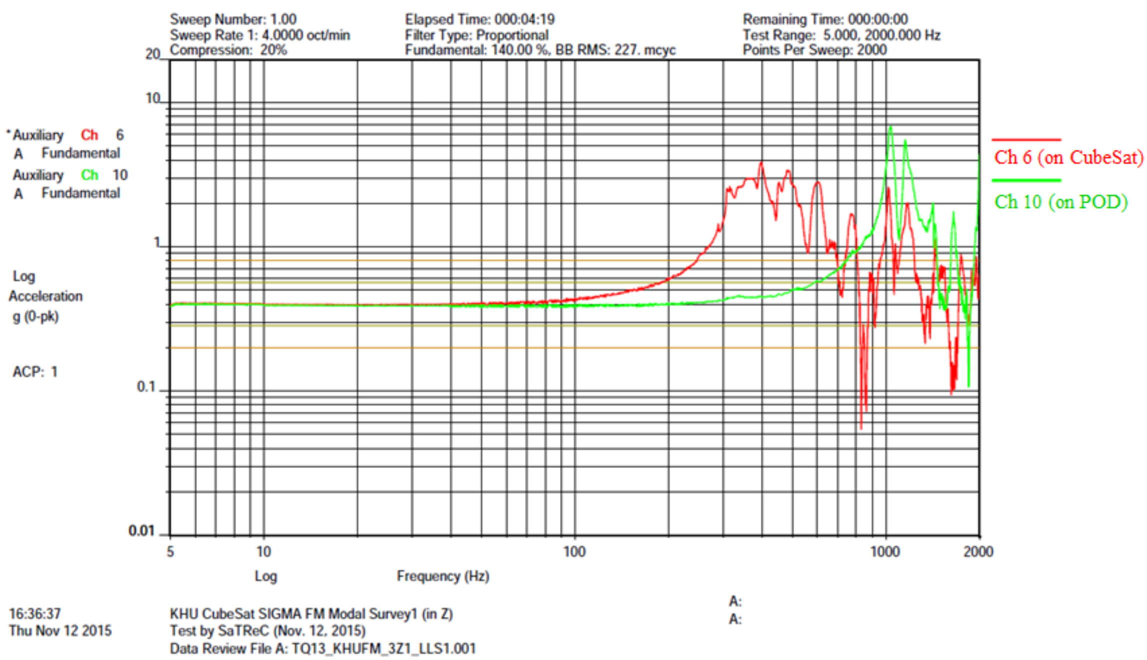


Figure 19. Pre sine sweep vibration test result (Z axis)

4.4.1.2 Random vibration test (Z axis)

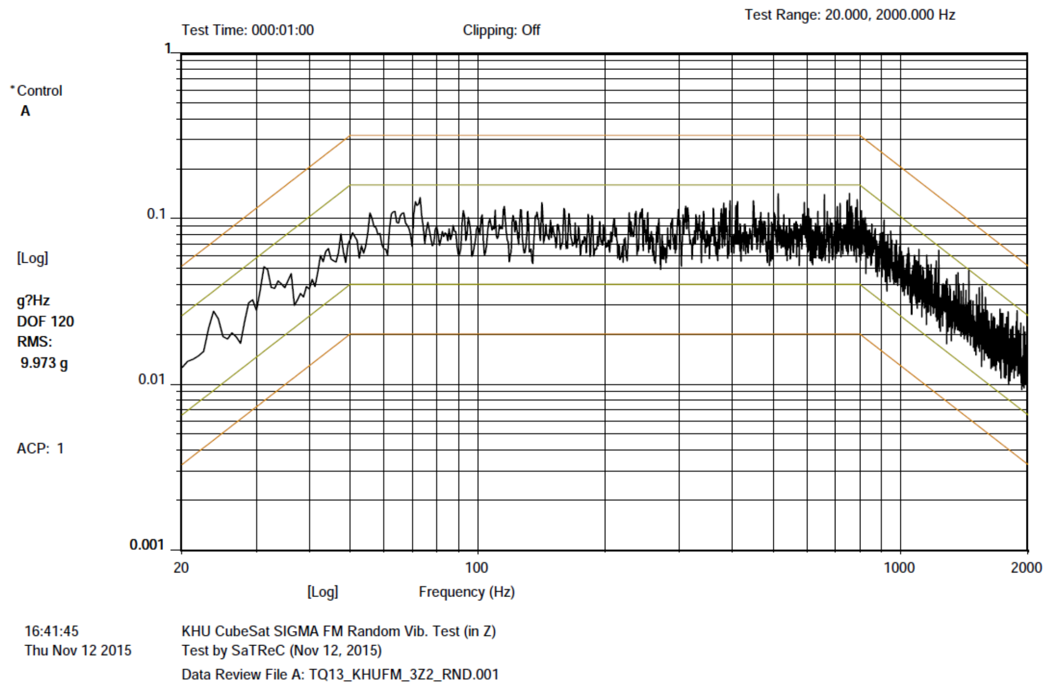


Figure 20. Random vibration test result of accelerometer control sensor (Z axis)

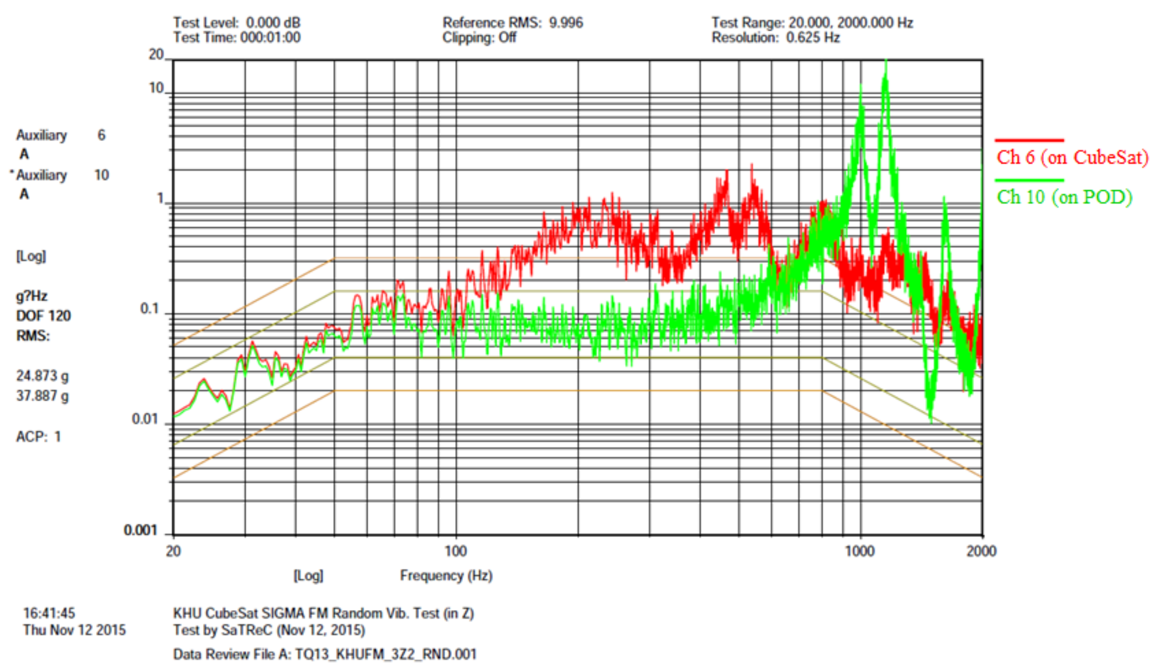


Figure 21. Random vibration test result (Z axis)

4.4.1.3 Post sine sweep vibration test_1 (Z axis)

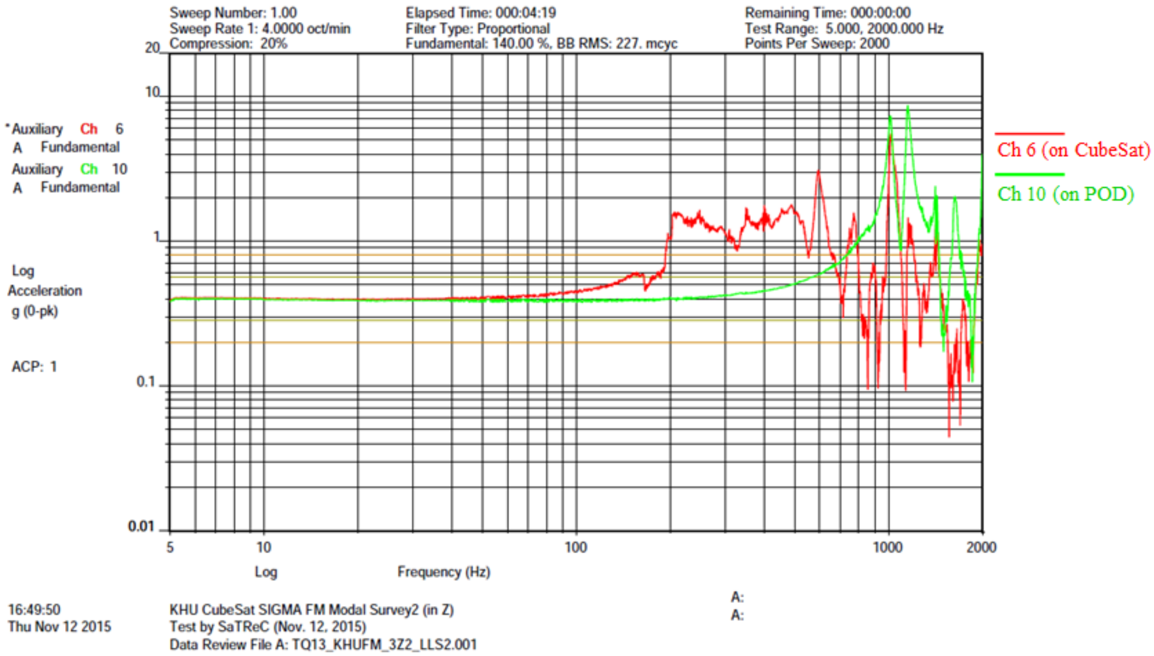


Figure 22. Post sine sweep vibration test result (Z axis)

CubeSat SIGMA
Scientific cubesat with Instruments for Global Magnetic fields and rAdiations

SCHOOL OF SPACE RESEARCH
KYUNG HEE UNIVERSITY

4.4.2 Result

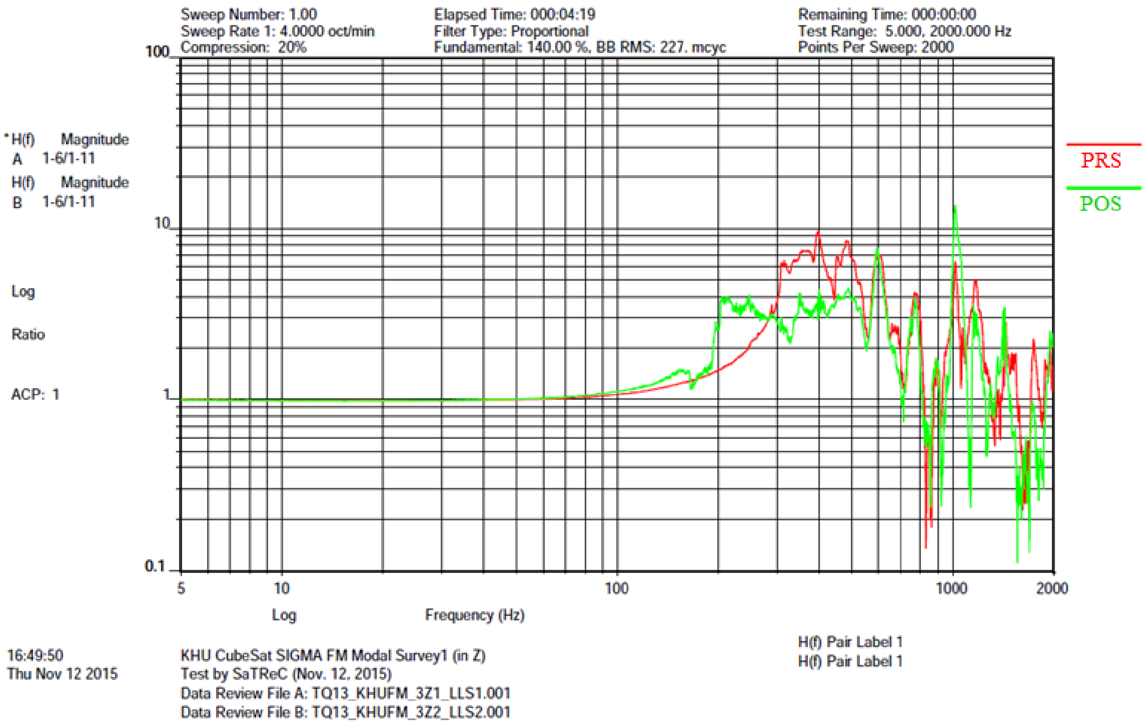


Figure 23. Comparison of natural frequency about pre sine sweep vibration and post sine sweep vibration test on ch 7 (Z axis)

Table 18. Comparison of natural frequency (Z axis)

Axis	Test type	Natural frequency	Remarks
Z	PRS	314 Hz	N/A
	RV	N/A	
	POS	211 Hz	

5. Pass/Fail criteria

A successful test is defined by a component not being at all affected by the vibrations test. This is measured by visual inspection, as well as performing a physical and/or electrical inspection before and after the vibration test. This ensures that the component was working before testing began, and continued to work after testing was completed. Even if the component passes the physical/electrical test after the vibration test, any noticeable changes made to the component during the vibration test will be enough to fail the component.

UUT has successfully passed vibration testing if the unit is not degraded mechanically, functionally, or structurally. Success criteria shall consist of:

Verification will consist of visual inspections, inspection of accelerometer output data, and acceptable functional deployment. Note: It is not possible to codify a completely comprehensive PASS/FAIL Criteria for this type of Vibration Data. Test Conductor along with SSR/KHU Mechanical Engineer shall evaluate all test data.

Table 19. Explanation of run # for functional test, check

Run 1	Function test is going to start before all vibration test.
Run 3	After X_axis vibration test, check by Eye and check the CMD
Run 5	After Y_axis vibration test, check by Eye and check the CMD
Run 7	After Z_axis vibration test, function test is going to start.

Table 20. Check list of pass/fail criteria

NO	Category	Check Item	Run 1	Run 3	Run 5	Run 7
1. TEPC						
1	TEPC	No mechanical damage	P	F	F	F
2	TEPC	Electrical functionality	P	P	P	P
2. MAG						
1	MAG	No mechanical damage	P	P	P	P
2	MAG	Electrical functionality	P	P	P	P
3. Avionics stack						
1	Deployment switch	Plunger travels smoothly	P	P	P	P
2	RBF switch	Remains closed	P	P	P	P
3	Motherboard	Retains full functionality	P	P	P	P
4	Motherboard	No mechanical damage	P	P	P	P
5	EPS	Retains full functionality	P	P	P	P
6	EPS	No mechanical damage	P	P	P	P
7	Battery	Retains full functionality	P	P	P	P
8	Battery	No mechanical damage	P	P	P	P
9	UHF Receiver	No mechanical damage	P	P	P	P
10	IIB	Retains full functionality	P	P	P	P
11	IIB	No mechanical damage	P	P	P	P
12	HVPS (Mockup)	No mechanical damage	P	P	P	P
4. Chassis						
1	Chassis	No galling on chassis rails	P	P	P	P
5. Torque coils						
1	Torque coils	No mechanical damage	P	P	P	P
2	Torque coils	Retain full functionality	N/A	N/A	N/A	N/A
6. Solar panels						
1	Solar panels	No structural damage that causes loss of functionality	P	P	P	P
2	Solar panels	Electrical functionality	P	P	P	P
7. UHF antenna assembly						
1	UHF antenna	No loss of deployment functionality	N/A	N/A	N/A	N/A

2	UHF antenna	No loss of radio functionality	N/A	N/A	N/A	N/A
8. Patch antennas						
1	Patch antennas	Coax still intact	P	P	P	P
2	Patch antennas	No physical damage	P	P	P	P
3	Patch antennas	Electrical Functionality	N/A	N/A	N/A	N/A
9. Calex DC-DC Converter						
1	Calex DC-DC converter	Pins still intact and physically undamaged	N/A	N/A	N/A	N/A
2	Calex DC-DC converter	Electrical Functionality	N/A	N/A	N/A	N/A
10. Harnessing						
1	Harnessing	No loss of captivity	P	P	P	P
2	Harnessing	Electrical Functionality	P	P	P	P

6. Appendix A

6.1 Mechanical problem of TEPC (Korean)

1. 진동 시험 요약

▪ FM KHUSAT-03 진동시험 (2015. 11. 12일, SaTReC)에서 X축 진동 후 부품이탈 소리 확인

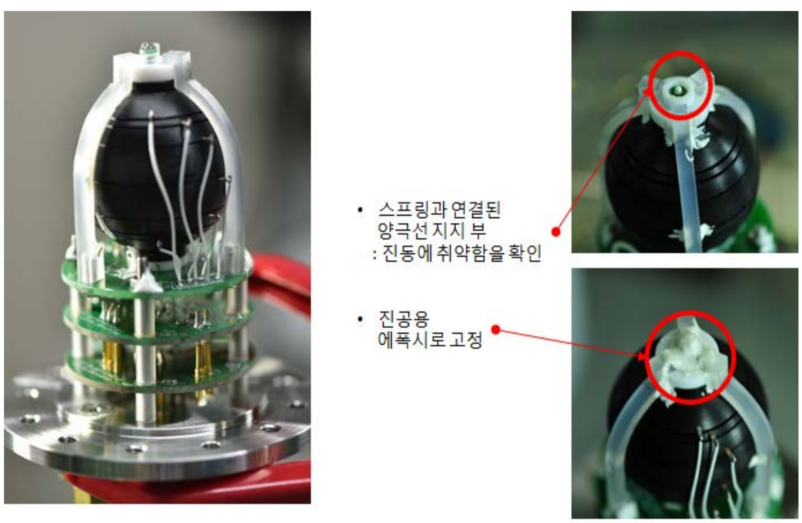
▪ TEPC 내부에서 나는 소리로 확인

▪ 진동시험 후 신호는 정상적으로 검출됨을 확인 하였음.

▪ 하우징을 열어 본 결과, 스피링과 연결된 양극선지지 부분이 떨어졌음. 이것은 양극선의 스프링을 보호하는 캡부분이 없은 구조였음.(이 버전 이후에 제작된 TEPC는 보호 갭이 있음).

▪ 조치사항 : TEPC 재 조립 후, 진공용 에폭시를 사용하여 지지대에 고정하였음.

▪ 결과 : TEPC 독립적으로 진동시험을 수행하여 FM TEPC 모델에 대한 구조적 안정성 확인과 진동 시험 전후의 기능시험 정상동작 확인



<TEPC 내부구조> <TEPC조치내용>

Figure 24 TEPC 내부구조(좌)와 재조립 후 조치사항(우)

2. 시험 내용

- Cubesat이 경험할 발사체의 Acceptance Level에서의 Random 진동시험 수행
- 시험순서는 X(Lateral), Z(Lateral), Y(Vertical)축 순으로 진행하였으며, 각 축의 시험은
- Low level sine sweep → Random Vibration → Low level sine sweep 순으로 진행
- 각 축의 시험이 끝나면 TEPC 육안 검사 수행
- 진동시험 전후 TEPC 기능시험 수행

3. 시험 스펙

Characteristic		Qualification	Acceptance	Proto-flight
Test		Required	Required	Required
Directions	{BRF}	X, Y, Z	X, Y, Z	X, Y, Z
Type		Harmonic	Harmonic	Harmonic
Amplitude	See Notes, 2	0.4 [g]	0.4 [g]	0.4 [g]
Frequency range		5 – 2000 [Hz]	5 – 2000 [Hz]	5 – 2000 [Hz]
Sweep Rate		2 [oct/min]	2 [oct/min]	2 [oct/min]

Figure 25. Resonance Survey Test Profile

Characteristic		Qualification	Acceptance	Proto-flight
Test		Required	Required	Required
Directions	{BRF}	X, Y, Z	X, Y, Z	X, Y, Z
Profile	Frequency range [Hz]	Amplitude $[g^2/Hz]$	Amplitude $[g^2/Hz]$	Amplitude $[g^2/Hz]$
	20	0.026	0.013	0.026
	50	0.16	0.08	0.16
	800	0.16	0.08	0.16
	2000	0.026	0.013	0.026
RMS acceleration		14.1 [g]	10.0 [g]	14.1 [g]
Duration		180 [sec/axis]	60 [sec/axis]	60 [sec/axis]

Figure 26. Random Vibration Test Profile

4. 시험 구성

아래 그림은 각 축별로 진동시험 모습을 나타낸다.

TEPC 검출기의 진동 센서 위치는 치구와 조립되는 인터페이스 면 위에 3축 센서를 부착하였고, 제어센서는 치구에 각 축 방향과 일치하게 고정하였다. 센서 정보는 아래 표에 정리했다.

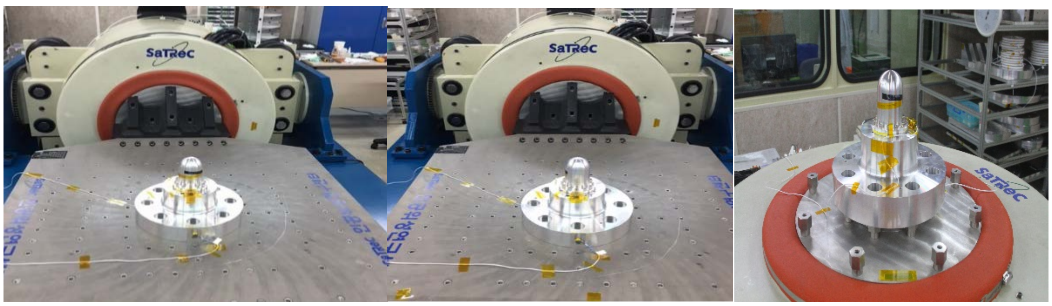


Figure 27. Zig Axis (X, Z, Y)

Table 21. Sensor Information

Position	Sensor ID	Sensor Direction	Ch.	S/C Axis	Sensitivity [mV/g]	Remarks
On TEPC I/F	TA788	X	5	Z	52.01	
		Y	6	Y	46.07	
		Z	7	X	48.72	
Control	Sensor ID	Sensor Direction	Ch.	POD Axis	Sensitivity [mV/g]	Remarks
Lateral Control	S1004		11	Lateral (X, Z)	101.50	
	SA458		11	Vertical (Y)	104.10	
S/C Direction	Measurement channel information					
X	Ch. 7					
Y	Ch. 6					
Z	Ch. 7					

5. 시험 결과

각 축 시험의 결과는 아래 표에서 정리되었으며, 각 축의 진동시험 프로파일은 아래 그림에서 보는 것처럼 random 진동시험은 요구사항인 10g RMS 값으로 진동되었고, 모달 서베이 전후 결과는 구조적으로 변화없는 것으로 확인되었다. 탑재체의 Mass가 매우 적고, 치구의 Mass가 대부분을 차지하고 있는 형태여서, 탑재체의 자체 모드는 2000Hz 이하에서 보이지 않음을 확인 했다. 각 축의 진동시험 전후에 육안 검사를 수행했으며 흔들었을 때 소리가 발생하지 않으므로 파손이 없음을 확인했다. 또한 전체 진동시험이 끝나고 전자부와 연결하여 기능시험을 수행했으며, 이 결과는 진동시험 전 결과와 비교해서 변화없음을 확인했다. 따라서, TEPC FM 진동시험은 통과한 것으로 확인하였다.

Table 22. Vibration Test Summary

Sequence (lateral)		Test Files	Ref.	FRF@Natural Frequency Ch. 7 (on TEPC I/F)	Remarks
X	1	TQ13_KHUtepc_1X1_LLS1	Modal Survey 1	N/A	Ref=0.4g @5~2000Hz
	2	TQ13_KHUtepc_1X2_RND	Random Vibration	9.924g rms	Control=10.016g rms (Ref.=10g rms)
	3	TQ13_KHUtepc_1X3_LLS2	Modal Survey 2	N/A	Ref=0.4g @5~2000Hz
Sequence (lateral)		Test Files	Ref.	FRF@Natural Frequency Ch. 7 (on TEPC I/F)	Remarks
Z	1	TQ13_KHUtepc_2Z1_LLS1	Modal Survey 1	N/A	Ref=0.4g @5~2000Hz
	2	TQ13_KHUtepc_2Z2_RND	Random Vibration	9.874g rms	Control=9.998g rms (Ref.=10g rms)
	3	TQ13_KHUtepc_2Z3_LLS2	Modal Survey 2	N/A	Ref=0.4g @5~2000Hz
Sequence (Verticall)		Test Files	Ref.	FRF@Natural Frequency Ch. 6 (on TEPC I/F)	Remarks
Y	1	TQ13_KHUtepc_3Y1_LLS1	Modal Survey 1	N/A	Ref=0.4g @5~2000Hz
	2	TQ13_KHUtepc_3Y2_RND	Random Vibration	9.476g rms	Control=9.979g rms (Ref.=10g rms)
	3	TQ13_KHUtepc_3Y3_LLS2	Modal Survey 2	N/A	Ref=0.4g @5~2000Hz

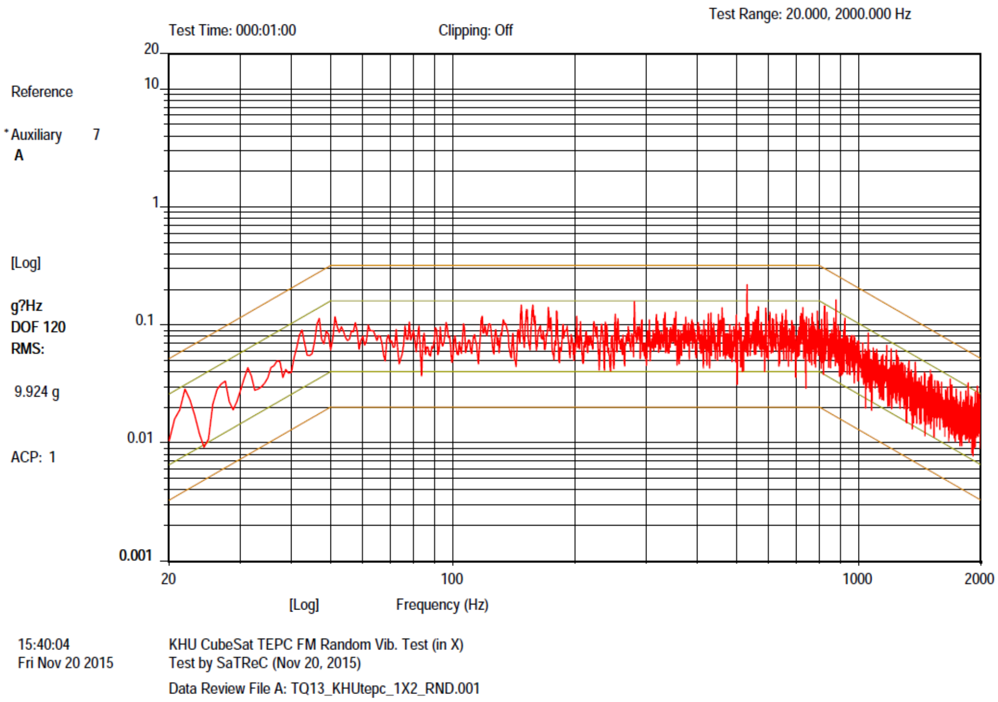


Figure 28. X axis Random Test Result

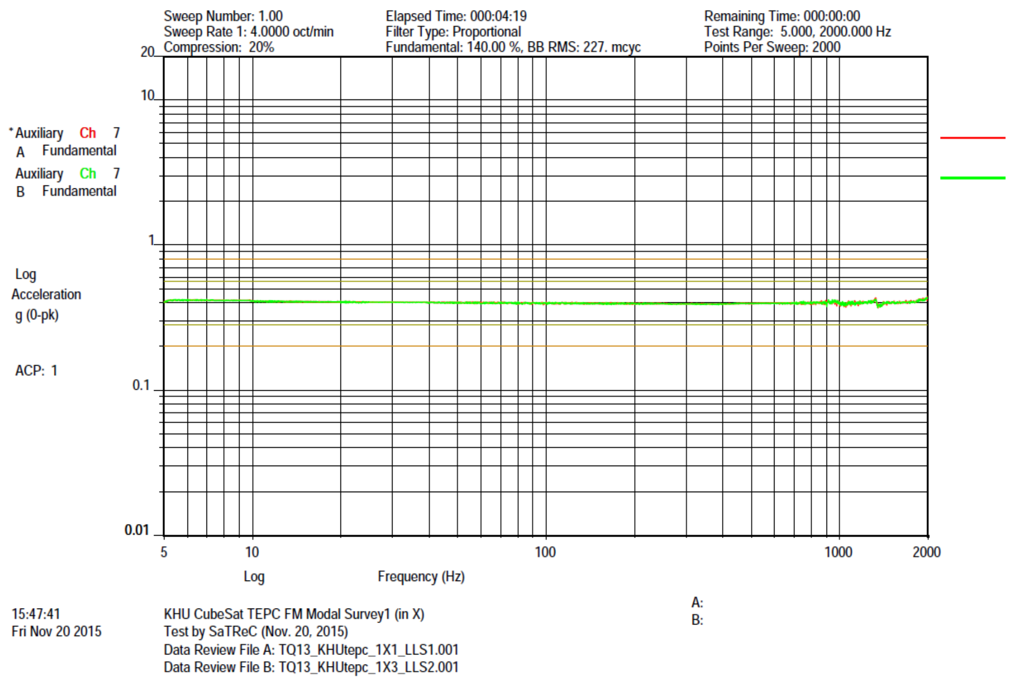


Figure 29. X axis Modal Survey Comparison

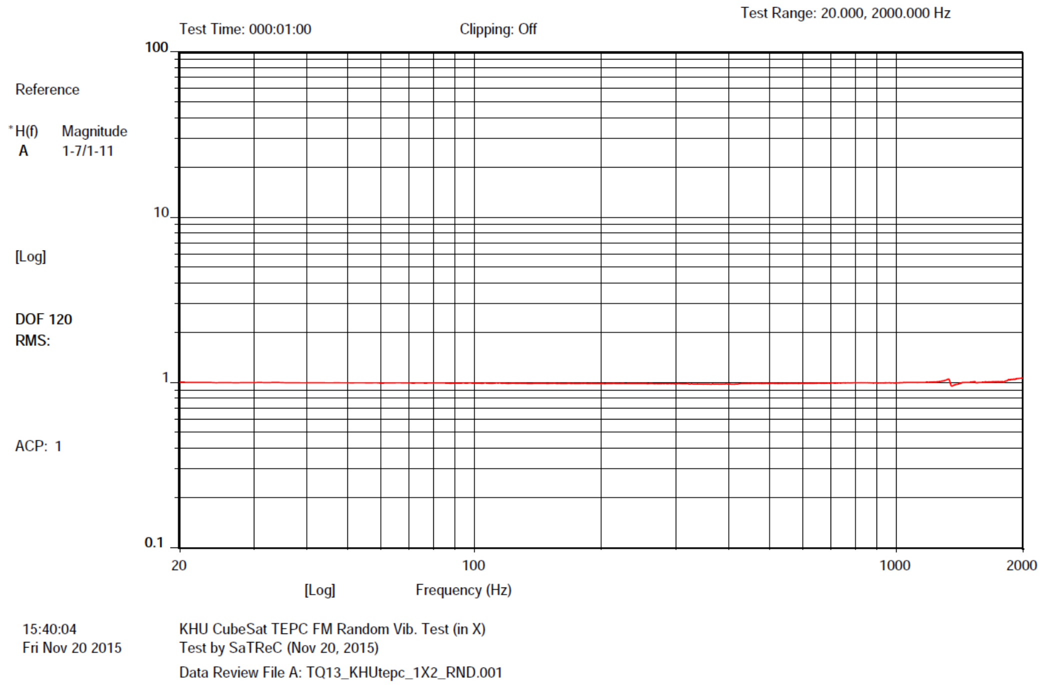


Figure 30. X axis Random Test FRF

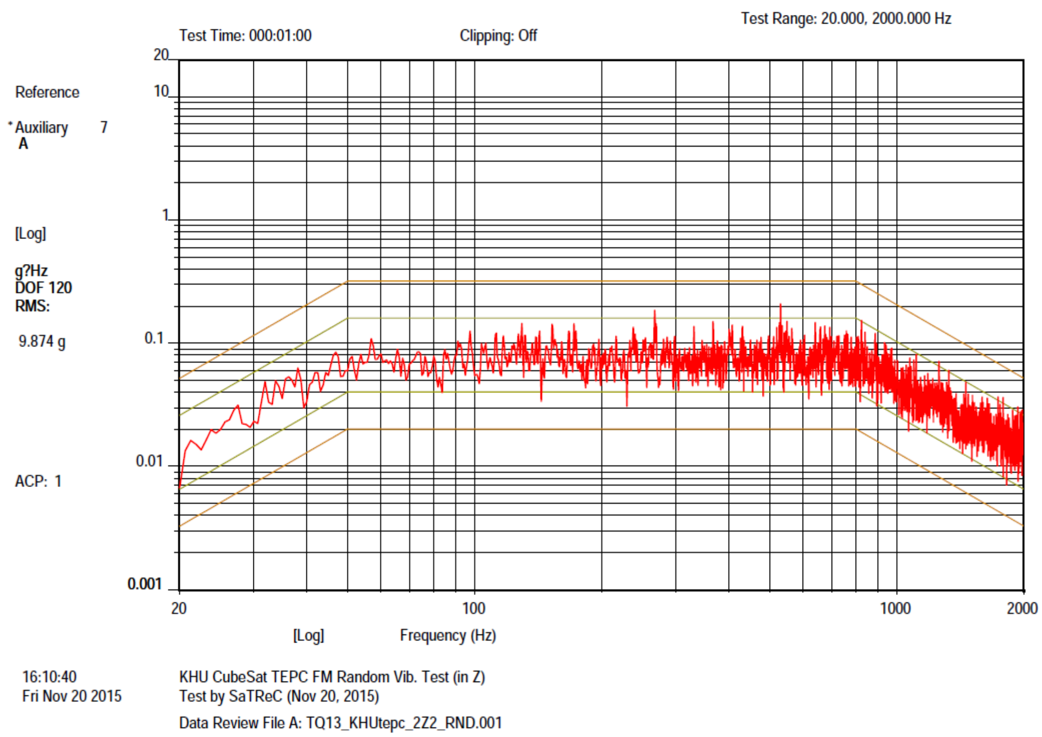


Figure 31. Z axis Random Test Result

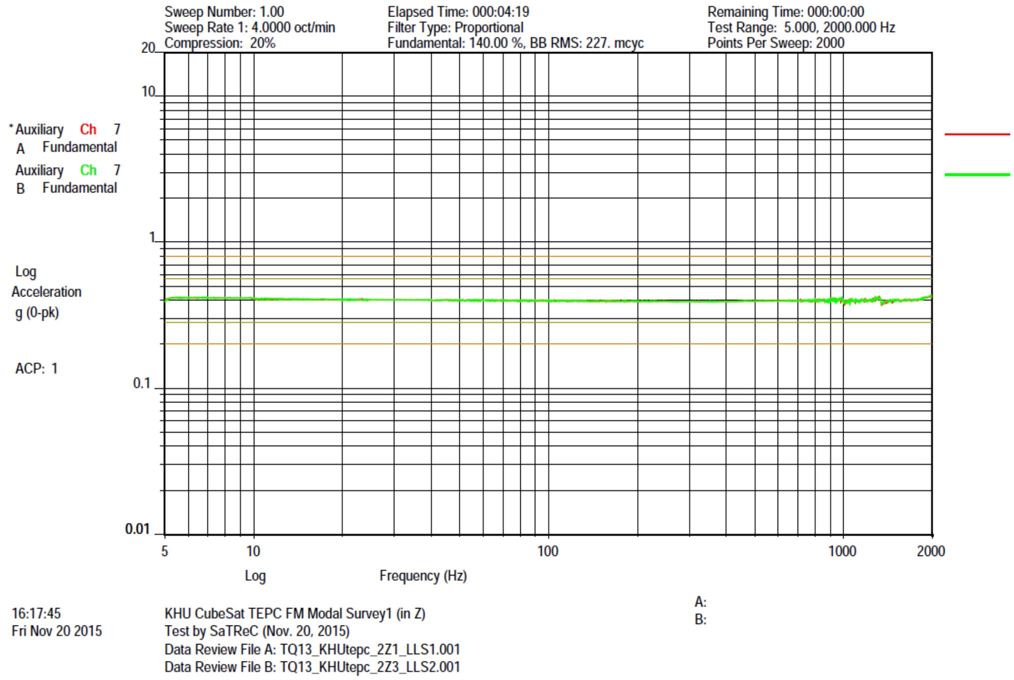


Figure 32. Z axis Modal Survey Comparison

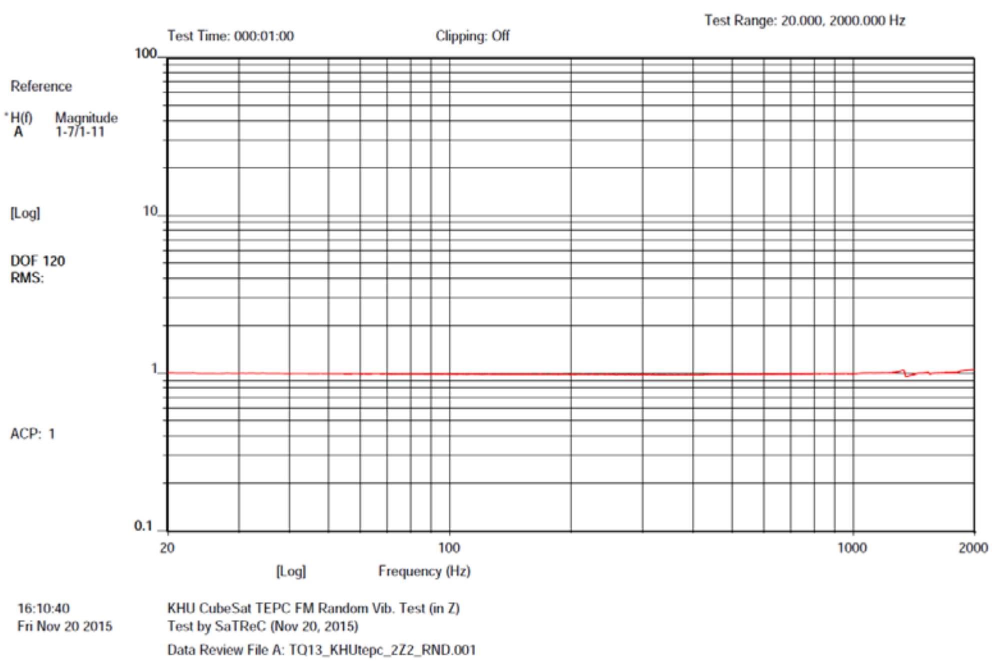


Figure 33. Z axis Random Test FRF

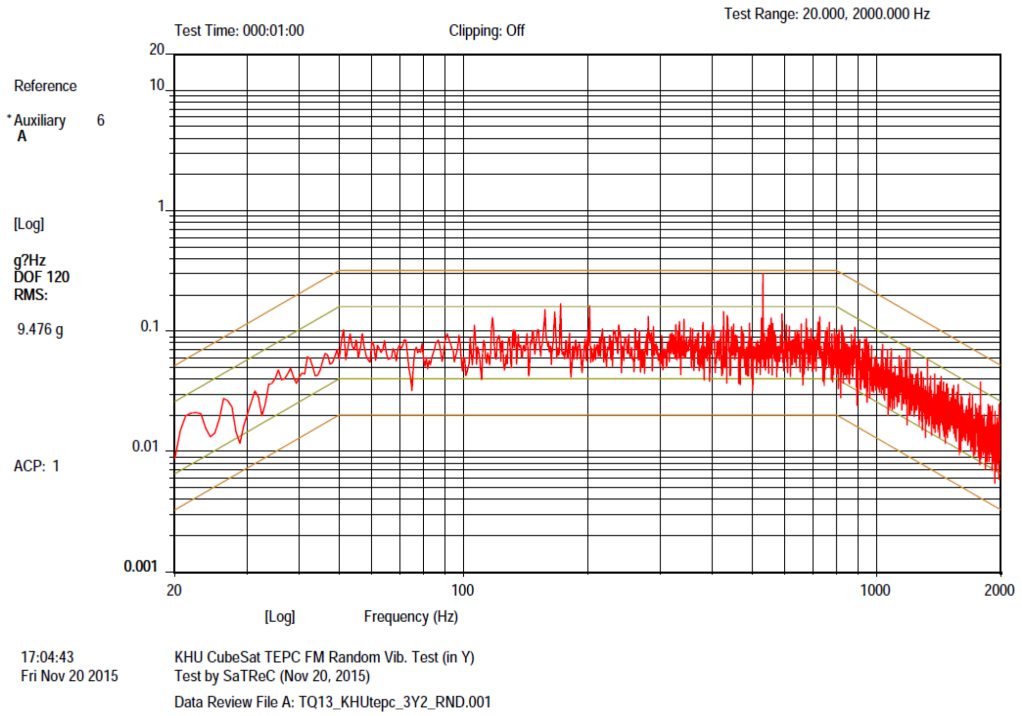


Figure 34. Y axis Random Test Result

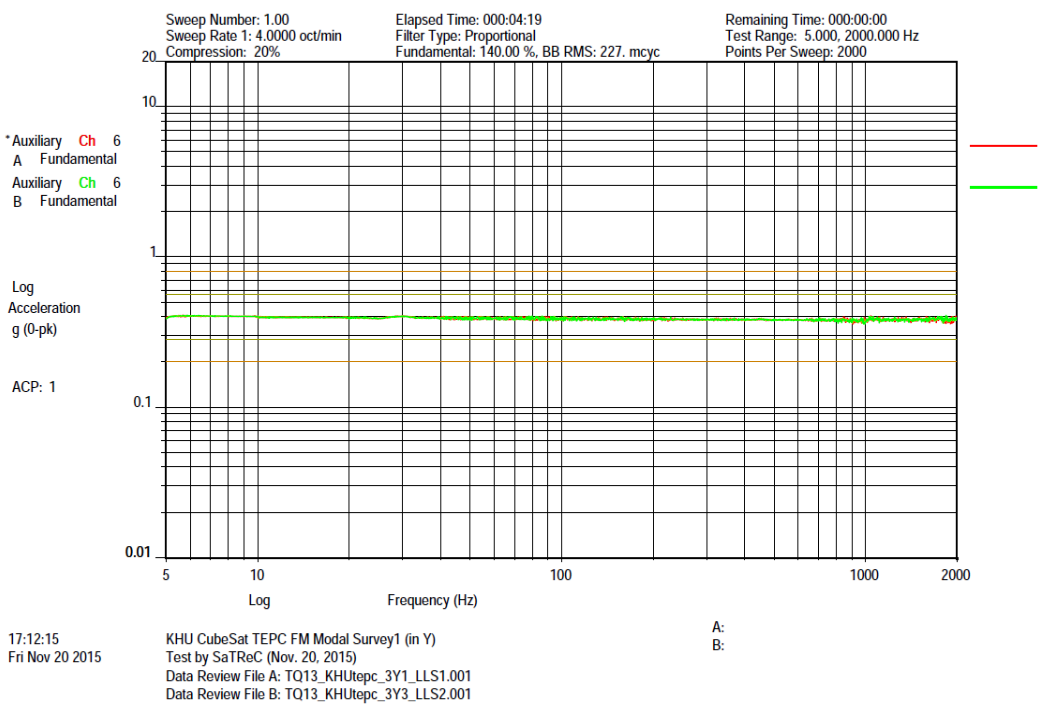


Figure 35. Y axis Modal Survey Comparison

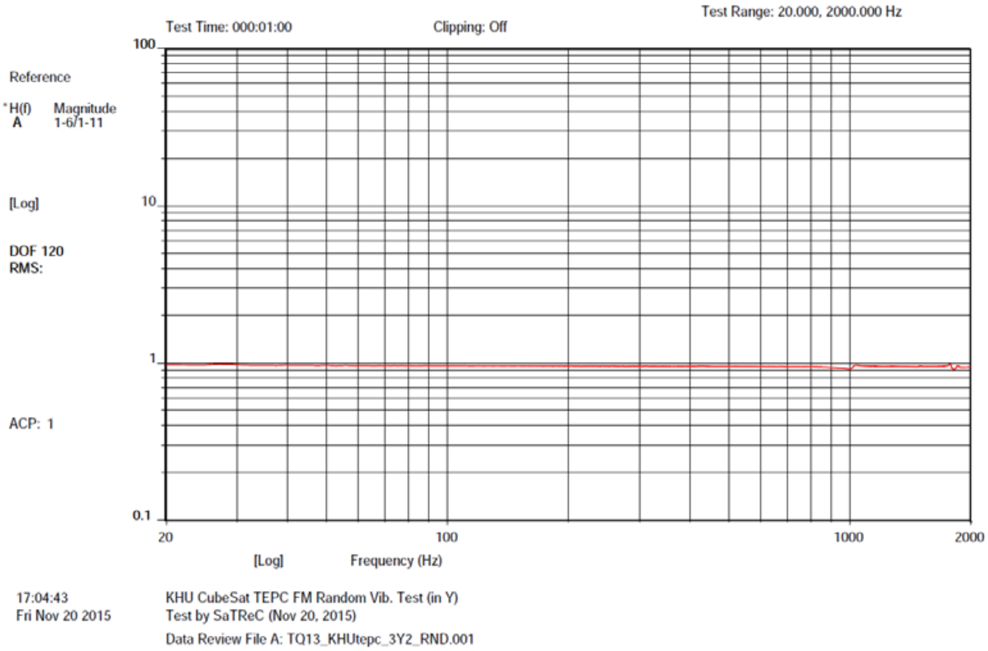
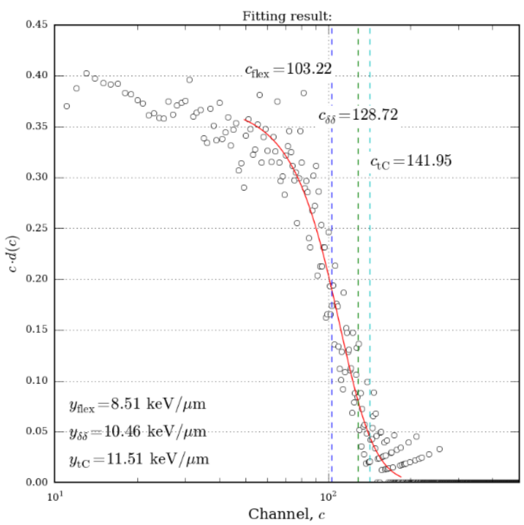
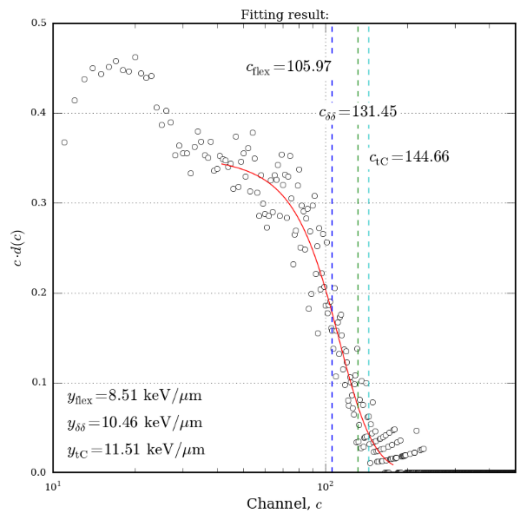


Figure 36. Y axis Random Test FRF

6. 진동시험 전후 스펙트럼 비교

- 진동시험 전, 후 electron edge값이 128.72채널(진동시험 전), 131.45채널(진동시험 후)로서 건의 같은 지점에서 측정되었음.
- 스펙트럼의 윈편편의 약간의 기울기 차이는 DAQ의 threshold 값 차이 때문임.
- 따라서 기능시험결과 진동시험 전, 후 성능변화가 없음을 확인 하였음.

Table 23. Test Result of FM TEPC

<table>
<tr><th>Pre Vibration Test</th><th>Post Vibration Test</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>● 검출기 : D30-1
● DAQ : DAQ04
● edge ch : 128.72 ch</td><td>● 검출기 : D30-1
● DAQ : DAQ04
● edge ch : 131.45 ch</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>