한국소음진동공학회 창립10주년 기념 소음진동학술대회논문집, pp.1234~1239.

LAUNCH ENVIRONMENT TEST OF KOMPSAT-1 SATELLITE

Sang-Seol Lee   Hong-Bae Kim   Sang-Mu Moon   Sung-Hyun Woo

ABSTRACT

KOMPSAT-1(Korea Multi-Purpose Satellite), which opened the space era in Korean peninsula, was developed from 1994 and launched successfully in December of 1999 at VAFB, USA. This paper presents a launch environment test of KOMPSAT and a short description of environment test facilities at Korea Aerospace Research Institute as well.

The launch environment tests of KOMPSAT-1 satellite, such as vibration, acoustic, pyro-shock and mass properties measurement test, were performed during its system integration and test period. The participating engineers concluded that KOMPSAT-1 satellite would withstand environment during its launch period.

KEYWORDS

KOMPSAT, Launch environment, Vibration test, Mass properties measurement test.

INTRODUCTION

Launch vehicle carrying a spacecraft usually faces with severe environments, such as noise and vibration caused by gigantic thrust force, rapid dynamic pressure variation and unimaginable shock during its launch period. These injurious environments propagate or penetrate into a spacecraft boarded and cause malfunction of spacecraft itself or on boarding payloads[1]. Thus, successful management of the spacecraft, which requires a long period and high budget in its development, demands very careful consideration on launch environments during its designing and manufacturing stages. The verification process for a developed model must proceed prior to its flight. This paper presents a series of KOMPSAT launch environmental tests performed at KARI(Korea Aerospace Research Institute) to help the understanding of the launch environments and to promote the communication between engineers in this field.

KARI'S FALICITIES FOR LAUNCH ENVIRONMENT TEST

Satellite Integration and Test Center(SITC) at KARI(see figure 3), which was founded to support KOMPSAT (Korea Multi-purpose Satellite), is the first comprehensive test facility for space object development in Korea. SITC, being maintained at 10,000 cleanliness class during the spacecraft integration and test, is equipped with 50 μm resolution alignment system for precise integration of spacecrafts and their payloads, electro-magnetic vibrators and mass property measurement system which can test up to 3.5 ton spacecraft, thermal vacuum chambers for space environment simulation, EMI/EMC chamber and other test equipments. SITC has been the Mecca to develop and test a series of Korean space program, such as KOMPSAT, KITSAT, KoreaSat, Sounding Rocket (KSR) and Koreanized space components.

Vibration tests, such as sine, random, and low level shock test, is usually performed with a test configuration as shown in figure 1. SITC is equipped with a 80 kN class base shaking system for a small sized satellite or components and a 260 kN class one for a large or medium sized satellite. The smaller one can generate 100 g sine, 70 g random(RMS) and 210 g shock acceleration with maximum 36.4 mm stroke. The other one can generate 53 g sine, 40 g random(RMS) and 180 g shock acceleration with maximum 50.8 mm stroke. In vertical configuration, both systems use head expander with hydraulic bearing to increase their lateral stiffness. It can sustain 40 kN-m static turning moment with maximum 5,000 kg test object. In horizontal configuration, those use slip table with hydraulic bearing, which can accommodate 147 kN-m static turning moment.

For the control of both shakers, it has eight control channels. On the other hand, it has 64 channels for accelerometer signals and 32 channels for direct signals for the acquisition of response from test object as well.

KARI's mass property measurement systems are designed to measure the product of inertia and dynamic center of gravity of test objects weighing up to 3,500 Kg. In addition, this instrument measures the moment of inertia and static center of gravity up to 4,500 Kg. The machine is of the vertical type(Rotation axis vertical) with true two plane measurement and correction capability(see figure 2). Incorporated with L-shaped fixture, mass property measurement can be done for three orthogonal axis, X, Y, and Z. It also can perform dynamic balancing of satellite with more than two separation planes. In balancing mode, the system provides the operator with weight and location information that will theoretically enable him to balance of the satellite. For the shock simulation at component level, KARI has a free fall shock test system. It can accommodate test payloads weighing up to 20 kg and provide shock acceleration over 5,000 g.

LAUNCH ENVIRONMENT OF SATELLITE

The representative launch environments in terms of satellite are as follows. First, steady state

Fig. 1 Test Setup for Vibration Test

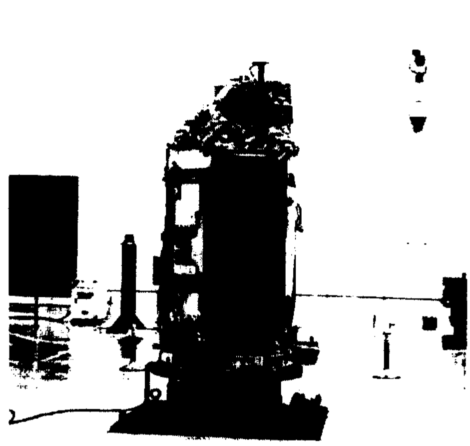


Fig. 2 Test Setup for Mass Properties Measurement

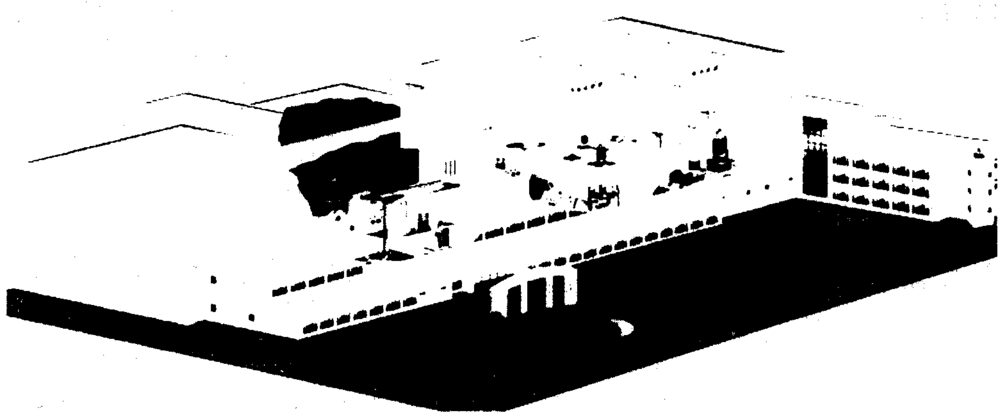
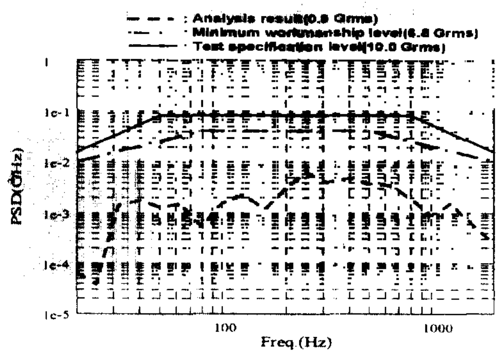


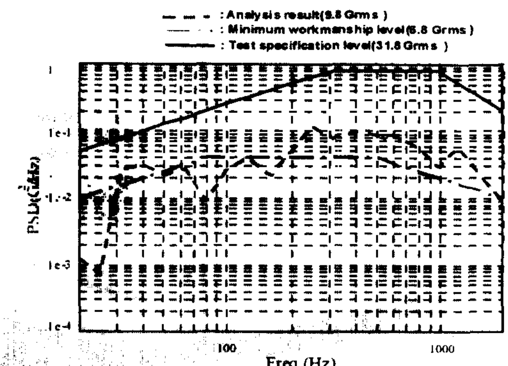
Fig. 3 Satellite Integration & Test Center at KARI

acceleration due to ascending of launch vehicle and transient forcing components caused by thrust excitation, steering of launch vehicle and rapid variation of dynamic pressure around launch vehicle are usually propagate into launch vehicle and excite the on boarding satellite. These excitation forces are usually very low frequency less than 100 Hz and must be considered in the primitive design stage of satellite's primary and secondary structures. Although these forces exist in broad spectral band, most of components except the resonance frequency of launch vehicle are chopped because of the filtering effect of launch vehicle itself. The fundamental resonance of launch vehicles are usually different along with different type. They usually start from around 10 Hz at the initial take-off stage and are slowly increased due to its mass reduction caused by propellant consumption and abrupt stage separation. Thus, sine vibration test to check the mechanical strength of satellite must be performed from 5 or 10 Hz up to one hundred Hz to reflect the real launch environment. The designing of acceleration level usually comes from the statistical values, such as an average and standard deviation value if there are affluent flight careers. However, for the case of first flight or only a few data are available, an analytical approach, such as coupled load analysis between satellite and launch vehicle is performed to estimate the acceleration level. Test engineer usually adds up several margin to accommodate the uncertainties of analysis results[2]. Secondly, gigantic noise up to 150 dB encompasses the vehicle during launch period and penetrates into a payload fairing and causes high frequency vibration of satellite itself and on boarding components[3]. Some vehicles adopt an acoustic barrier to reduce the interior noise level, but very limited areas are allowed. Thus the interior of payload fairing becomes an acoustic reverberant chamber, which keeps an uniform high acoustic sound level. This noise component exists up to several thousand Hz and causes fatigue failure of control, telecommunication and optical equipment, which are vital to spacecraft mission. Generally noisy environment is dramatically reduced after passing trans-sonic, which takes about 1 or 2 minutes from take-off, so acoustic test is usually performed during a same period. Finally, stage separation of vehicle itself, spacecraft separation from vehicle and solar array deployment from spacecraft bring a shock phenomena because of the explosion of pyrotechnic device. Although these shock vibrations are occurred during a very short time, these can cause severe effects especially on satellite components. In performing the analysis of shock phenomena, the response of a system to an transient input is usually used rather than being concerned with the complex time history of input itself. Generally shock response spectrum(SRS) consists of peak responses of a set of single degree of freedom mass-damper-spring oscillators that are excited by shock input[4]. Each oscillator is characterized so that their resonance frequencies are logarithmically spaced at integer fractions of an octave(1/3 or 1/6 octave) and resonance gains are same for all of the oscillators(normally $\xi = 5\%$ or $Q = 10$). The duration of shocks are usually ranging from 0.5 to 30 milliseconds.

Fig. 4 Test Setup for Component Vibration Test



(a)



(b)

Fig. 5 Acceleration PSD vs. Frequency Plot. (a) Response at Propulsion Platform. (b) Response at Solar Array.

ENVIRONMENTAL TEST FOR KOREANIZED COMPONENTS OF KOMPSAT-1

Many Korean companies have been participating in the development of KOMPSAT by manufacturing each [illegible]stem boxes. Those are AOCS, EPS, propulsion and [illegible] items of the first Korean multi-purpose satellite. They manufactured and supplied each items to KARI and KARI performed a series of environmental test before installation in order to verify their environmental endurance. Among the launch environment, random vibration test for electronic boxes, sensors and thruster were performed to simulate the high frequency excitation caused by acoustic noise(see figure 4). Only one item, solar array was performed acoustic test because of the difficulty in simulating its environment by vibration test. The test specifications of components mostly came from KOMPSAT heritage, such as SSTI and TOMS-EP. Prior to assemble flight model, OSC, which is a launch vehicle company, performed vibroacoustic coupling analysis of KOMPSAT by using SEA(Statistical Energy Analysis) model and provided the power spectral density of acceleration response at each platform[5] as described in figure 5. Structural engineers compared this result with the test specification applied on koreanized components and finally concluded that applied load was enough to cope with both real flight and recommended minimum workmanship level.

LAUNCH ENVIRONMENTAL TEST OF KOMPSAT-1

During KOMPSAT-1 program, two satellites were made. One is proto-flight model(PFM), which was made for qualifying spacecraft functionally and structurally. It was integrated and tested at TRW, USA. The other one is for real flight, which was integrated and tested at KARI. Integration of KOMPSAT FM started from April of 1998 and ended its whole process completely in June of 1999.

Table 1. KOMPSAT Launch Environment Test Specifications and Configurations

	PFM	FM
TEST CONFIGURATION	● **P/L MASS SIMULATOR (EOC/PDTS/X-BAND ANTENNA)**	● Flight Configuration
VIBRATION TEST ITEMS	● Low Level Random Vibration ● Random Vibration(Flight+3dB) ● Sine Burst Test ● Separation Shock Test ● Acoustic Test(S/A only) - One Wing : 141.8 dB - 2nd Wing : 138.8 dB	● Low Level Random Vibration ● Random Vibration(Flight) ● Acoustic Test(S/A only) - Two Wings : 138.8dB
MASS PROPERTIES MEASUREMENT	● Dry Mass(not included fuel) ● CG(X), CG(Y) ● Static Balancing	● Dry Mass(not included fuel) ● CG(X), CG(Y) ● MOI(Z) ● Static Balancing

Table 2. The result of Natural Frequency Measurements

Mode No	Frequency(Hz) PFM	Frequency(Hz) FM	Description
1	40.2	42.5	1st Bending
2	40.7	43.5	1st Bending
3	70.7	75.0	Nadir Platform
4	**72.4**	**60.8**	**Payload Platform**
5	77.2	75.0	Propulsion Platform
6	88.6	87.8	Central Platform

KOMPSAT system launch environment test was performed with mechanical vibration tests, separation shock and mass properties measurements. And these tests were done with PFM and FM separately as described in Table 1. The KOMPSAT system vibration test series consisted of pre- and post- low level random vibration, sine burst vibration, flight random vibration and solar panel acoustic test. Sine sweep vibration test was not performed because KOMPSAT does not have large scaled secondary structure or payloads, which may severely interact with primary structure while launching. The low level random vibration test was run to measure transfer functions up to 100Hz(X and Y axes) and 150Hz(Z axis) in order to verify the fundamental frequency requirements of spacecraft – KOMPSAT was designed to the natural frequencies higher than 35Hz in axial and 20Hz in lateral direction – and to tune the modal frequencies of the KOMPSAT finite element model. This test was performed before and after the main vibration test to check whether there is any damage in spacecraft due to environmental test. The measurement results of KOMPSAT natural frequencies is described in the Table 2.

The sine burst test was run to verify the strength of the primary structural members under 110% of the worst case launch loads of the Taurus launch vehicle.

Specification

Weight : 500 kg

Dimension : 253(H)x134(D)x690(L)cm

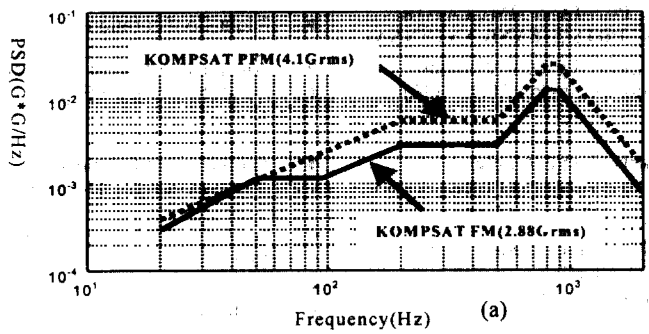
Orbit : 685 km Sun-synchronous

Payload : - EOC
- LRC
- SPS

Launch : 1999

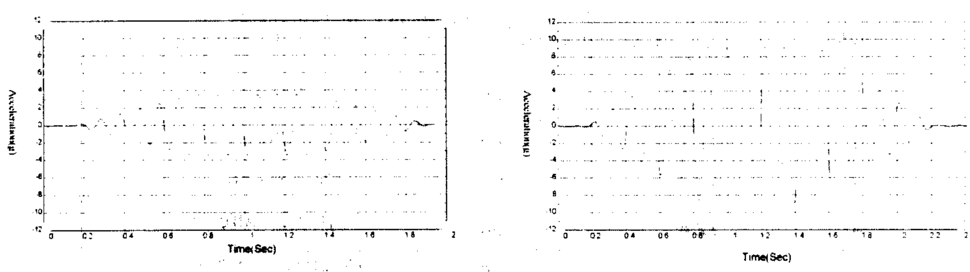
Primary Mission :
- Earth Observation
- Ocean Color Monitoring
- Scientific Experiment

Fig. 6 KOMPSAT –1 Description



(a)

KOMPSAT PFM (1/98)	
2	: .000
20	: .005
50	: .005
80	: .025
88	: .025
200	: .001
KOMPSAT FM (5/99)	
2	: .000
5	: .001
9	: .001
20	: .002
50	: .002
80	: .012
88	: .012
200	: .000



Sine Burst Profile for X & Y Axes(3.4G at 8Hz)

Sine Burst Profile for Z Axes(8.8G at 13Hz)

(b)

Fig. 7 OMPSAT FM Vibration Test Specification. (a) Random Vibration. (b) Sine Burst

Table 3. KOMPSAT Mass Properties Measurements and Balancing Results

Mass Property	Requirements	PFM	FM
		W/ 3 Ballastic Weights (Total 18 lbs on +Y side)	W/ 5 Ballastic Weights (Total 27lbs on +X+Y)
C.G. in X axis (cm)	0.64±0.25	-0.264	-0.196
C.G. in Y axis (cm)	0.64±0.25	-0.645	-0.480
MOI_{zz} (Kg m²)	No Constraint with ± 5.0 %	-	54.289
Mass (Kg)	510kg ± 0.5%	346.929	384.981

Since this test is intended to impose quasi-static load to satellite, test frequency should be less than one-third the satellite resonant frequency to avoid dynamic amplification during test[6]. For KOMPSAT case, 8Hz for lateral and 11Hz for vertical axis were selected as test frequencies. The flight random vibration test was run to qualify the satellite for the launch vibro-acoustic environments and to verify the integration workmanship. Figure 7 describes the KOMPSAT vibration test specifications of sine burst and random vibration.

The random vibration level was controlled with the averaged value of 4 control accelerometers to cope with fixture flexibility, but the sine burst level in all axes was controlled with only one control accelerometer. The satellite was instrumented with 47 response accelerometers; 37s on the platforms and 10s on the solar panels to get the response level and modal information of satellite. When the equivalent random vibration test of an acoustic noise environment is performed with a shaker system, the excitation load is propagated directly to the satellite through the attachment pad rigidly mounted to a shaker. As this test configuration brings a significant over-test to a satellite in some frequencies bands especially at the natural frequencies of the satellite, the satellite components and payloads are possible to be damaged severely. To avoid this phenomenon, the random vibration level was controlled by notching logic. The notching control scheme is an attempt to compensate for the nearly infinite impedance of the mounting plate and follow the real situation as possible by limiting the several acceleration levels of satellite. Structural engineers chose some response accelerometers installed on the place expected to have large response. These responses were fed into vibration control inputs for avoiding the spacecraft damage during the random vibration test.

The mass properties, such as center of gravity, moment of inertia and product of inertia are important parameters to achieve the satellite mission successfully. The dynamic stability of launcher is linked with its payloads mass properties and the satellite itself also would control with exact mass properties in orbit. As KOMPSAT is non-spinning spacecraft, there is no dynamic balance constraint, but the static imbalance directly influences the spacecraft angular rate at separation. According to requirement, spacecraft should be balanced to produce a C.G. within 0.25 cm of its geometric centerline. To put C.G. of satellite into target area, test engineers added some ballast weights as shown in Table 3.

CONCLUSIONS

This paper presents a launch environment test of KOMPSAT and a short description of environment test facilities at Korea Aerospace Research Institute as well. The first Korean multi-purpose satellite was successfully integrated and tested at KARI and Korean engineers got a valuable experience while doing this program.

REFERENCES

(1) Chetty, P.R.K, 1991, *Satellite Technology and Its Applications,* TAB Professional and Reference Books, pp. 345~365.

(2) Coladonato, R.J, 1991, "Derivation of the Sinusoidal Sweep Vibration Levels for the Cosmic Background Explorer," Proceedings of the 13th Aerospace Testing Seminar, pp. 233~239.

(3) Steinberg, D.S, 1982, "Design Guides for Random Vibration," Proceedings of Designing Electronic Equipment for Random Vibration Environments, pp. 13~16.

(4) Szymkowiak, E, 1983, *Optimized Vibration Testing and Analysis,* The Institute of Environmental Sciences.

(5) Webb, C.S, 1997, *KOMPSAT Acoustic Analysis Report,* Orbital Sciences Corporation.

(6) *Sine-burst Load Test,* Goddard Space Flight Center.