SPD 1004 – QM Vibration Testing

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

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Revision History

Revision	Description	Author	Date
00	Draft Document	Jehyuck Shin	10/22/14
01	Revision Update	Seongwhan Lee	11/01/14
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07	Revision Update	Jehyuck Shin	01/12/15
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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

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

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 QM (Qualification Model) by falcon 9 environment data. The sine sweep vibration test, sine vibration test, random vibration test and quasi-static test of the SIGMA QM are going to do at KAIST Satellite Research Center in Korea.

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

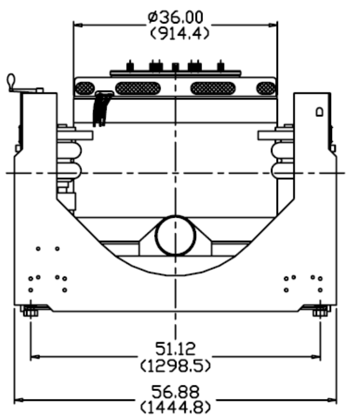

Figure 1. Front side of shaker 1216VH

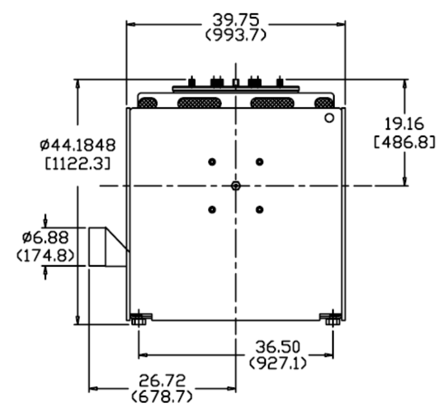

Figure 2. Left side of shaker 1216VH

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

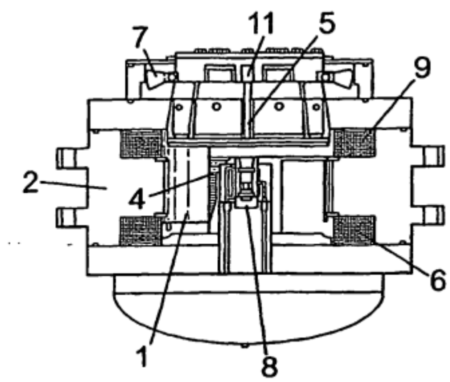

Figure 3. Inner structure of shaker V964

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)

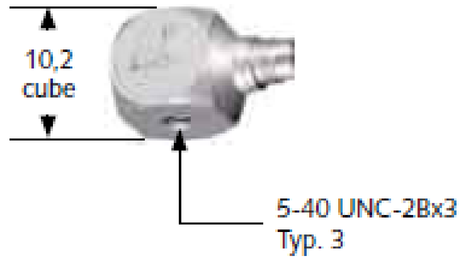

Figure 5. Dimension of accelerometer (1 axis)

Figure 6. KISTLER accelerometer (1 axis)

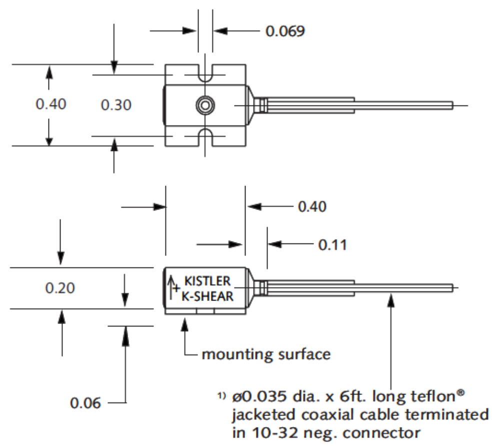

Figure 7. Dimension of accelerometer (1 axis)

Table 4. Specification of KISTLER accelerometer

Specification	Unit	Accelerometer (3 axis)	Accelerometer (1 axis)
Range	g	± 50	± 500
Sensitivity, ± 10%	mV/g	100	10
Frequency response, ± 5 %	Hz	0.5 to 7000	2 to 10000
Threshold, nom	grms	0.0003	0.01
Transverse sensitivity, typ.	%	2.5	1.5
Non-linearity	%FSO	± 1	± 1
Temp. coeff.: sensitivity	%/℃	-0.06	-0.03
Operating temperature	℃	-55 to 90	-65 to 250
Mass	grams	4.5	1.3

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 Qualification 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. SIGMA vibration test work flow

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

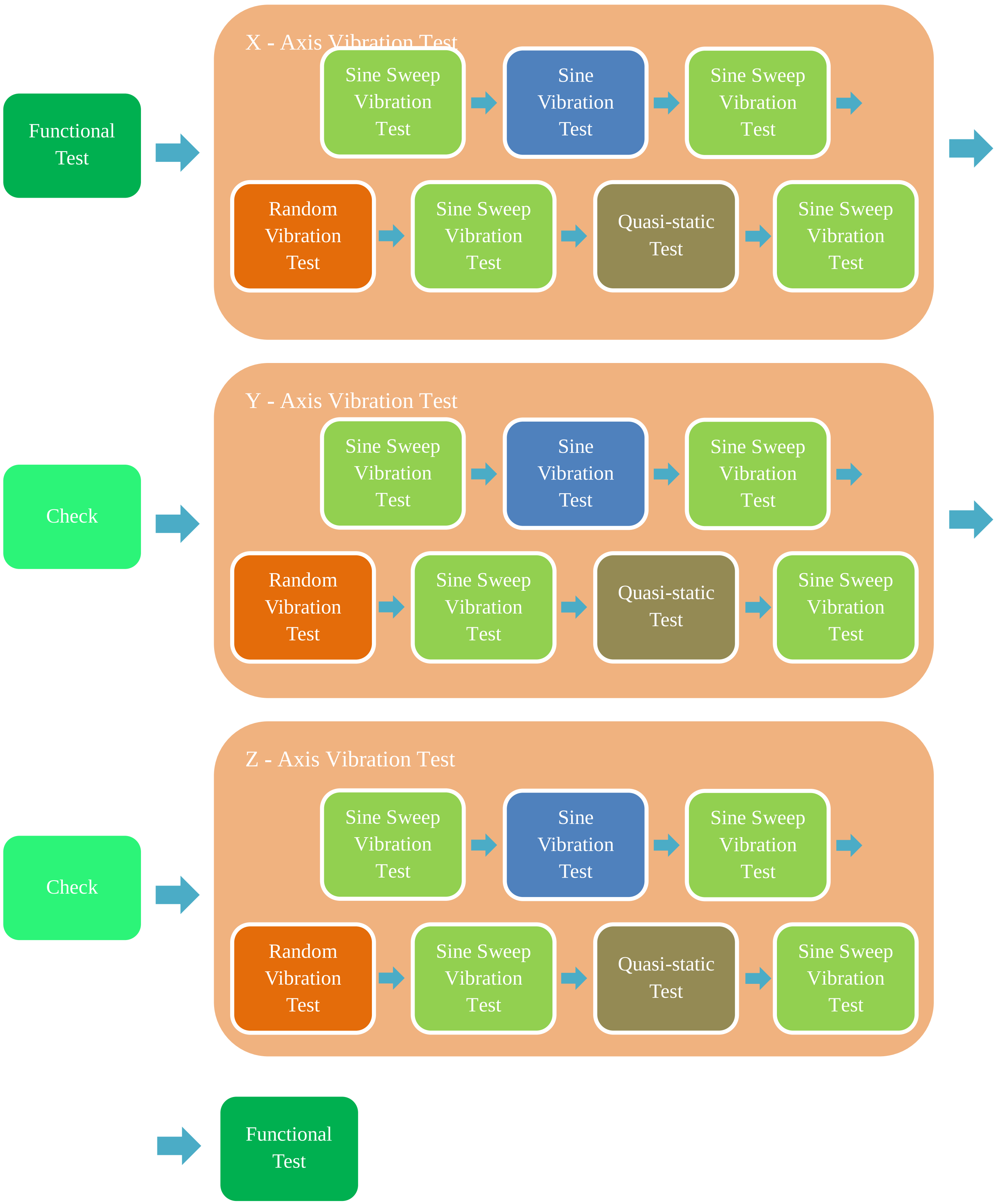

Figure 8. Block diagram of SIGMA vibration test work flow

3.1. Test Requirement

Test characteristics of qualification followed ISL pre-document(TBD). ISL document (ISL.ISILaunch09.EL) was not delivered before QM vibration test. Levels in parenthesis on table 6, 7, 8, 9 are characteristics of ISL pre-document.

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 (0.2) g**	0.4 g
Frequency range		**5 – 2000 [Hz]**	5 – 2000 [Hz]
Sweep Rate		**2 (2) [oct/min]**	2 [oct/min]

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

3.1.2 Sine Vibration Test Characteristics

Table 7. Test characteristics of sine vibration test

Characteristic		Qualification	Acceptance
Test		**Not required**	Not required
Directions	{BRF}	**X, Y, Z**	X, Y, Z
Profile	Frequency range [Hz]	**Amplitude [g]**	Amplitude [g]
	5	**1.3**	1.0
	8	**2.5**	2.0
	100	**2.5**	2.0
Sweep rate		**2 [oct/min]**	4 [oct/min]
Tolerance		Amplitude: ± 3dB	

**** Qualification test of sine vibration is not required but test was conducted based on Falcon9 level.**

3.1.3 Random Vibration Test Characteristics

Table 8. 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 (0.016)**	0.013
	50	**0.16 (0.1)**	0.08
	800	**0.16 (0.1)**	0.08
	2000	**0.026 (0.016)**	0.013
RMS acceleration		**14.1 (11.2) [g]**	10.0 [g]
Duration		**120 (120) [sec/axis]**	60 [sec/axis]

3.1.4 Quasi-Static (Sine Burst) Test Characteristics

Table 9. Test characteristics of quasi-static(sine burst) test

Characteristic	Qualification [g]	Acceptance [g]
Analysis	**Required**	Required
Test	**Required**	Required
Longitudinal {LRF}	**+ 18.75 (22.5) g**	+ 15.0 g
Transverse {LRF}	**+ 18.75 (22.5) g**	+ 15.0 g
Duration	**≥5 cycles@full level per axis (7 ramp cycles) 60 (60) sec**	≥5 cycles@full level per axis 30 sec

3.2 Accelerometer Points

Table 10. Test point location

Test Point Location				
Equipment	**ID**	**Axis**	**Location**	**Remarks**
Chassis	A	X	Near TEPC	Internal
Chassis	B	Z	Near TEPC	Internal
TEPC mount	C	Y	TEPC mount	Internal
DC-DC Converter mount	D	X, Y, Z	DC-DC Converter mount	Internal
Test POD	E	X, Y, Z	Top plate	External
Fixture	F	X, Y, Z	Top plate	External

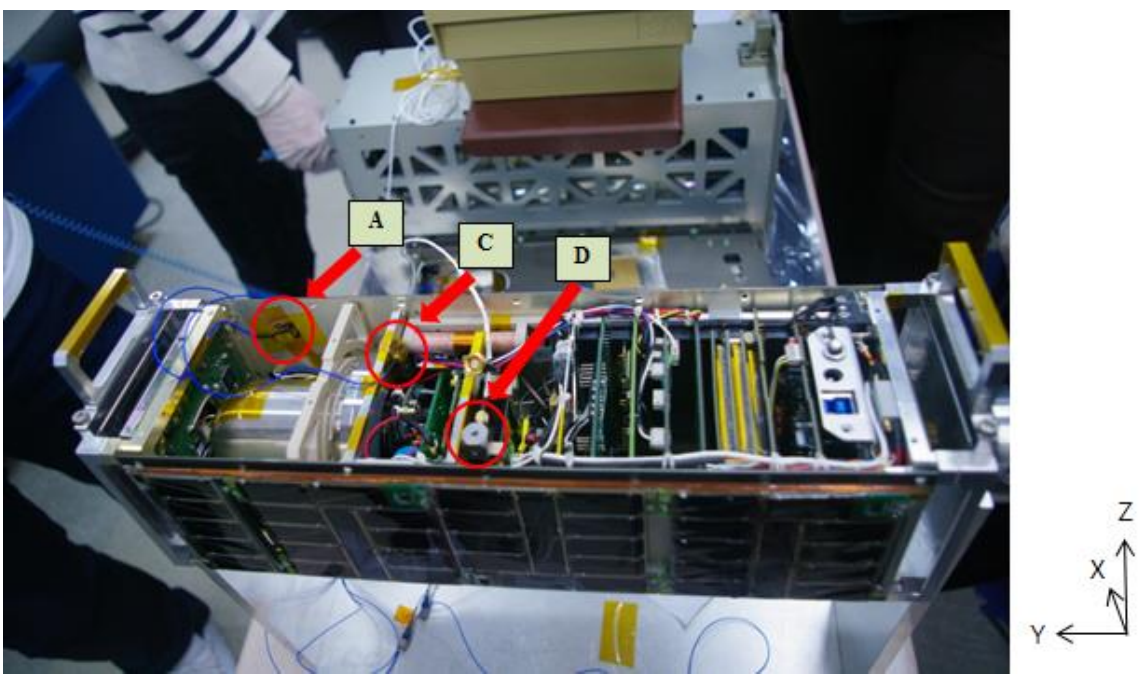

Figure 9. Location of internal accelerometer points (A, C, D)

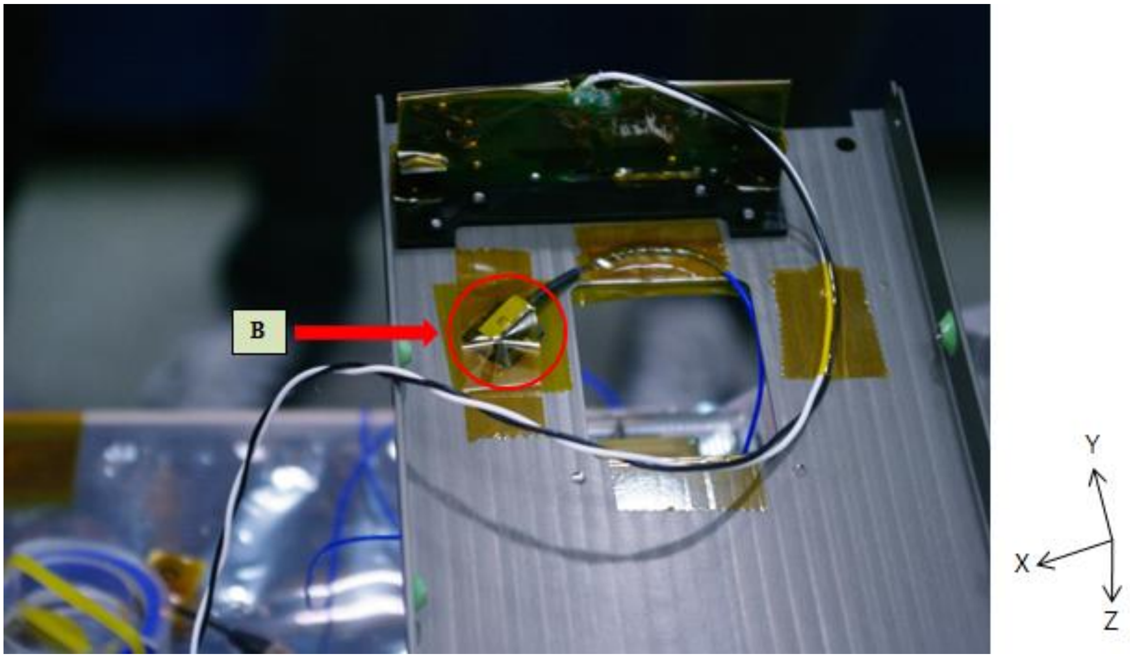

Figure 10. Location of internal accelerometer point (B)

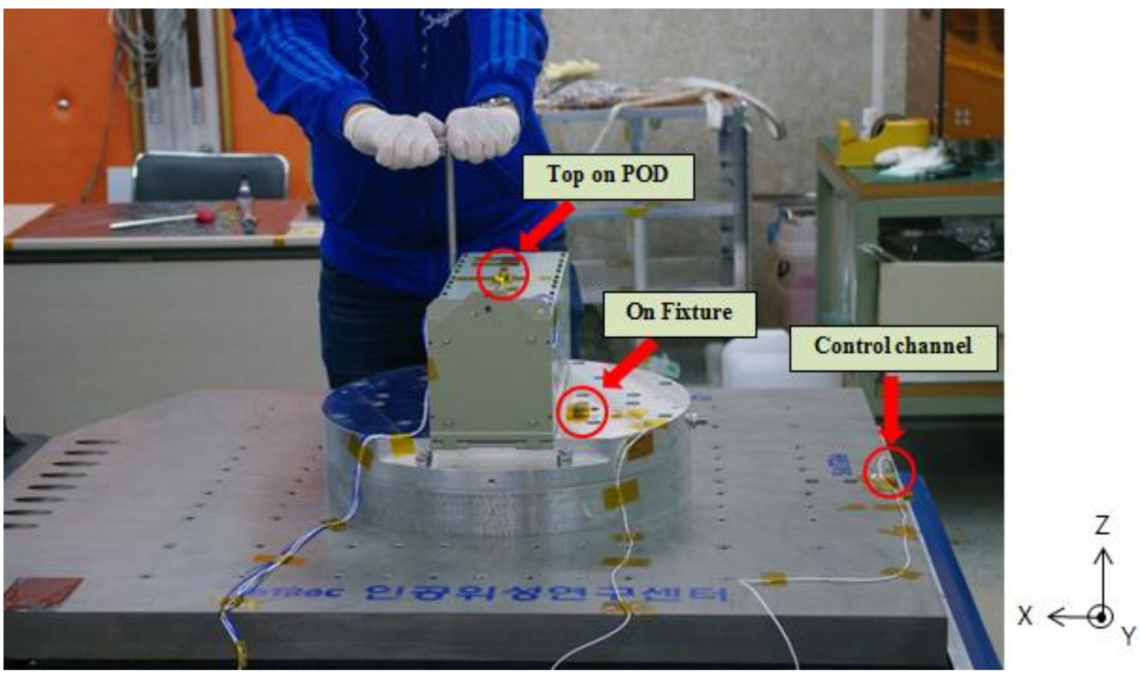

Figure 11. Location of external accelerometer points

Table 11. Information of accelerometer sensors

Position	Sensor ID	Seosor direction	Ch	Asix of SIGMA	Sensitivity (mV/g)
Top Plate	S03	-	7	Z	9.97
Left Plate	S12	-	8	X	9.84
Internal Mount	S10	-	9	Y	9.83
DC-DC Converter Mount	SN751	x	11	X	10.83
		y	12	Z	10.89
		z	13	Y	9.94
Top on POD	SN870	x	14	Y	10.18
		y	15	X	9.81
		z	16	Z	10.12
On Fixture	SN334	x	17	X	10.18
		y	18	Z	10.29
		z	19	Y	10.86

Table 12. Information of accelerometer control sensors

Control	Sensor ID	Sensor direction	Ch	Asix of SIGMA	Sensitivity (mV/g)
Lateral control (fixture)	SN492	Lateral	2	Lateral	101.30
Vertical Control (fixture)	SN492	Vertical	2	Z	101.30
	*SN493	Vertical	3	Z	101.60
	SN717	Vertical	4	Z	101.40

***replaced to SN494 at random vibration test of Z axis**

Table 13. Channel information of each axis

Direction of SIGMA	Measurement channel information
X axis	Ch8, Ch11, Ch15, Ch17
Y axis	Ch9, Ch13, Ch14, Ch19
Z axis	Ch7, Ch12, Ch16, Ch18

4. QM Vibration Test

4.1 Issues of Vibration Test

Table 14. Issues of vibration test per each axis

Axis	Type of vibration test	Remarks
X	PRS	-
	SIN	-
	POS #1	Natural frequency was changed because of non-fixing of satellite with spring and pod.
	RAN	-
	POS #2	Natural frequency was changed because of non-fixing of satellite with spring and pod.
	QSS	Because of spring, all axis of satellite was tested under more high amplitude level. But by checking data of control sensor, we confirmed input amplitude level as 22.5 g.
	POS #3	Natural frequency was changed because of non-fixing of satellite with spring and pod.
Y	PRS	-
	SIN	In 19 ch, unusual peak was occurred at 14 Hz. We checked problem of SN334 and ignored data of 19ch.
	POS #1	-
	RAN	-
	POS #2	-
	QSS	Because of spring, all axis of satellite was tested under more high amplitude level. But by checking data of control sensor, we confirmed input amplitude level as 22.5 g Program shut down for reason of high amplitude level by spring. So we couldn't get quasi-static test data of Y axis except control data. But test was verified by checking control data and functional test of Y axis.
	POS #3	-
Z	PRS	Test was shut down at 1998 Hz. So we couldn't get data of from 1998 to 2000 Hz section.

	SIN	In 18 ch, unusual peak was occurred. We considered simple noise problem about that peak but origin was unknown. Sensor of 18ch position was placed on fixture, we decided peak wasn't affect satellite.
	POS #1	After sine vibration test, NF peak and shape was changed. We considered some part was non-fixing by sine vibration test. In functional test and visual inspection, we checked a loose screw.
	RAN	SN493 that vertical control sensor was changed to SN494.
	POS #2	Because of change of NF peak and graph, we couldn't find accurate NF. But overall shapes of graph was similar with other sine sweep vibration tests
	QSS	Because of spring, all axis of satellite was tested under more high amplitude level. But by checking data of control sensor, we confirmed input amplitude level as 22.5 g
	POS #3	Because of change of NF peak and graph, we couldn't find accurate NF. But overall shapes of graph was similar with other sine sweep vibration tests

***PRS : Pre sine sweep vibration test, SIN : Sine vibration test, POS : Post sine sweep vibration test, RAN : Random vibration test, QSS : Quasi-static test**

4.2 X Axis

4.2.1 Response Data

4.2.1.1 Pre Sine Sweep VibrationTest (X Axis)

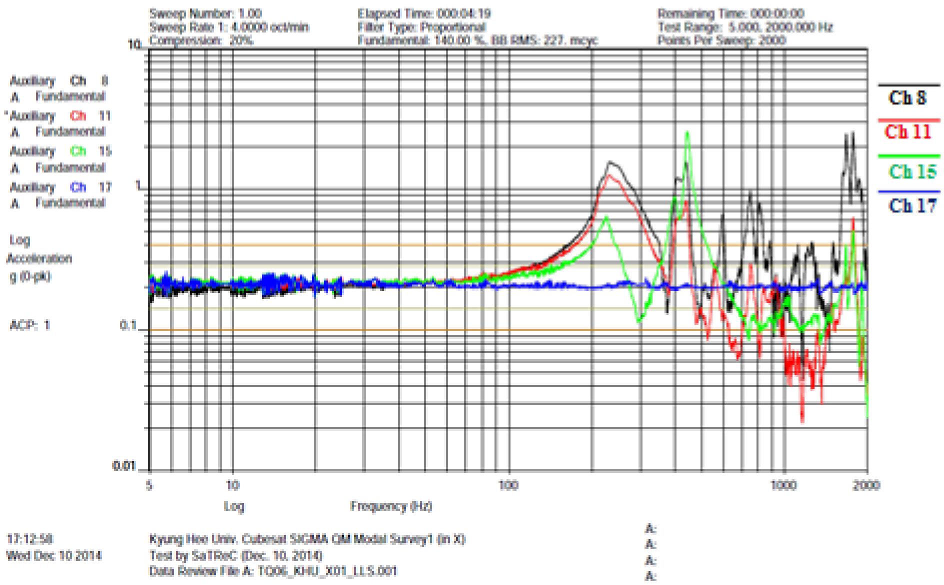

Figure 12. Pre sine sweep vibration test (X axis)

4.2.1.2 SineVvibration Test (X Axis)

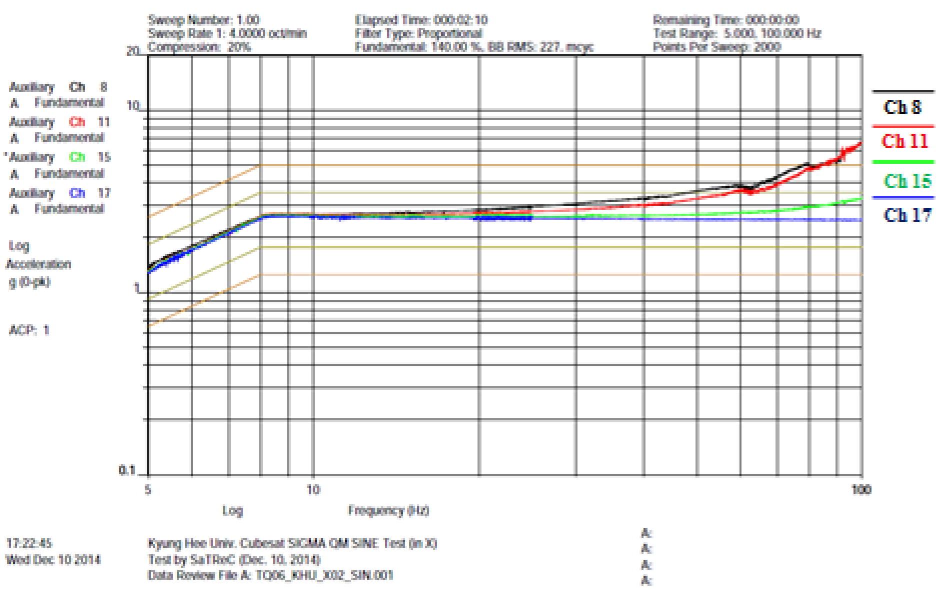

Figure 13. Sine vibration test (X axis)

4.2.1.3 Post Sine Sweep VibrationTest_1 (X Axis)

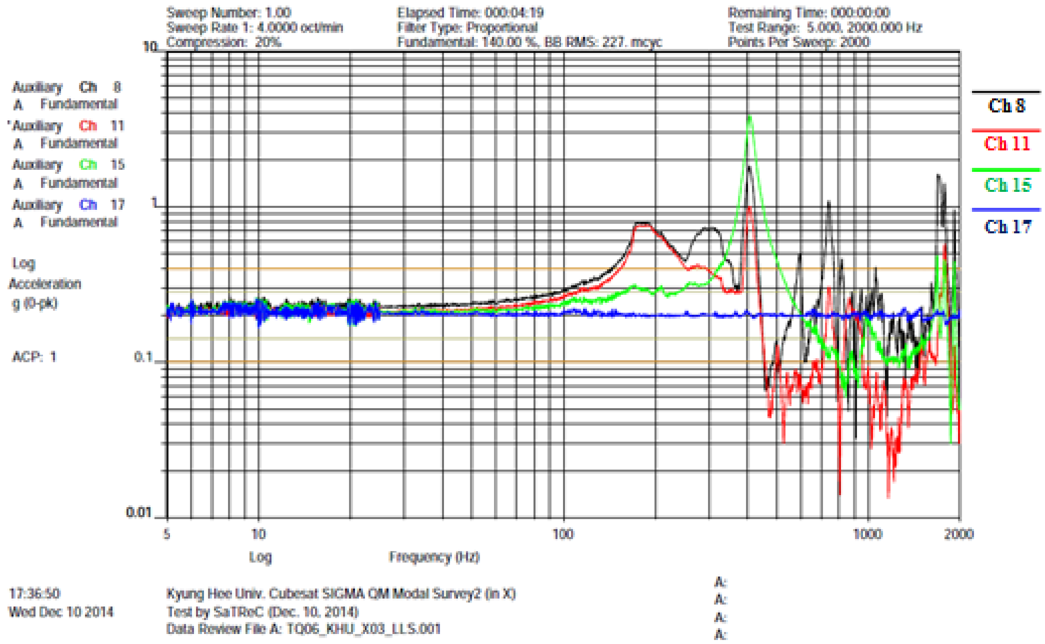

Figure 14. Post sine sweep vibration test_1 (X axis)

Natural frequency was changed because of non-fixing of satellite with spring and pod.

4.2.1.4 Random Vibration Test (X Axis)

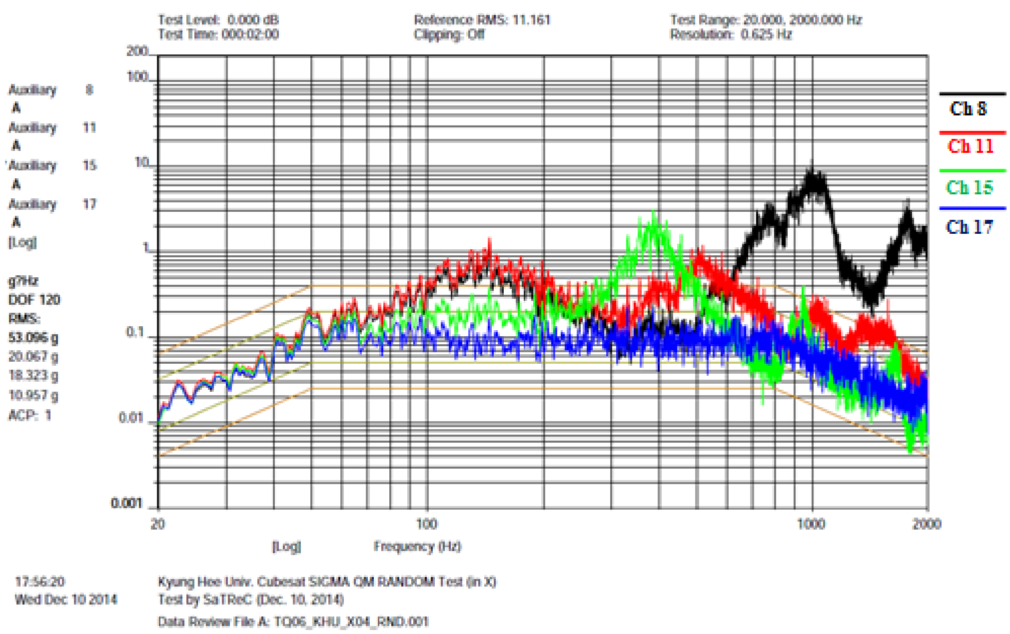

Figure 15. Random vibration test (X axis)

4.2.1.5 Post Sine Sweep Vibration Test_2 (X Axis)

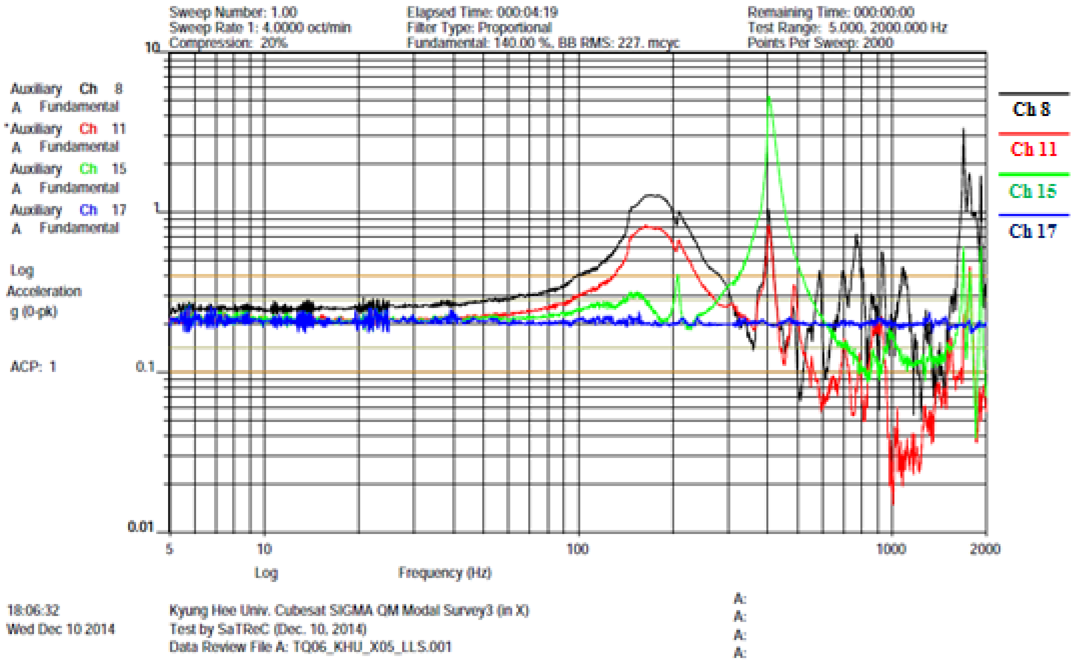

Figure 16. Post sine sweep vibration test_2 (X axis)

Natural frequency was changed because of non-fixing of satellite with spring and pod.

4.2.1.6 Quasi-Static (Sine Burst) Test (X Axis)

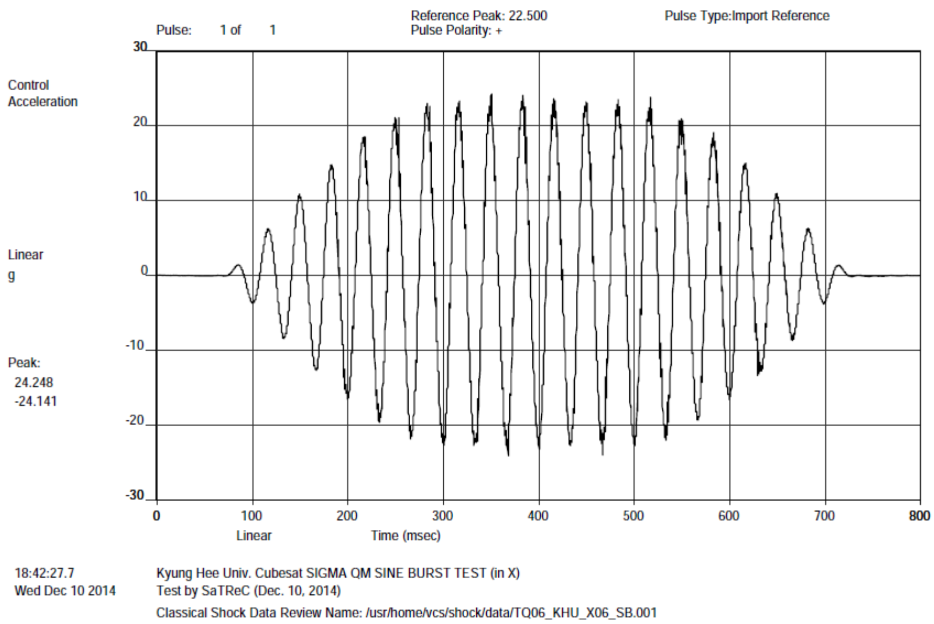

Figure 17. Control data of quasi-static (sine burst) test (X axis)

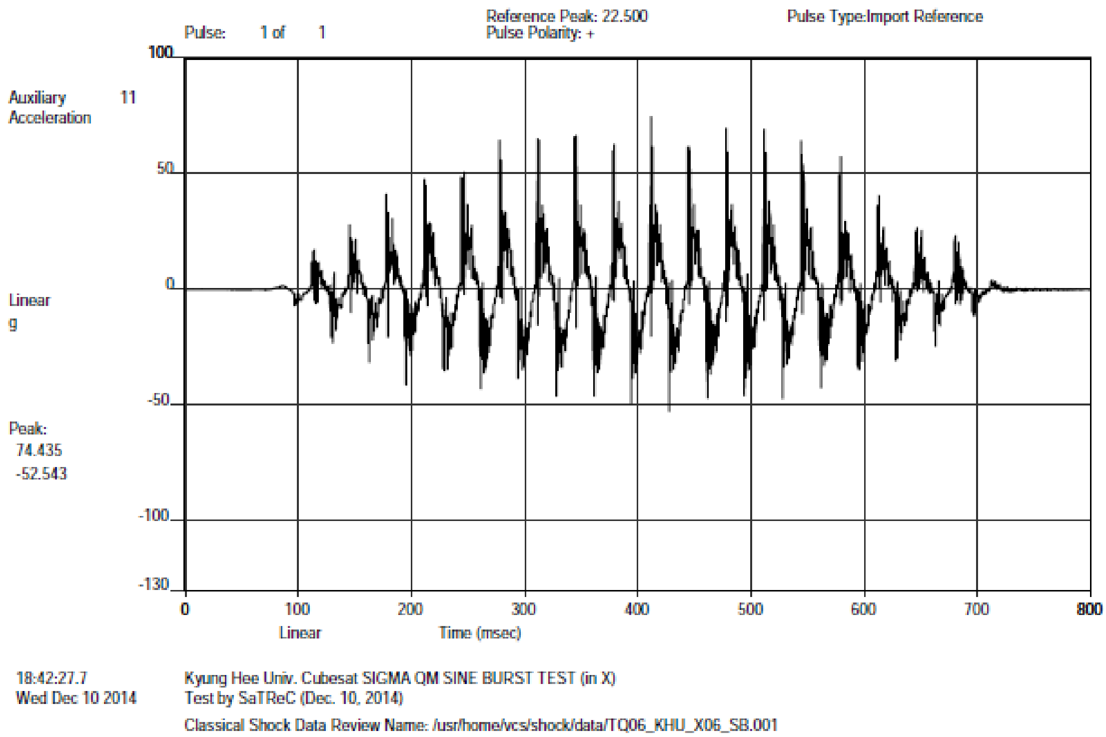

Figure 18. 11ch data of quasi-static (sine burst) vibration test (X axis)

Because of spring, all axis of satellite was tested under more high amplitude level. But by checking data of control sensor, we confirmed input amplitude level as 22.5 g.

4.2.1.6.1 Real Input Data of Quasi-Static (Sine Burst) Test (X Axis)

Table 14. Real input data of X axis quasi static vibration test

Characteristic			Real input data
Amplitude [g]	11 ch	22.5 g * 1/2	11.8 g
		22.5 g	24.203 g

4.2.1.7 Post Sine Sweep Vibration Test_3 (X Axis)

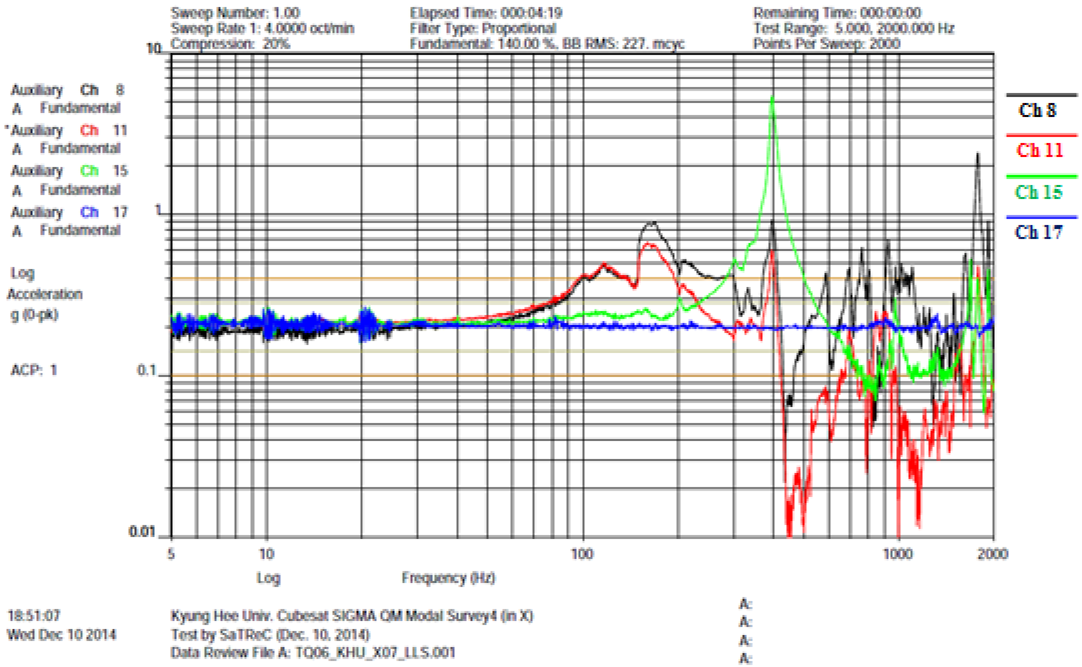

Figure 19. Post sine sweep vibration test_3 (X axis)

Natural frequency was changed because of non-fixing of satellite with spring and pod.

4.2.2 Result

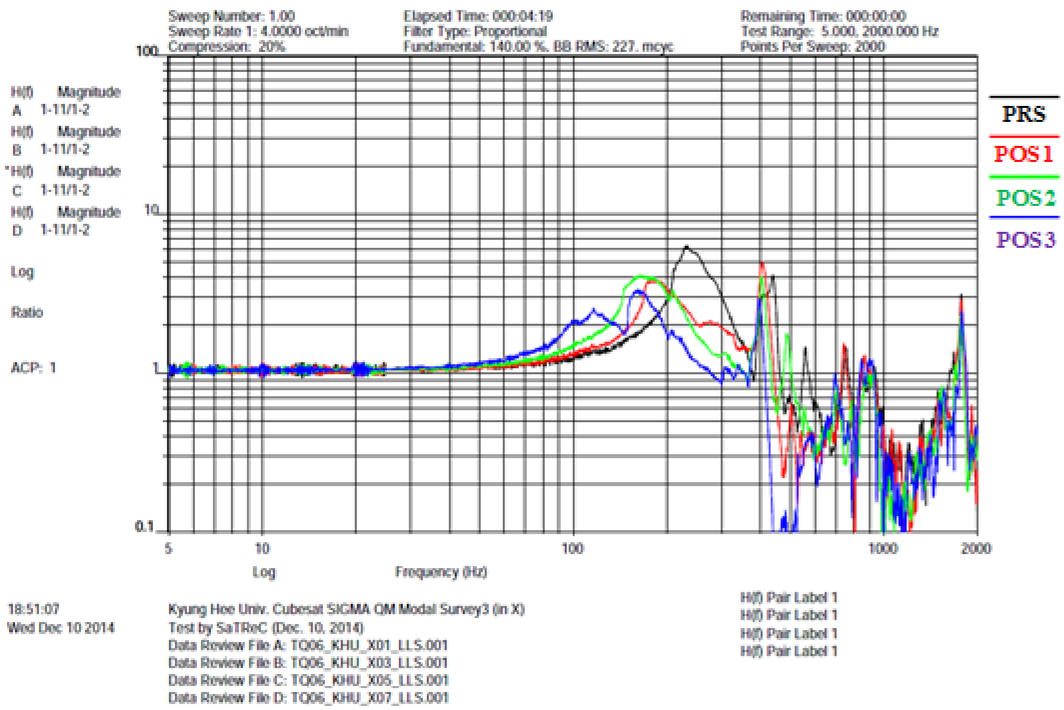

Figure 20. Comparison of ch11 sine sweep vibration test

SN751 (ch11, ch12, ch13) was placed on DC – DC converter mount. DC – DC converter mount is well fixed satellite. So SN751 was less-affected by vibration damping. For that reason, we checked channels of SN751 for verification natural frequency of each axis.

Table 15. Comparison of X axis natural frequency

Axis	Test type	Natural frequency	Remarks
X	PRS	213.10 Hz	Natural frequency is changed because of non-fixing of satellite with spring and pod. Functional test and eye check have been passed.
	SIN	-	
	POS #1	184.58 Hz	
	RAN	-	
	POS #2	166.70 Hz	
	QSS	-	
	POS #3	160.81 Hz	

4.3 Y Axis

4.3.1 Response Data

4.3.1.1 Pre Sine Sweep Vibration Test (Y Axis)

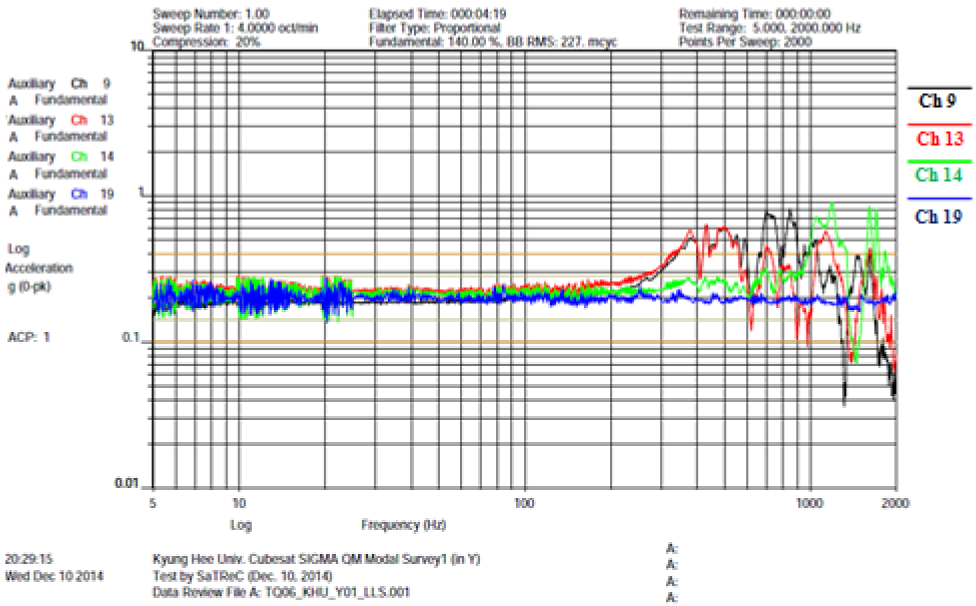

Figure 21. Pre sine sweep vibration test (Y axis)

4.3.1.2 Sine Vibration Test (Y Axis)

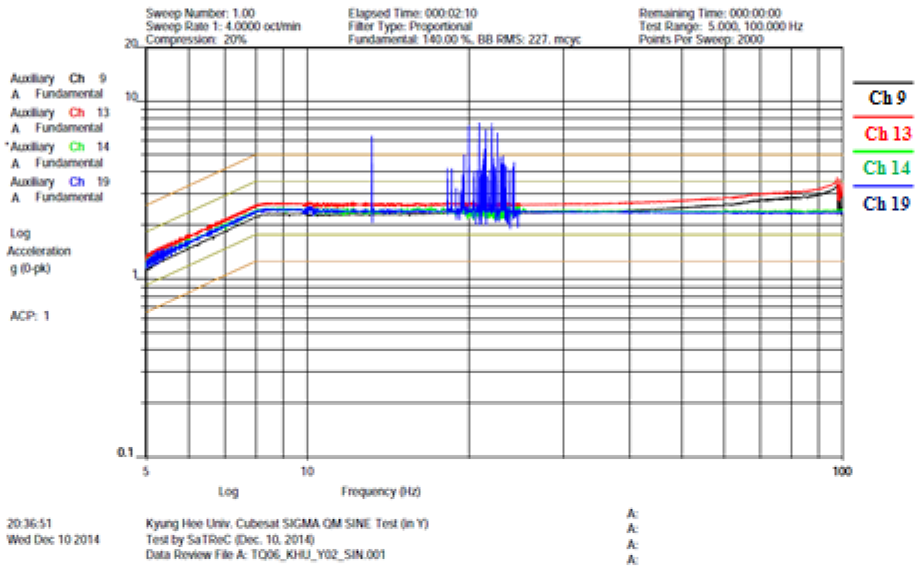

Figure 22. Sine vibration test (Y axis)

In 19 ch, unusual peak was occurred at 14 Hz. We checked problem of SN334 and decided to ignore data of 19ch.

4.3.1.3 Post Sine Sweep Vibration Test_1 (Y Axis)

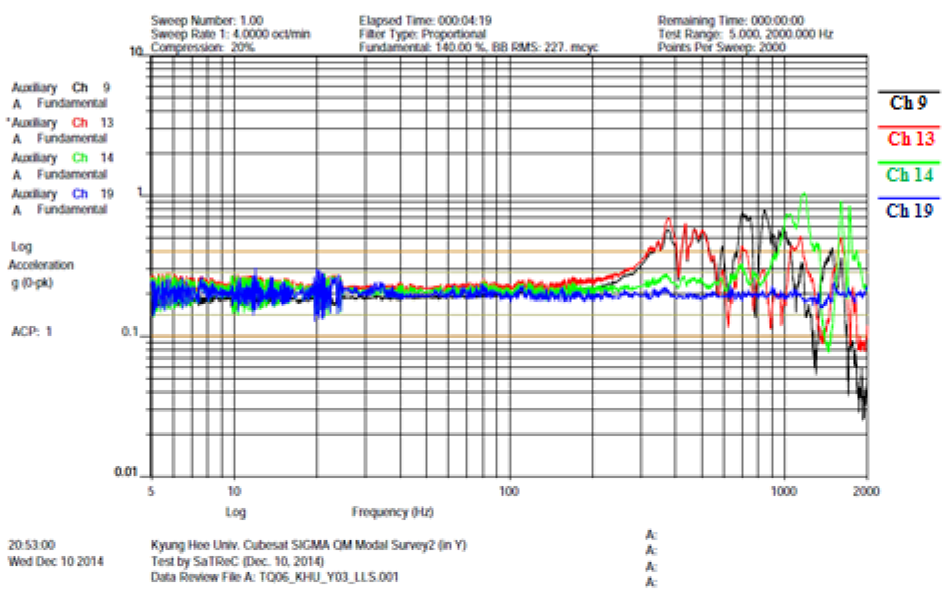

Figure 23. Post sine vibration test_1 (Y axis)

4.3.1.4 Random Vibration Test (Y Axis)

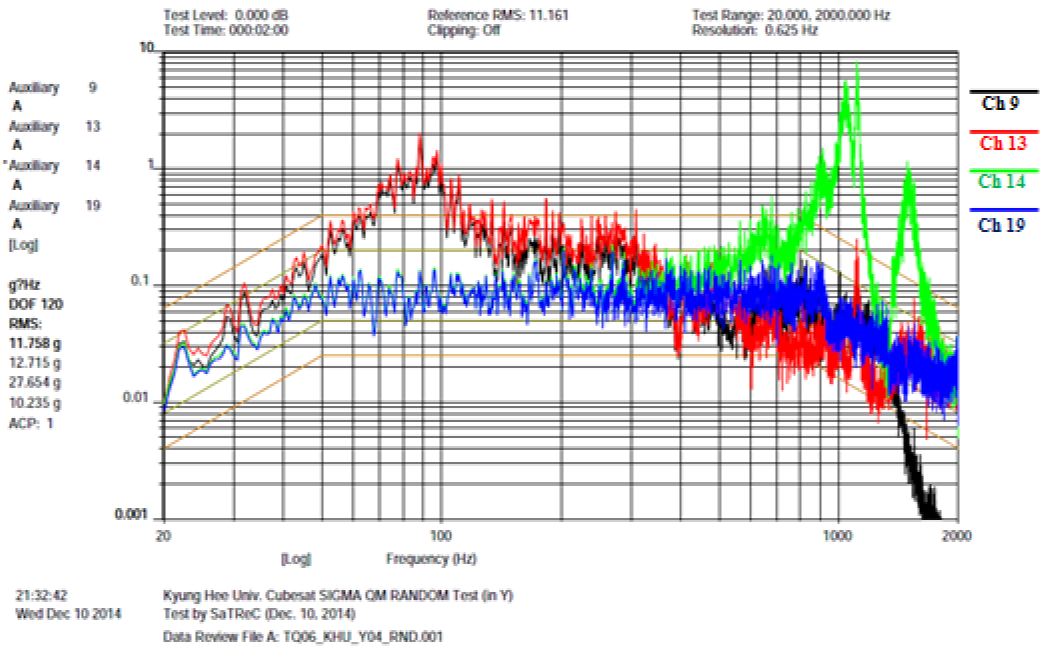

Figure 24. Random vibration test (Y axis)

4.3.1.5 Post Sine Sweep Vibration Test_2 (Y Axis)

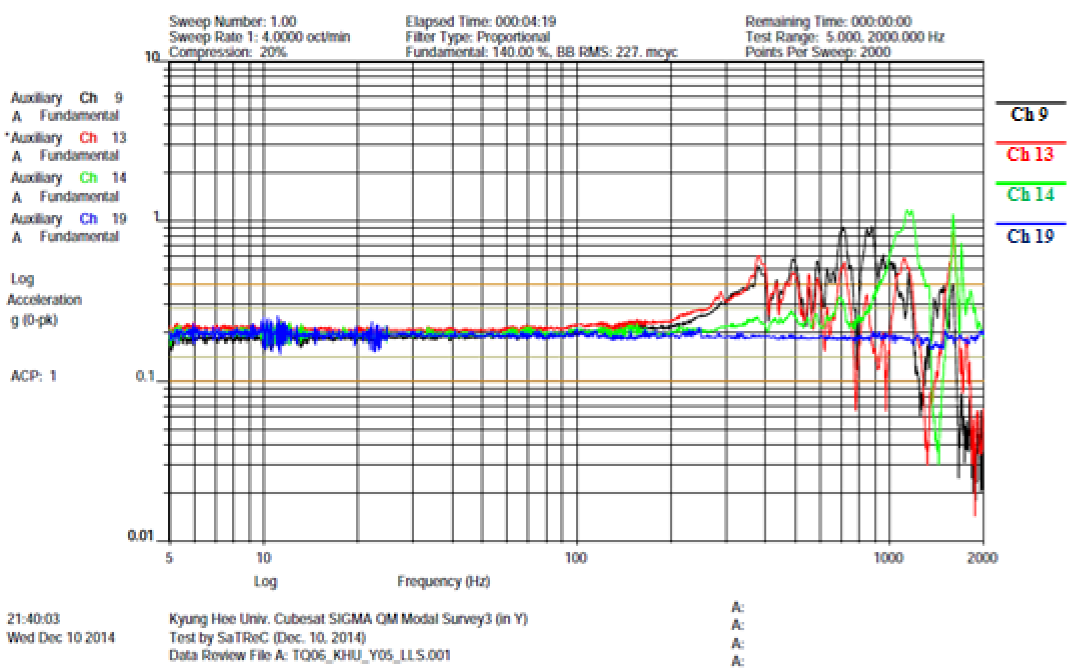

Figure 25. Post sine vibration test_2 (Y axis)

4.3.1.6 Quasi-Static (Sine Burst) Test (Y Axis)

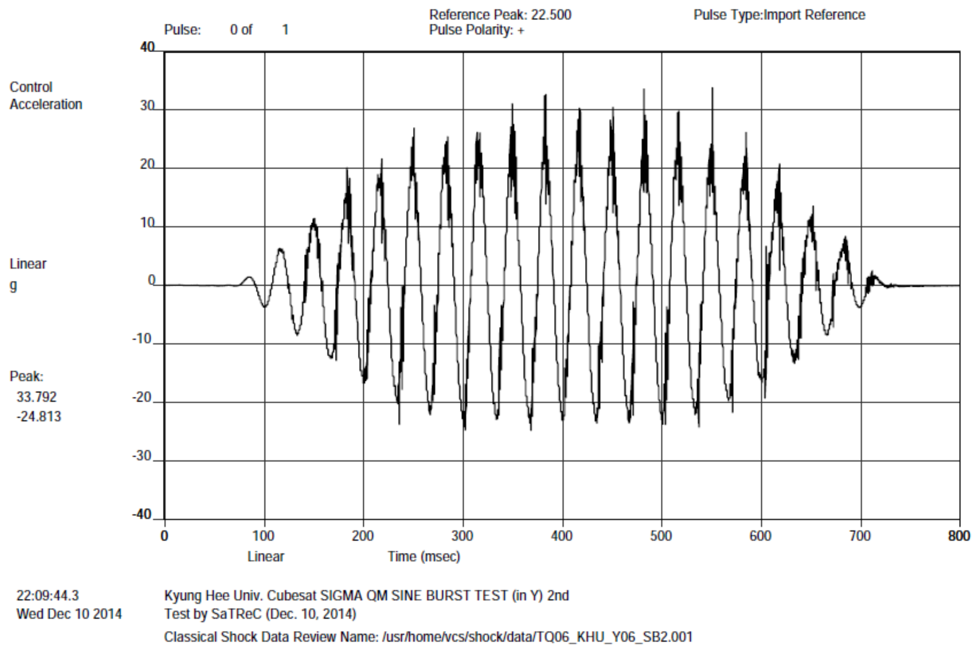

Figure 26 Control data of quasi-static (sine burst) test (Y axis)

Because of spring, all axis of satellite was tested under more high amplitude level. But by checking data of control sensor, we confirmed input amplitude level as 22.5 g

When we tested to quasi-static test of Y axis was applied reference peak level 22.5, program shut down because of high amplitude level. So we couldn’t get quasi-static test data of Y axis except control data. But as we can see, Figure 26 is shown that reference peak level was applied to quasi-static test of Y axis as 22.5. And we verified quasi-static test of Y axis by checking functional test of Y axis which was conducted after quasi-static test, post sine sweep vibration test_3 .

4.3.1.6.1 Real Input Data of Quasi-Static (Sine Burst) Test (Y Axis)

Table 16. Real input data of quasi static vibration test (Y axis)

Characteristic			Real input data
Amplitude [g]	13 ch	22.5 g * 1/2	16.986 g
		22.5 g	33.775 g

4.3.1.7 Post Sine Sweep Vibration Test_3 (Y Axis)

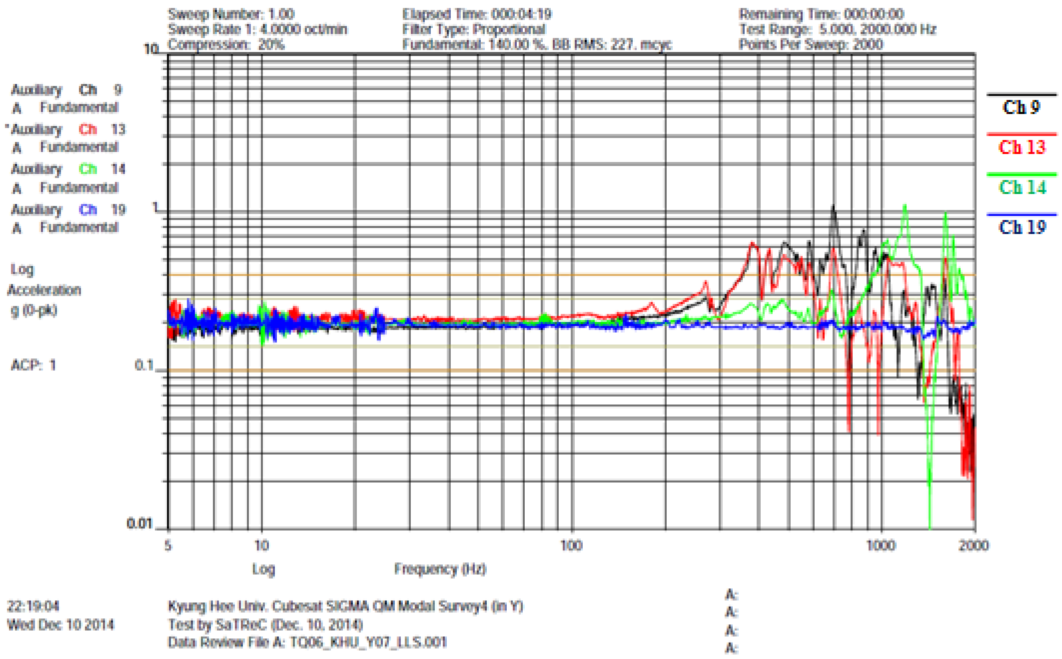

Figure 27. Post sine sweep vibration test_3 (Y axis)

4.3.2 Result

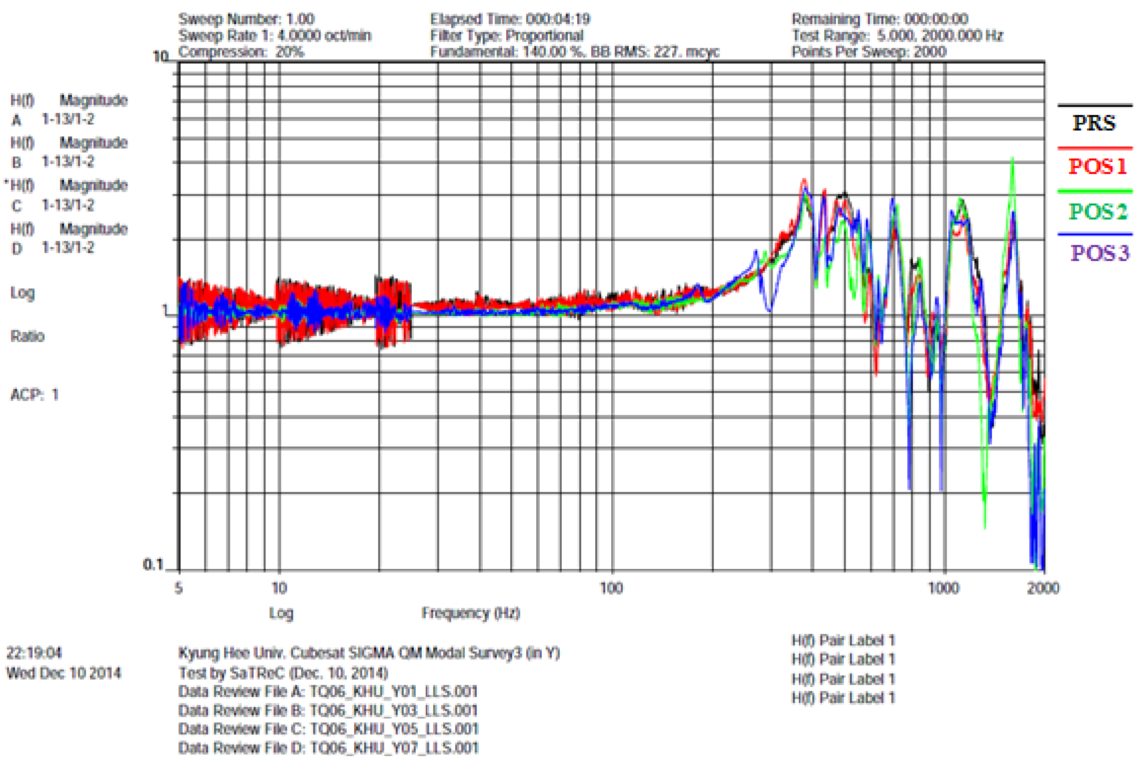

Figure 28. Comparison of ch13 sine sweep vibration test

Table 17. Comparison of natural frequency (Y axis)

Axis	Test type	Natural frequency	Remarks
Y	PRS	377.83 Hz	
	SIN	-	
	POS #1	377.83 Hz	
	RAN	-	
	POS #2	381.24 Hz	
	QSS	-	
	POS #3	381.24 Hz	

4.4 Z Axis

4.4.1 Response Data

4.4.1.1 Pre Sine Sweep Vibration Test (Z Axis)

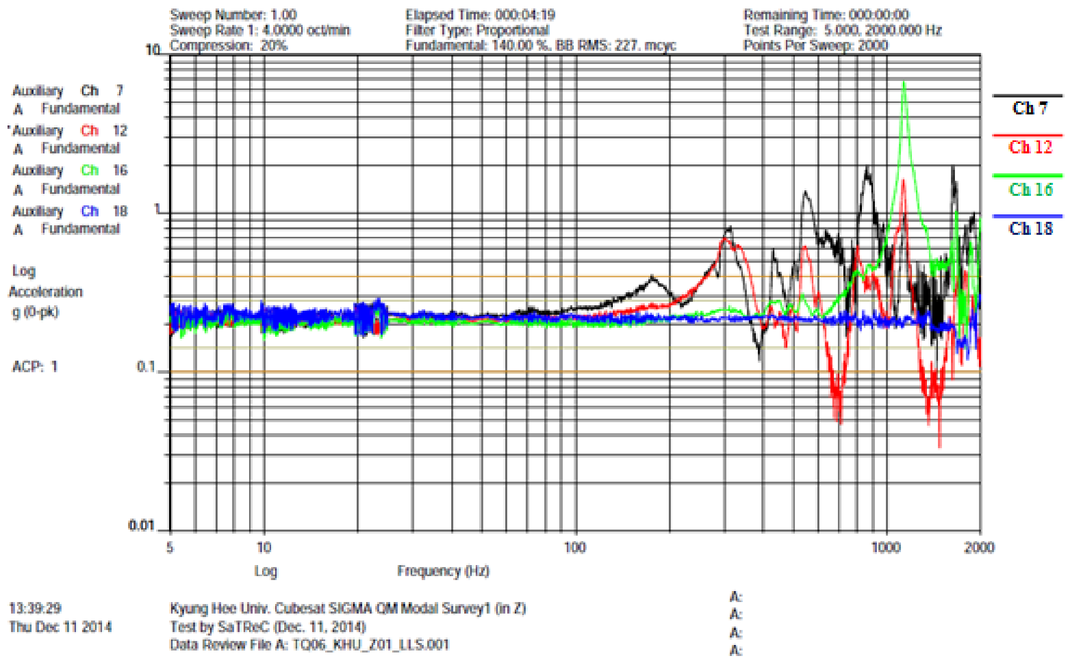

Figure 29. Pre sine sweep vibration test (Z axis)

Test was shut down at 1998 Hz. So we couldn't get data of from 1998 to 2000 Hz section.

4.4.1.2 Sine Vibration Test (Z Axis)

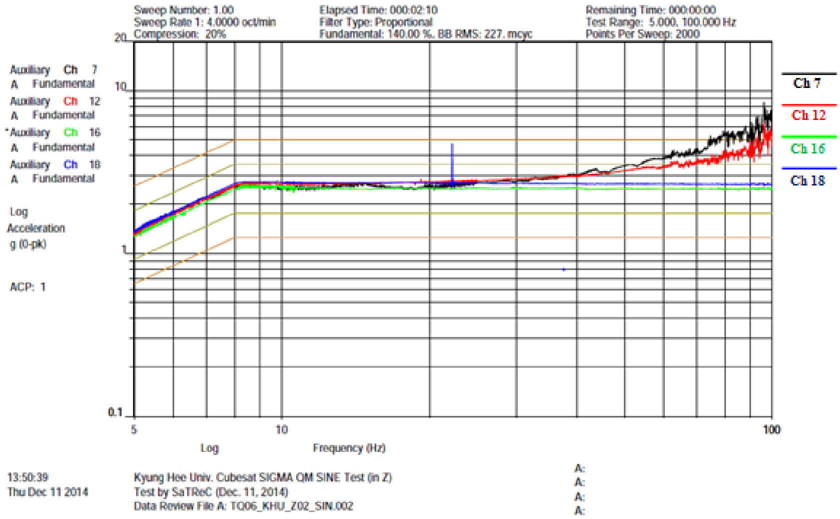

Figure 30. Sine vibration test (Z axis)

In 18 ch, unusual peak was occurred. We considered simple noise problem about that peak but origin was unknown. Sensor of 18ch position was placed on fixture, so we decided peak wasn't affect satellite and ignored that peak.

4.4.1.3 Post Sine Sweep Vibration Test_1 (Z Axis)

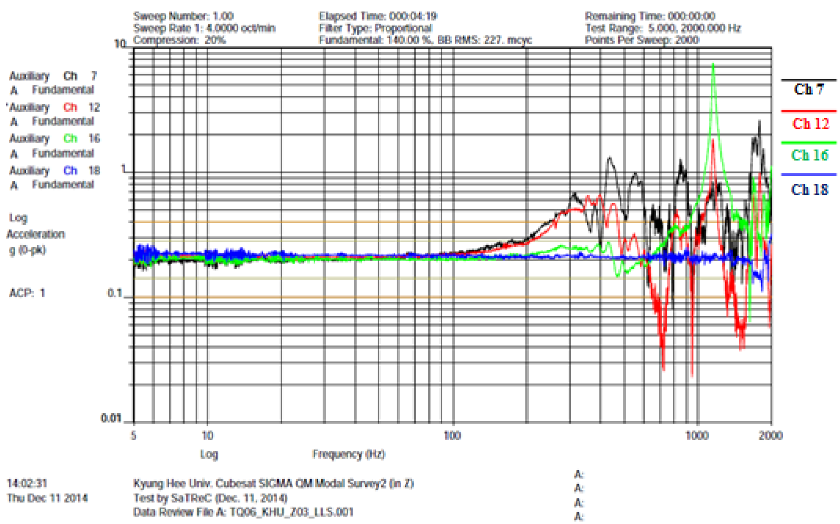

Figure 31. Post sine sweep vibration test_1 (Z axis)

After sine vibration test, NF peak and graph shape was changed. We considered some part was non-fixing by sine vibration test. At functional test and visual inspection, we checked a loose screw.

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4.4.1.4 Random Vibration Test (Z Axis)

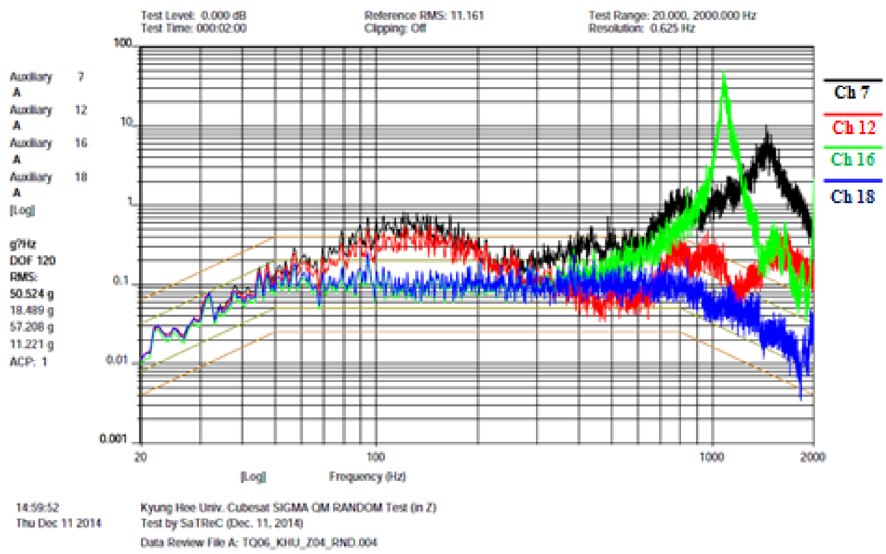

Figure 32. Random vibration test (Z axis)

SN493 vertical control sensor was changed to SN494.

4.4.1.5 Post Sine Sweep Vibration Test_2 (Z Axis)

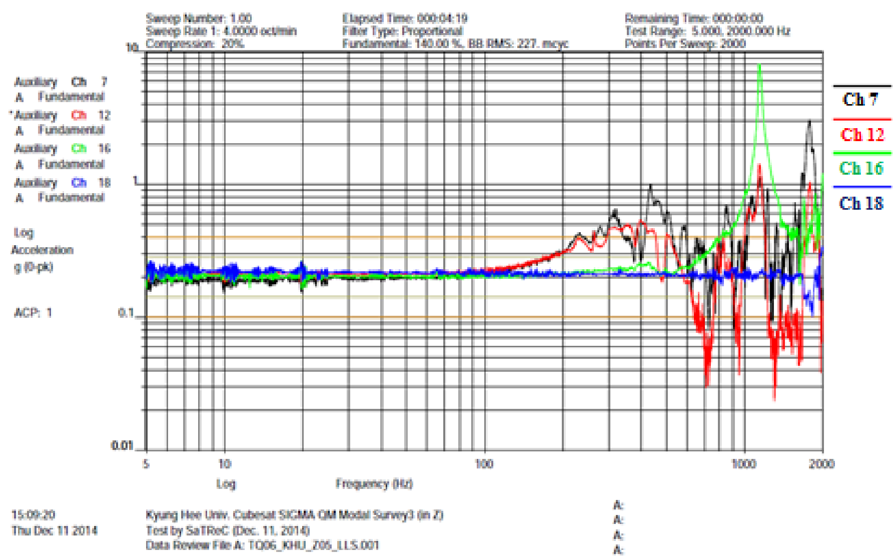

Figure 33. Post sine sweep vibration test_2 (Z axis)

Because of change of NF peak and graph shape, we couldn't find accurate NF. But overall graph shape was similar with other sine sweep vibration tests.

4.4.1.6 Quasi-Static (Sine Burst) Test (Z Axis)

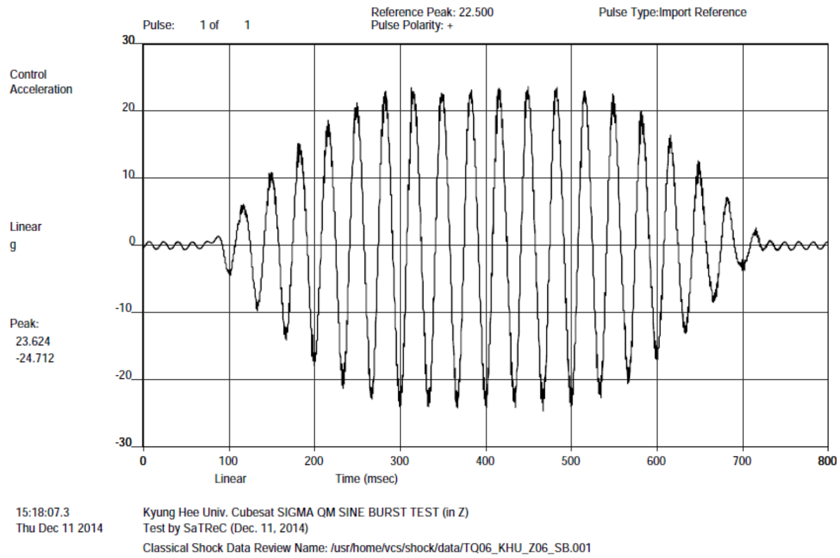

Figure 34. Control data of quasi-static (sine burst) test (Z axis)

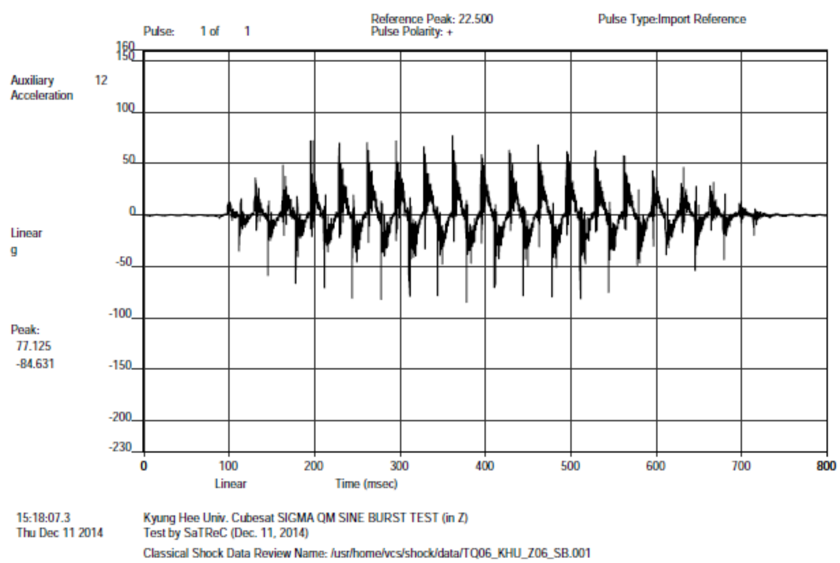

Figure 35. 12 ch data of quasi-static (sine burst) vibration test (Z axis)

Because of spring, all axis of satellite was tested under more high amplitude level. But by checking data of control sensor, we confirmed input amplitude level as 22.5 g

4.3.1.6.1 Real Input Data of Quasi-Static (Sine Burst) Test (Z Axis)

Table 18. Real input data of quasi static (sine burst) vibration test (Z axis)

Characteristic			Real input data
Amplitude [g]	12 ch	22.5 g * 1/2	12.597
		22.5 g	24.692

4.4.1.7 Post Sine Sweep Vibration Test_3 (Z Axis)

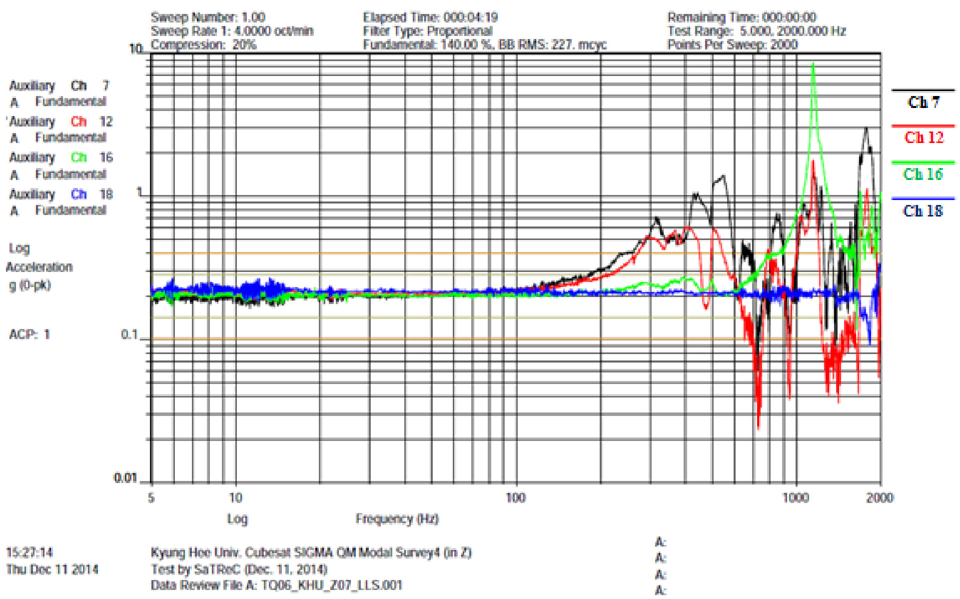

Figure 36. Post sine sweep vibration test_3 (Z axis)

Because of change of NF peak and graph shape, we couldn't find accurate NF. But overall graph shape was similar with other sine sweep vibration tests.

4.4.2 Result

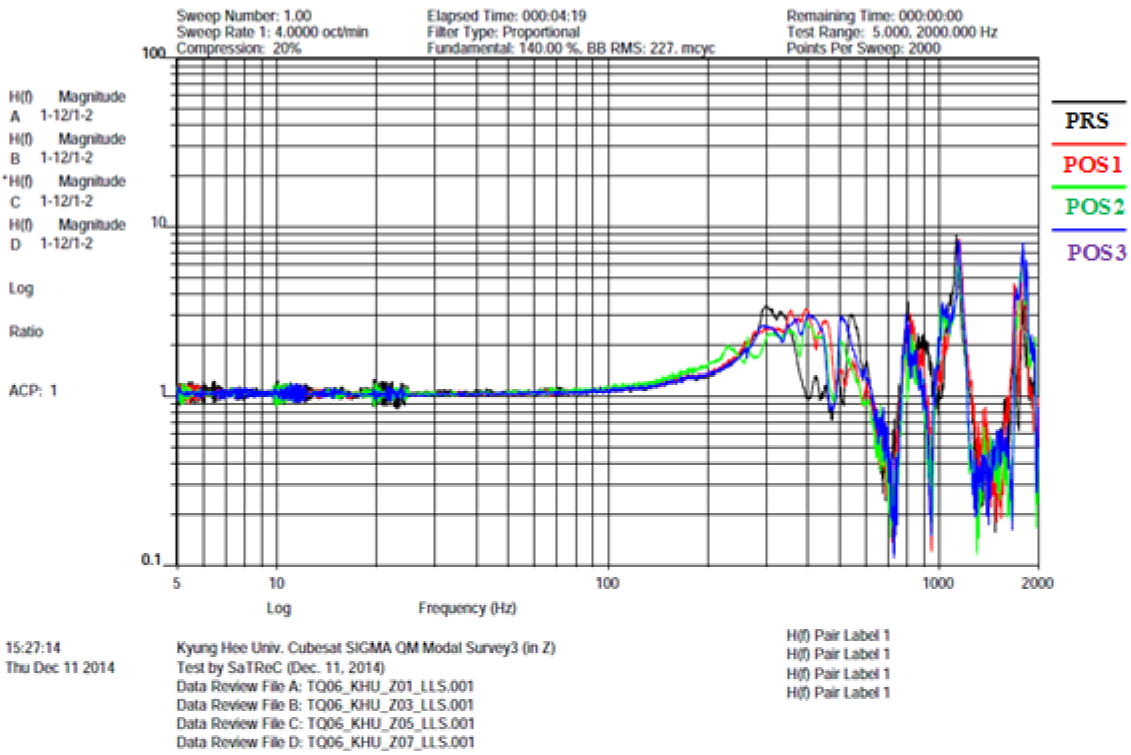

Figure 37. Comparison of ch12 sine sweep vibration test (Z axis)

Table 19. Comparison of natural frequency (Z axis)

Axis	Test type	Natural frequency	Remarks
Z	PRS	300.86 Hz	From POS 2 to POS 3, we couldn't find accurate NF. Even if NF and test graph was changed gradually, overall graph shape is similar with each other. Functional test and eye check have been passed.
	SIN	-	
	POS #1	355.85 Hz	
	RAN	-	
	POS #2	-	
	QSS	-	
	POS #3	-	

4.5 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.

Table 20. Explanation of run #

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 21. 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	P	P	P
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
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	P	P	P	P
2	Calex DC-DC converter	Electrical Functionality	P	P	P	P
10. Harnessing						
1	Harnessing	No loss of captivity	P	P	P	P
2	Harnessing	Electrical Functionality	P	P	P	P

* P: Pass, F: Fail, N/A: Not Applicable