Report of Space Qualification Tests

For

AMS-02 Electromagnetic Calorimeter

(AMS-02 / ECAL)

AMS Beijing Group

Feb. 2003

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1. Introduction

This is the report on the space qualification tests of the AMS-02/ECAL structure prototype. The tests include two parts: Random Vibration Tests and Sine-burst Tests. The tests were carried on the B340 shaker in Beijing Institute of Satellite Environment Engineering (BISEE) during Jan. 20-25, 2003.

This report will present the Random Vibration tests and the Sine-burst tests respectively in three orthogonal axes.

In these tests, there are 36 acceleration measurement points with 92 channels in total, and 16 strain measurement points with 48 channels in total on ECAL structure.

The low level Sine Sweep tests were performed before and after each full level Random vibration test and Sine-burst test, in order to verify the dynamic characteristic of ECAL structure and to detect eventual changes caused by the tests.

The conclusion of the tests: the prototype of the ECAL structure is qualified by the Random Vibration tests and the Sine-burst tests.

2. Test objectives

The response data of the strain and acceleration of the ECAL structure during the Tests are used to verify:

1). Tthe endurance of the ECAL system subjected to dynamic environment.

2). Tthe dynamic characteristic of the ECAL system under dynamic environment.

3. Reference Documents

“AMS-02 Structural Verification Plan” JSC-28792

“AMS ECAL Random Vibration Test Outline”

“AMS ECAL Sine-burst Test Outline”

PRACTICE NO.PT-TE-1420 Sine-burst Load Test

4. Test Personnel and Responsibility

4.1 Test Personnel

Title	Responsibility	Name
Test Coordinator	Chief Responsible for test	XIANG Shuhong
Test Technique Conductor	Responsible for the test and specimen handling	YANG Song
Test Control System Conductor	Responsible for the shaker control system	XU Lanju
Test Measurement System Conductor	Responsible for the Dynamic Data measurement	HAN Xiaojian

4.2 Responsibility

BISEE is responsible for

- The test plan and test flow
- The test equipment
- The reliable operation and control of test facility
- The calibration of accelerometers and strain gauges including cabling and installation on the ECAL system and test fixture.
- The data recording/reduction including acceleration and strain curves(some selected measurement points data should be provided after each test)
- The test report with photographs of test installation

IHEP is responsible for

- The test article, test level, test requirement and test outline
- The test performance and handling/transportation of test article
- The international coordination with the ECAL colleagues from LAPP and Pisa., as well as NASA/LM.

Both sides have the responsibility to resolve the technical problems during the tests, and to evaluate the test results.

5. Test condition

5.1 Test article

The test article is the prototype of the AMS-02 Electromagnetic Calorimeter (ECAL), ~~which is composed up by~~comprised of the ECAL Mechanical Structure, Pancake, and PMT Simulators.

The total mass: 570kg + 72kg(non structure mass);

Geometry dimension: 1142mm×1142mm×250mm.

Boundary condition: USS-02 (AMS02 Unique Support Structure) simulator with the mass of 109kg;

Total mass of the ECAL system for the tests: 751kg.

Other detailed information refers to “ECAL Random Vibration Outline”

5.2 Test condition

5.2.1 Random Vibration Test

The random vibration test levels are listed in table 1, and the test duration is 60 seconds per axis.

Table 5.1 Random Vibration Test Levels

Test Direction	Frequency Range(Hz)	Test levels(g^2/Hz)	Grms(g)
X Axis	20-58	0.0025	3.1
	58-125	9dB/oct	
	125-300	0.025	
	300-900	-9dB/oct	
	900-2000	0.001	
Y Axis	20-90	0.008	2.3
	90-100	9dB/oct	
	100-300	0.01	
	300-650	-9dB/oct	
	650-2000	0.001	
	20-45	0.009	
	45-125	3dB/oct	

Z Axis	125-300	0.025	3.2
	300-900	-9dB/oct	
	900-2000	0.001	

5.2.2 Sine-Burst Test

ECAL system will be applied the quasi-static load in the Sine-burst. The frequency of the test excitation source must be much smaller than the fundamental frequency of the ECAL system to avoid the dynamic magnification. A general principle is that the test frequency is smaller than one-third of the fundamental frequency of the test article. The following table lists the Sine-burst test level:

Table 2 Sine-burst Test Level

Test Direction	Frequency （Hz）	Number of Peaks	duration (s)	Test Level (g)
X、Y、Z	17	10	2.7s	12g

5.2.3 Dynamic characteristic Check Test

Before and after each full level dynamic test, the Sine-sweep vibration test should be performed to verify the dynamic characteristic of the ECAL system and the structural integrity. Table 3 is the test condition.

Table 3 Sine sweep vibration test level

Frequency Range (Hz)	Test Level (g)	Sweep Rate (oct/min)
10-300	0.25	2.0

Before the formal test, the system check~~-up~~ out test (0.1g, 10-300Hz, 2oct/min) was carried out to check the measurement system and other test equipment in the normal working status. ~~Afterwards, we can start~~ T~~t~~he formal tests were started after the check out tests.

5.2.4 Control strategy

During the test, the test level will be controlled by the four accelerometers attached close to the fixation points between ECAL and USS-02. This strategy is the so-called ~~the~~

multi-point close-loop control. The average measurement value of these accelerometers is considered as the control result.

In the Sine-burst tests, the strategy is the single point open-loop control method. One of the four accelerometers attached close to the fixation points is used as the control measurement point in vibration test, and the response of ~~another~~ the other 3 accelerometers will be monitored at same time.

5.2.5 Test Precisions

In the random tests:

Spectrum: ±3 dB

Total Grms: ±1.5 dB

Test duration: ±1sec

In the Sine-burst tests and the sine-sweep tests:

Test duration: ±1sec

Acceleration: ≤ ±5%

5.2.6 Boundary Condition

In the vertical tests, the test fixture is connected with the shaker table by 32, M12 Bolts ~~of M12~~.

In the horizontal tests, the test fixture is connected with the shaker table by 36, M12 Bolts ~~of M12~~.

The USS-02 simulator is connected ~~with~~ to the fixture by 40-bolts.

The USS-02 simulator is connected with the ECAL prototype by 8, M16 bolts ~~of~~ ~~M16~~.

The fundamental natural frequency of the fixture should be more than 150Hz, in order to have enough rigidity to reduce the coupling effects on the ECAL structure, and to meet the requirements of the test precisions.

5.3 Measurement points in tests

There are 36 accelerometers with 92 channels and 16 strain gauges with 48 channels

during the Space Qualification tests. These points are showed in figure 1 and figure 2. The photograph of these points are showed in Appendix 1: AMS-02/ECAL Measurement Points Gallery. The measurement uncertainty are:

Acceleration: ±5%

Strain : ±10%

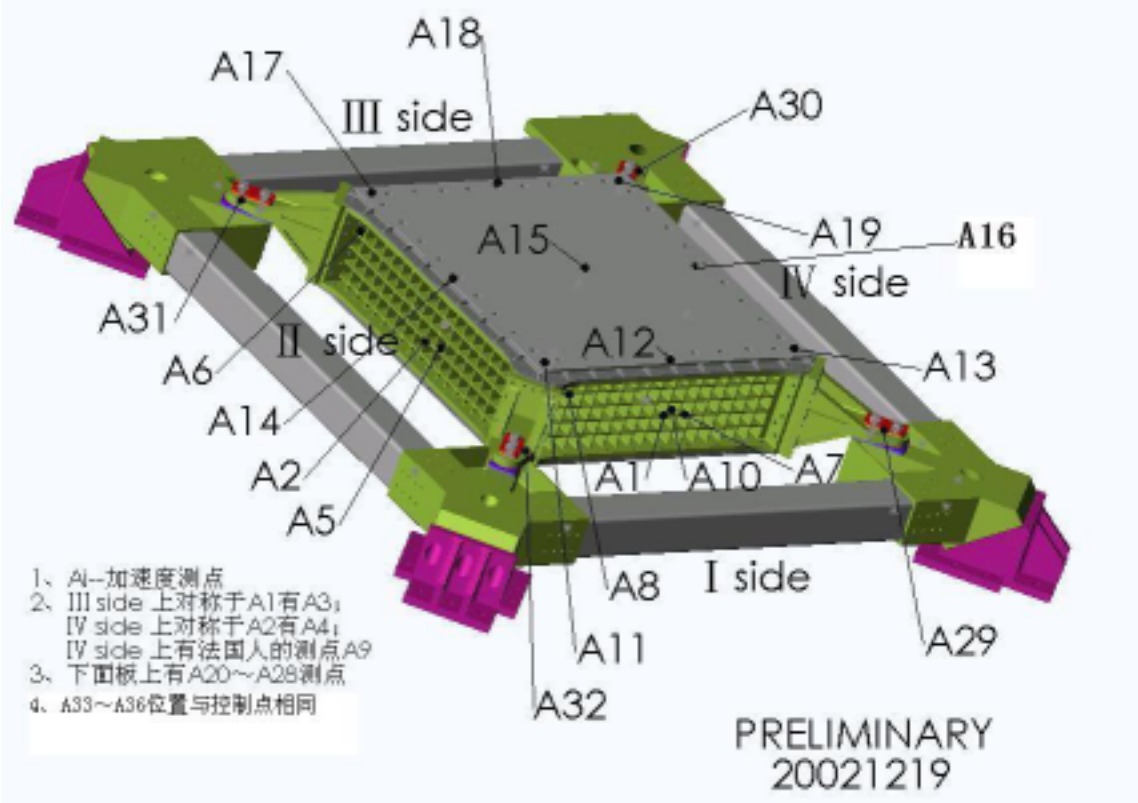


Figure 1 Measurement points for Acceler~~oation~~ meters

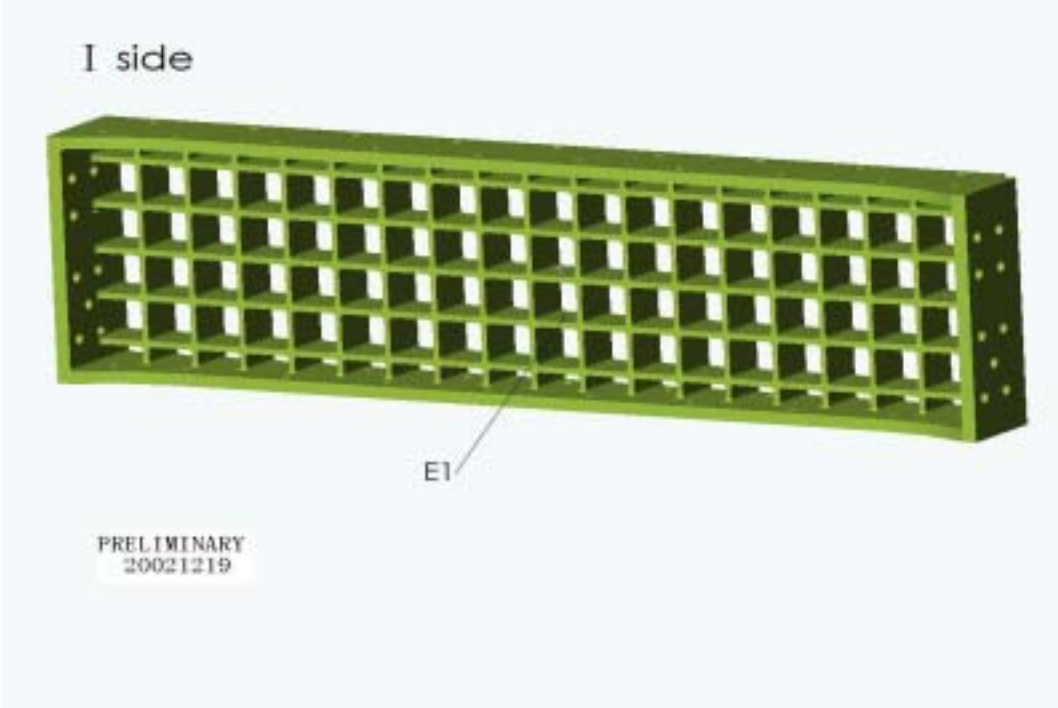


Figure 2a Measurement points for Strain gauges

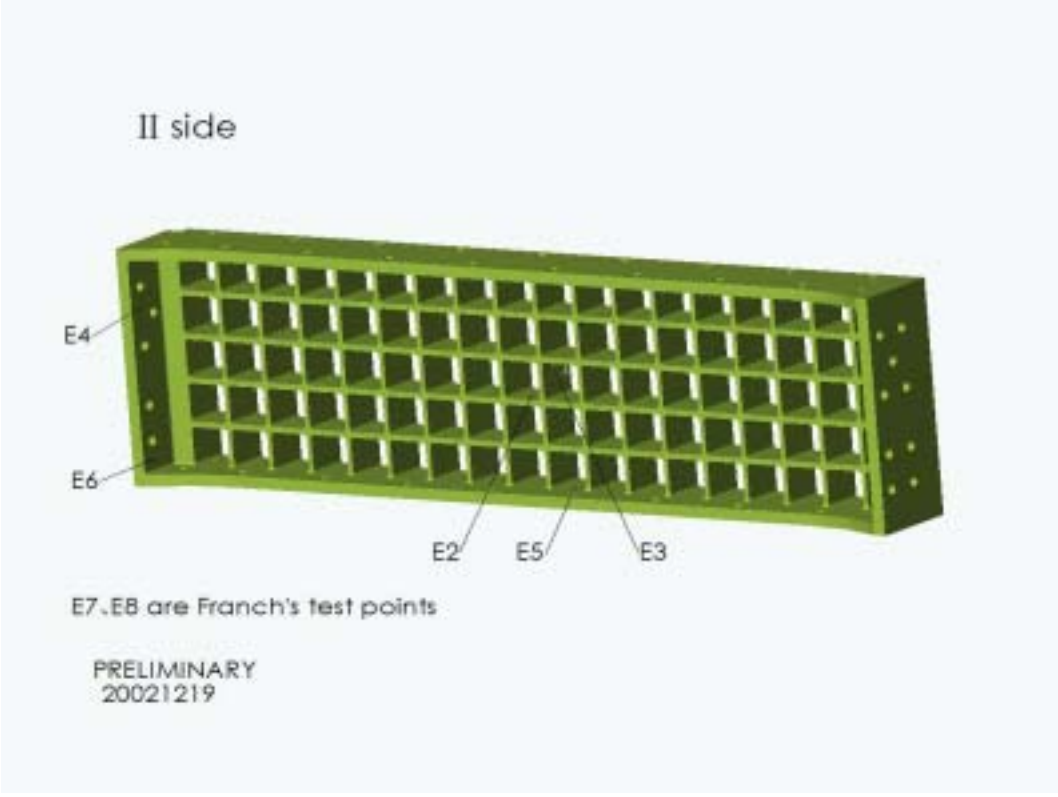


Figure 2b Measurement points for Strain guages

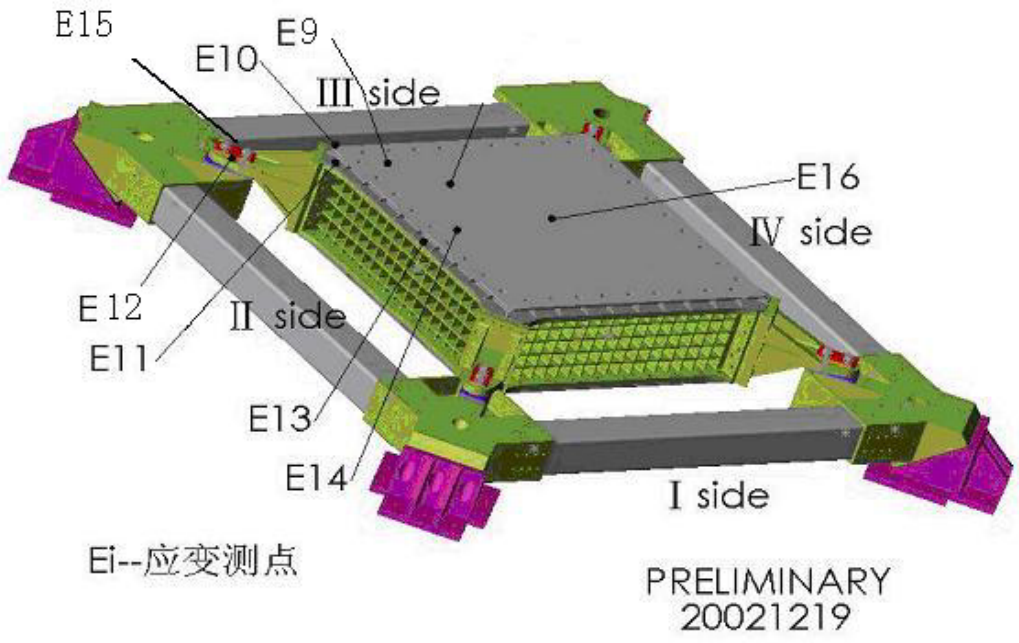


Figure 2c Measurement points for Strain gauges

5.4 Standard Laboratory Ambient Conditions

The laboratory ambient conditions for performing the tests should be specified as below:

— Temperature 20 ±5°C

— Relative Humidity ≤60%

— Atm. Pressure Room ambient (100±10) kPa

— Cleanliness class 100,000

6 Test Method

6.1 Test System Installation

ECAL system is mounted on the shaker table by the test fixture. The installation sketch maps of ECAL system are shown in figure 3 and figure 4.

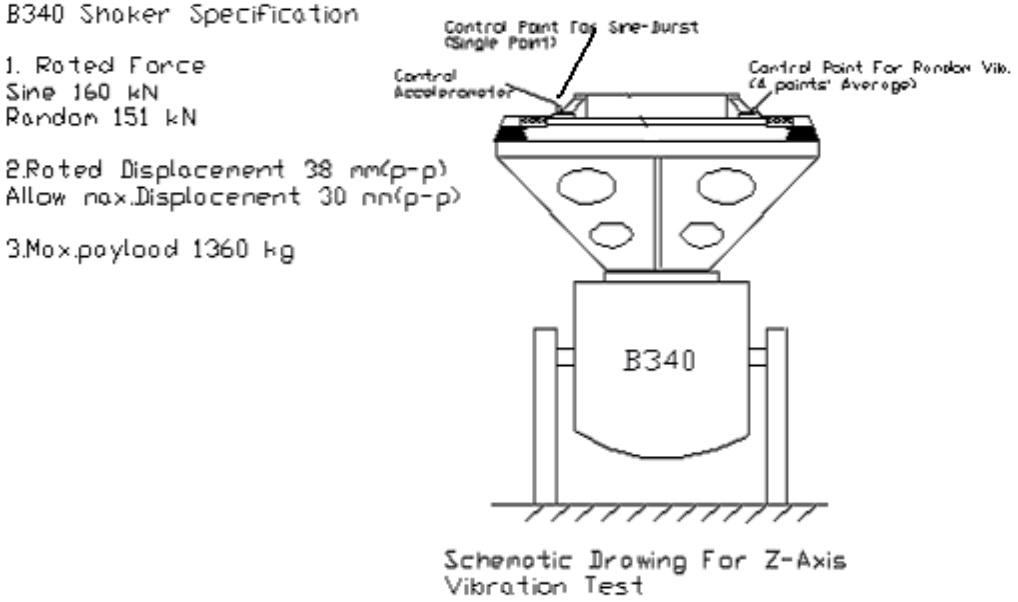


Figure 3 Installation sketch of the test in the Z direction

(shaker system is vertical direction)

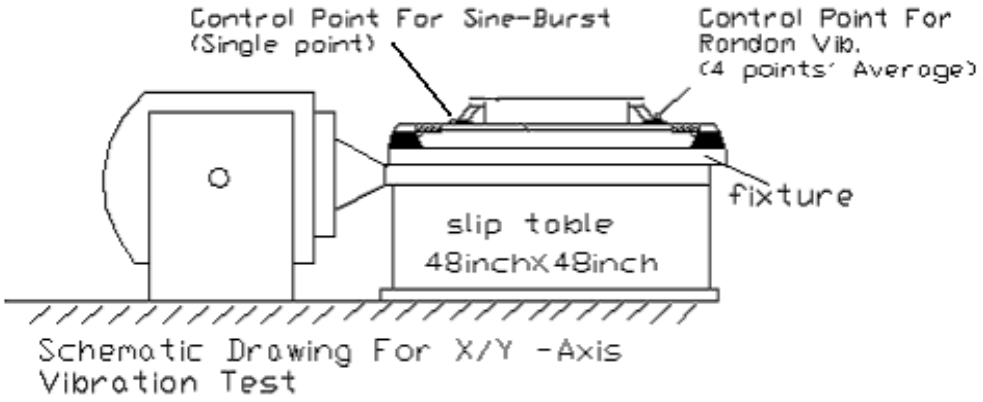


Figure4 Installation sketch of the test in the X direction

(the shaker system is horizontal direction)

Note：In the Y direction test, ECAL system is turned 90 degree around Z axis.

Since the total mass of the active parts on the shaker system (including test fixture) is near the rating mass of shaker in vertical vibration test, therefore, the test article is suspended by spring ropes. The natural frequency of the suspending system should be smaller than 4Hz.

The actual installation pictures are showed in figure 5 and figure 6.

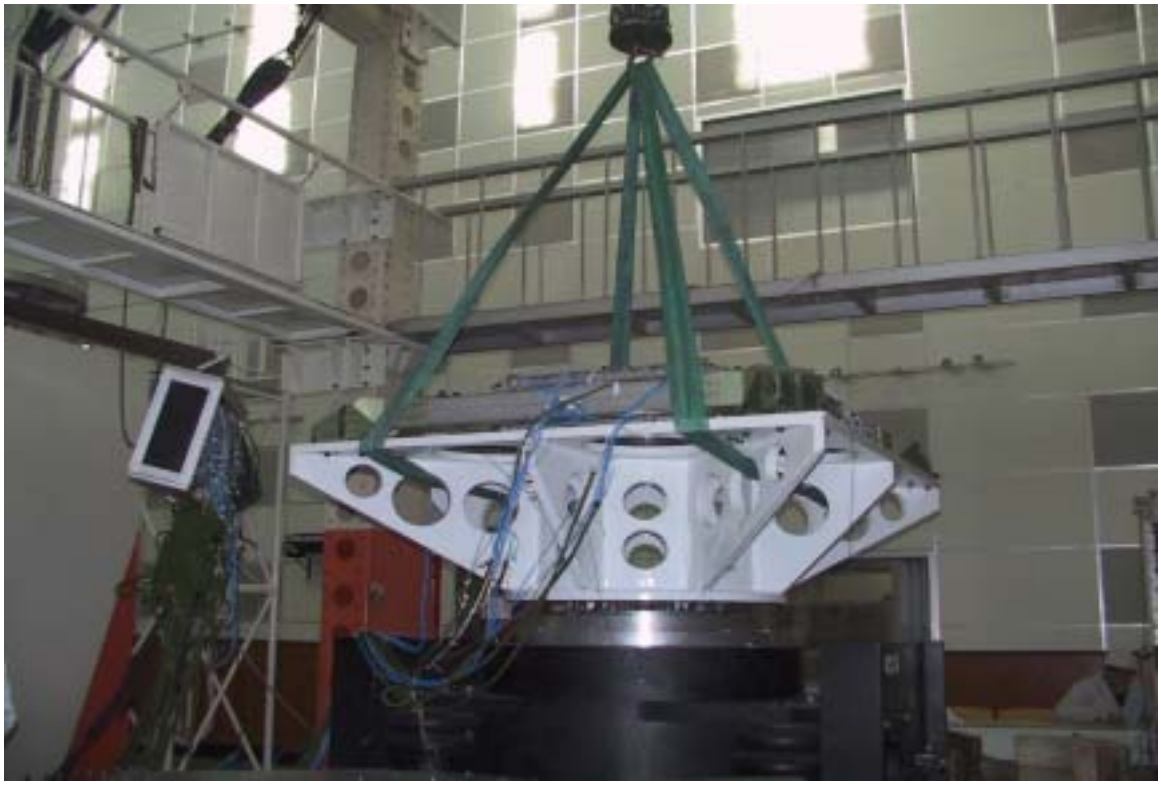
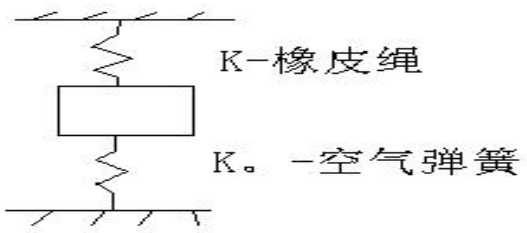


Figure 5　The actual installation in vertical direction

This equation (1) is used to calculate the natural frequency of the ~~suspending~~ suspension system.

$$f_r = \frac{1}{2\pi}\sqrt{\frac{K + K_0}{m}} \qquad (1)$$



K——the elasticity coefficient of the shunt-wound spring ropes, 200000N/m

K_0——the elasticity coefficient of the air springs, 458000N/m

m——the total mass of the active parts, 1412kg

f_r ——the natural frequency of the suspending system,

$$f_r = \frac{1}{2\pi}\sqrt{\frac{200000 + 458000}{1412}} = 3.4 < 4\,Hz$$

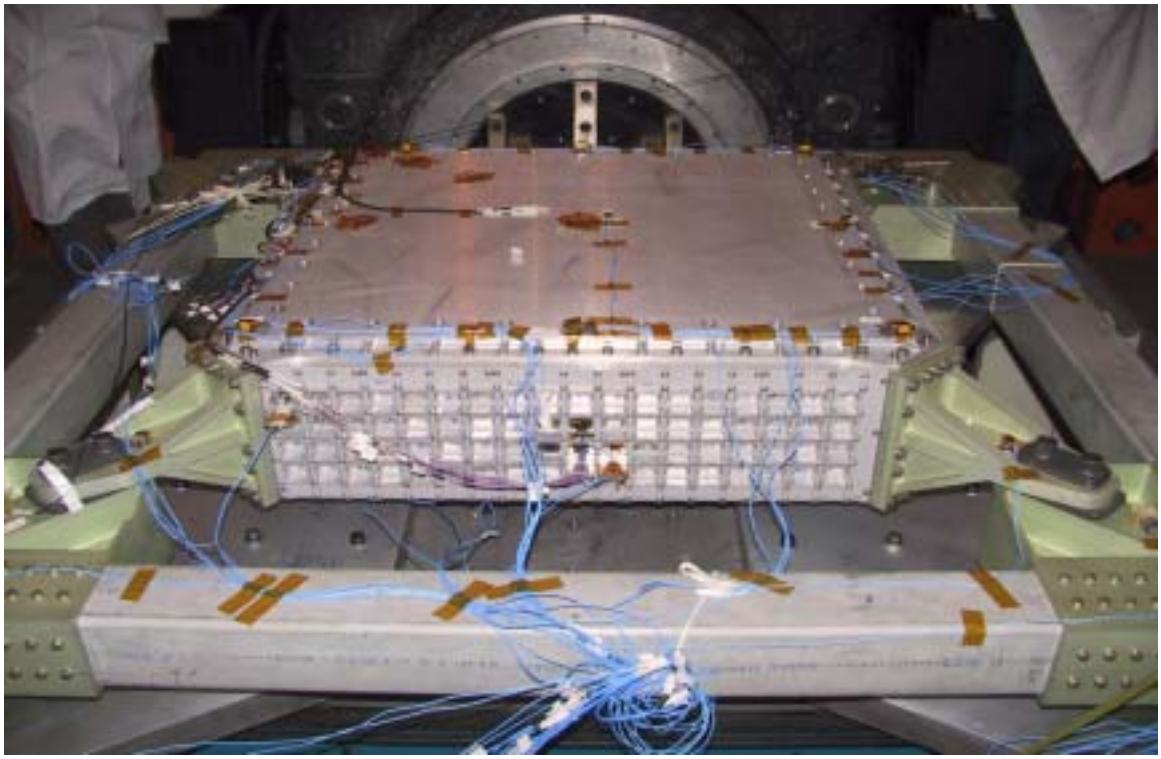


Figure 6 Actual installation in horizontal direction

6.2 Test Equipment and Instrument

The shaker system and measurement system are presented in detail in this chapter. The block diagram configuration for the test system including the shaker, vibration control system, and data acquisition and processing System is shown in figure 7.

Figure8 ~11 are the pictures of the test system.

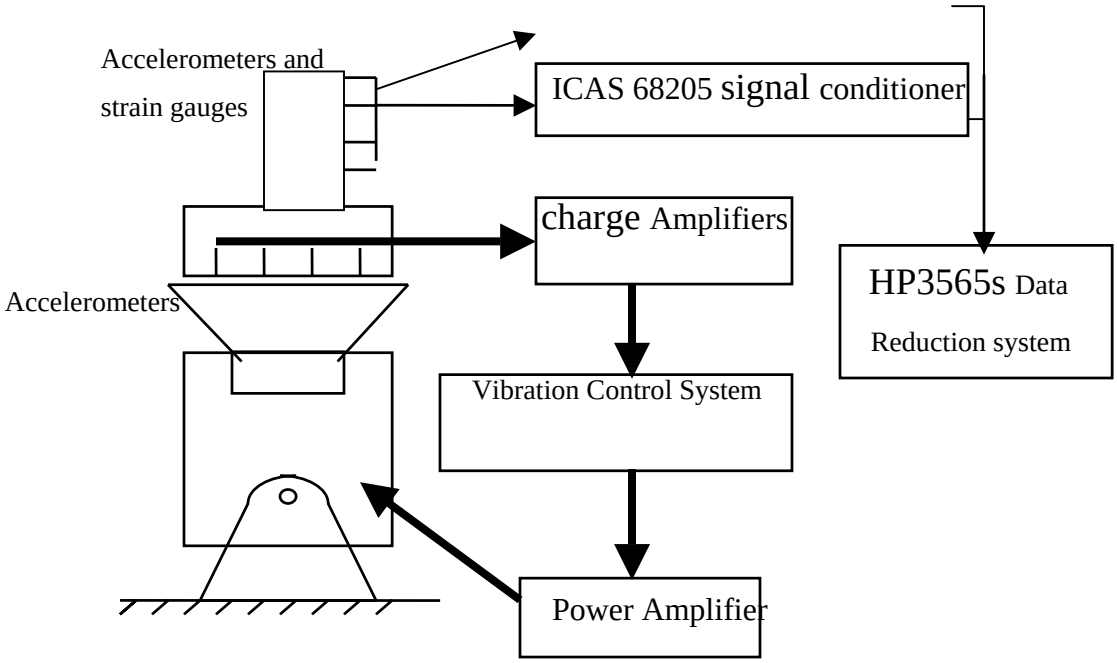


Figure 7 Block Diagram of test System

Figure 8　Control System

Figure 9　Amplifier System

Figure 10　Shaker System

Figure11　Measurement System

6.2.1 Exciting System

Table 4 Exciting System

Type	Name	Producer
B340	Electrodynamics Shaker	U.S.A LING Inc.
SD2560	Vibration control system	U.S.A SD Co.
B&K4383	Accelerometer	Denmark B&K Co.
B&K2626	Charge Amplifier	Denmark B&K Co.

6.2.1.1 Shaker system

The electrodynamics shaker B340 with horizontal slip table is manufactured by LING electronics Inc. which is used in the Random Vibration tests and the Sine-burst tests. The Space Qualification tests in the three orthogonal axes can be performed respectively.

Specification of The B340 shaker system:

- Sine Force: 160kN (Max.)
- Random Force: 140kN(Max.)
- Stroke (p-p): 50mm (Max.)
- Frequency range: 5-2000Hz
- Static load: 1360Kg(Max.)

6.2.1.2 Tests Control System

SD2560 Vibration control System is used, which includes Sine, Random, Classical shock control and Shock Response Spectrum (SRS) control software. The system meets ~~with~~ the requirements of the environmental testing standards such as MIL-STD-810F.

6.2.1.2.1 Random Vibration control

- Up to 8 measurement and control channels.
- Frequency range: up to 20kHz
- Frequency resolution: up to 3200 line
- Multi-point averaging strategy (average, peak, minimum, maximum and

channel weight)

6.2.1.2.2 Sine Vibration Control

- Up to 8 of measurement and control channels;
- Sweep range: 0.1Hz to 10kHz;
- Notching or alarm/abort control is available on any channel;
- Compression speed selectable and adjustable on-line;
- Resonance Dwell: sine control software can lock to a resonance and maintains excitation of that resonance even if the frequency changes with fatigue damage.

6.2.1.2.3 Shock Control

- Up to 8 of measurement channels;
- Classical pulses: half-sine, rectangle, initial peak saw-tooth, terminal peak saw-tooth, symmetric triangle, nonsymmetrical triangle, user defined or extremely measured reference;
- Shock response spectrum.

6.2.2 Measurement System

Table 5 Measurement System

Type	Name	Producer
HP3565s	Data Acquisition and Reduction System	Belgium LMS Co.
ICSA68205	Isotron Computer-Controlled Amplifier System	U.S. Endevoc Co.
365M41	Accelerometer	U.S. PCB Co.
BX120-3AA	Strain gauge	CHINA

6.2.2.1 Data Acquisition & Processing System

HP3565S system acquires the test data up to 80 channels. Two sets of HP3565S systems are used for the test with 160 channels in total.

6.2.2.2 Data processing system

The LMS CADA-X software running on HP9000/700 work stations on the UNIX operating system process measurement data. It comprises a set of the modular programs and provides real-time processing, ~~throughput~~ throughout the acquisition and processing, time/frequency domain analysis.

6.2.3 Measurement Instrument

6.2.3.1 Accelerometers

The acceleration responses of the ECAL system are measured by ICP piezoelectric accelerometers. One accelerometer can measure the responses with three orthogonal axes simultaneously.

6.2.3.2 Strain Gauges

Strain gauges are used to measure the strains ~~to analysis~~ at various locations on the structure ~~deformation in~~ during the test. One strain gauge can measure the responses with three directions simultaneously.

6.3 Sine-burst Test Control Theory

The Sine-burst test is a transient vibration test. It will be implemented in the shock module of SD2560 vibration control system ~~. The test~~ like~~s~~ ~~a~~the shock test. The reference waveform is imported from a data file that is written in UFF format (type 58) before test.

6.3.1 Waveform Equation

The sine-burst waveform should consist of a sinusoid with a ramp up to the maximum level, several cycles at the maximum level, and then a ramp down to zero. The number of cycles at maximum level should be ten. The ramp up and ramp down should consist of at least fifteen cycles each. The equations of Sine-burst list as follows：

$$\begin{cases} y = \dfrac{2A}{(\tau - \tau_1)} t \sin(2\pi f t) & t \le (\tau - \tau_1)/2 \\ y = A\sin(2\pi f t) & (\tau - \tau_1)/2 \le t \le (\tau + \tau_1)/2 \end{cases} \quad (2)$$

$$y = \frac{2A}{(\tau - \tau_1)}(\tau - t)\sin(2\pi f t) \qquad (\tau + \tau_1)/2 \le t \le \tau$$

$$y = 0 \qquad t \ge \tau$$

note：A——Peak level（g）；

τ——duration for pulse applying load（s）；

τ_1——duration when pulse applying load with maximum level（s）；

f——sine frequency when applying load （Hz）。

6.3.2 Waveform Synthesis

Since the waveform equations have been derived, ~~and to produce~~ the data file ~~that~~ will be transferred to control system~~, .~~ ~~this~~ This practice has been done to synthesize the waveform using a program with PC. The data format is UFF that is required for SD2560 system. And the sample frequency is 512. The choices of the parameters used in the equation are as follows:

A = 13.7g；

f = 17Hz；

τ = 2.7s（duration of appl~~l~~ying load）；

τ_1 = 0.5882s（Number of cycles at maximum level is 10）。

6.3.3 Applicability test

After the waveform data file was imported into the shaker control program, several pre-tests were performed during September-November 2002.

Firstly, a closed-loop debugging was run to check the system.

Then, Sine-burst pre-tests were run without payload, and with payload.

The total mass of payload was 1100kg for pre-test.

Four accelerometers were positioned around the shaker table, one was taken as the control point, 2 of others are the measurement points, and another accelerometer was also positioned on the shaker body in order to monitor its relative displacement.

The control system records the control waveform and the response waveforms at the full level tests (0dB). The results of these tests demonstrated that the shaker/control system could ~~assume~~ be used for the Sine-burst tests.

6.3.4 Safety Guarantee

Since sine-burst test is an open-loop test, it cannot control test levels in real time. In order to prevent over-shocking as well as to protect the shaker and the ECAL system from damage, some ~~steps should be obeyed~~precautions should be taken.

a. The test facilities including shaker and slip-table should be in good conditions (include electricity and mechanism) before formal test.

b. Before the ECAL system was mounted, a pre-test should be done with payload in order to ensure that the shaker/control system is in normal working ~~status~~condition.

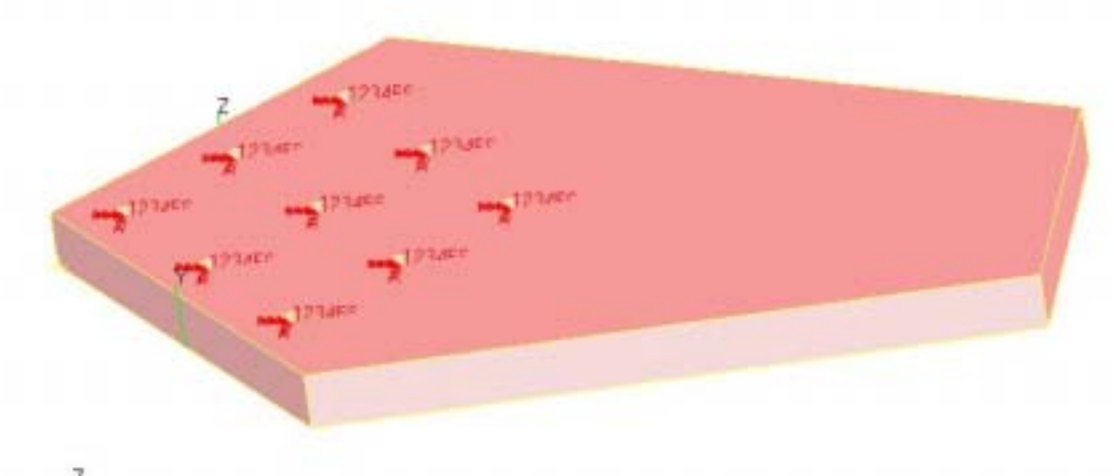
c. After the control system has completed the self-check, the drive voltage and current should be checked.

d. The waveform should be monitored to ensure that the total system is normal.

6.4 The Fixture Design

The Fixture is used to transfer the load to the test article in the ECAL Space Qualification Test, so that the test article can be verified ~~in~~ to the specified test levels. Since t~~T~~he performance of the fixture will affect the dynamic test result. ~~Reasonable~~ the proper design~~ing~~ of the fixture is ~~an important job~~very important.

Considering the actual capacity of the shaker system, we designed two sets of fixtures: one is the horizontal fixture, and the other is the vertical fixture. These fixtures are shown in figure 12.



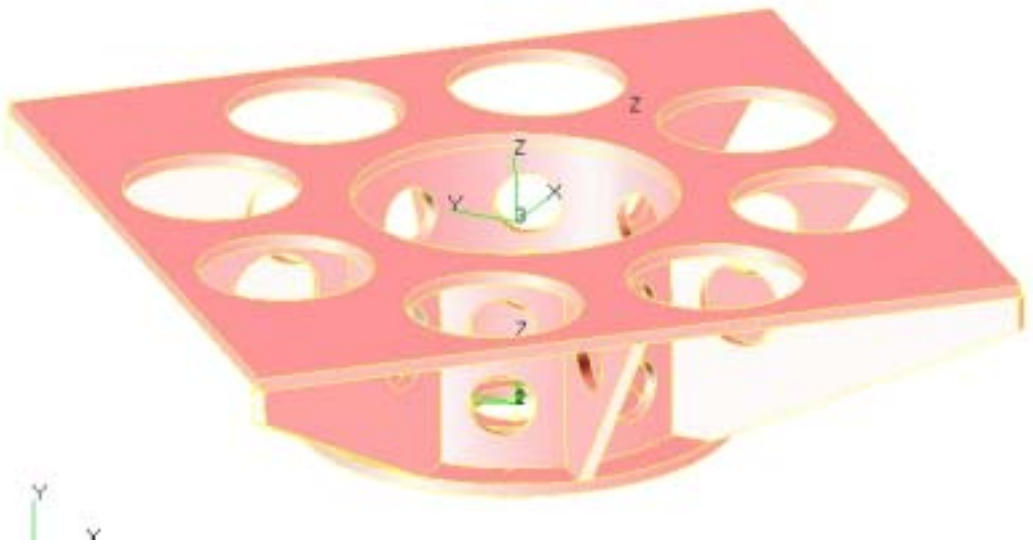


Figure 12　Horizontal Fixture and Vertical Fixture

The natural frequencies of the vertical fixture and the horizontal fixture are computed by NASTRAN analysis software.and the analytical ~~The~~ results ~~is~~ are shown in table 6.

The natural frequencies ~~test results~~ of the two sets of the fixtures based on tests are listed in table 7, and the curves are shown in Figure 13, ~~which~~ for the serial numbers ~~is~~ Ecal-fixture.006 and HTQH.013 respectively.

In table 8, shows the results of the ~~are the~~ natural frequencies of the fixture and the ECAL ~~simulative~~ simulated mass.

Table 6　The natural frequencies of the fixtures from NASTRAN

Mode No.	Frequencies of horizontal fixture （Hz）	Frequencies of vertical fixture（Hz）
1	155.3	197.0

Table 7　The natural frequencies of the fixtures from the test

Mode No.	Frequencies of horizontal fixture （Hz）	Frequencies of vertical fixture（Hz）

1	155.0	204.3

Table 8 The natural frequencies of fixtures (with ECAL ~~simulative~~ simulated mass)

Mode No.	Frequencies of horizontal fixture （Hz）	Frequencies of vertical fixture（Hz）
1	90.3	169.2

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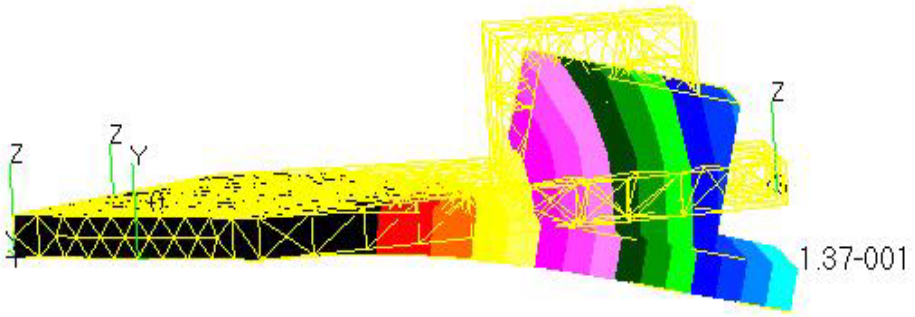
Fringe: SC1:DEFAULT, A1:Mode 1 : Freq. = 90.281: Eigenvectors, Translational-(NON-LAYERED) (MAG)

Deform: SC1:DEFAULT, A1:Mode 1 : Freq. = 90.281: Eigenvectors, Translational



:1:DEFAULT, A1:Mode 7 : Freq. = 169.24: Eigenvectors, Translational-(NON-LAYERED) (MAG)
C1:DEFAULT, A1:Mode 7 : Freq. = 169.24: Eigenvectors, Translational

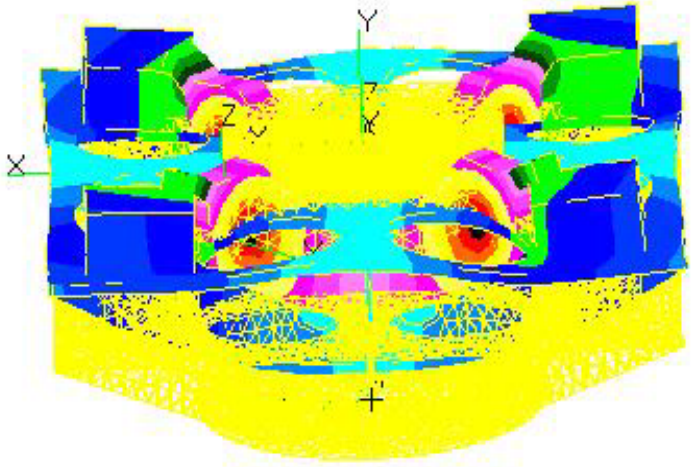


Figure 13 The natural frequencies of fixtures (with ECAL ~~simulative~~ simulated mass)

7 Test flow

The test flow is as follows:

7.1 Test preparation.

7.2 Before Jan. 20, 2003, the accelerometers and the strain gauges have been mounted on the ECAL.

7.3 Before Jan 20, 2003, the fixtures in the different directions have been tested respectively and the shaker system for the horizontal direction has been prepared.

7.4 ~~On~~ Jan 21, 2003, ~~the~~ performed random vibration test in the X direction of the ECAL system

a. ~~Installing~~ Installed the ECAL system on the shaker;

b. S~~s~~etup the measurement system and check it by the Sine-sweep test with the level of 0.1g between 10Hz~100Hz;

c. ~~finish~~ Completed the first X direction sine-sweep test(resonance search) with the level of 0.25g between 10Hz~300Hz;

d. evaluated test results;

e. ~~finish~~ Completed the X direction random vibration test with the level of 3.1g;

f. ~~finish~~ Completed the second X direction sine-sweep test (resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz;

g. ~~finish~~ Completed, data Processing, checking the ECAL system and ~~evaluate~~ evaluation of test results.

7.5 ~~Morning~~ Jan 22,2003, Performed the Random vibration test in Y direction of ECAL system

a. installed ECAL system on the shaker;

b. S~~s~~etup the measurement system and check it by sine-sweep test at ~~with the level of~~

0.1g between 10Hz~100Hz.

c. ~~finish~~ Completed the first Y direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz.

d. ~~finish~~ Completed the Y direction random vibration test with ~~the level of~~ 2.3g.

e. ~~finish~~ Completed the second Y direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz.

f. ~~finish~~ Completed, data processing, checking the ECAL system and ~~evaluate~~ evaluation of the test results.

7.6 Prepared the shaker system for the vertical direction tests

7.7 ~~On~~ Jan 22, 2003, Performed the Random vibration tests in the Z direction of the ECAL system

a. installed the ECAL system on the shaker；

b. ~~s~~setup the measurement system and check it by sine-sweep test ~~with the level of~~ 0.1g between 10Hz~100Hz.

c. ~~finish~~ Completed the first Z direction sine-sweep test(resonance search) at~~with the level of~~ 0.25g between 10Hz~300Hz.

d. ~~finish~~ Completed the Z direction random vibration test with the level of 3.2g.

e. ~~finish~~ Completed the second Z direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz.

f. ~~finish~~ Completed, data processing, checking the ECAL system and ~~evaluate~~ evaluation of the test results.

7.8 ~~On~~ Jan 24,2003, Performed the Sine-burst test in Z direction of ECAL system

a. C~~c~~heck the measurement system by sine-sweep test with the level of 0.1g between 10Hz~100Hz.

b. ~~finish~~ Completed the first Z direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz.

c. ~~finish~~ Completed the Z direction sine-burst test ~~with the level of~~ at 12g at17Hz.

d. ~~finish~~ Completed the second Z direction sine-sweep test(resonance search) ~~with~~

~~the level of~~ at 0.25g between 10Hz~300Hz.

e. ~~finish~~ Completed, the data processing, checking the ECAL system and ~~evaluate~~ evaluation of the test results.

7.9 Prepared the shaker system for the horizontal direction tests.

7.10 ~~On~~ Jan 25, 2003, Performed the Sine-burst test in X direction of ECAL system

a. C~~c~~hecked the measurement system by sine-sweep test ~~with the level of~~ at 0.25g between –10Hz~100Hz.

b. ~~finish~~ Completed the first X direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz.

c. ~~finish~~ Completed X direction sine-burst test ~~with the level of~~ at 12g at17Hz.

d. ~~finish~~ Completed the second X direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz.

e. ~~finish data~~Completed, Processing, checking the ECAL system and ~~evaluate~~ evaluation of test results.

7.11 ~~On~~ Jan 25,2003, Performed the Sine-burst test in Y direction of ECAL system

a. C~~c~~hecked the measurement system by sine-sweep test ~~with the level of~~ at 0.1g between 10Hz~100Hz.

b. ~~finish~~ Completed the first Y direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz.

c. ~~finish~~ Completed the Y direction sine-burst test ~~with the level of~~ at 12g at17Hz.

d. ~~finish~~ Completed the second Y direction sine-sweep test(resonance search) ~~with the level of~~ at 0.25g between 10Hz~300Hz..

e. ~~finish~~ Completed data Processing,and checking the ECAL system .

7.12 ~~On~~ Jan 25,2003, test evaluation

7.13 Wrap up all testing.

8 Test preparation

8.1 Pre-test in vertical direction

8.1.1 Installation of the simulator ：

Two test fixtures were used to simulate the formal tests on December, 2002. One fixture will be used in the ECAL dynamic test with the mass of 420kg, the other is used in AMS-01 dynamic test with the mass of 830kg.

In fact, the total mass of the ECAL system with four linkers is about 792kg.

8.1.2 Pre-test loading factors

a) Random pre-test: according to the formal test condition, ~~the random test~~ was done. The control curve is shown in figure 18, ~~which~~ identifying that the serial number is AMS- Z.012

In the control graph, there is an over-error about 800Hz. ~~According~~ compared to the analysis,

the over-error is caused by the rubber slice between two fixtures conjunction parts.

Before the formal tests, the ECAL system was used to check the total system,– to show which test level was the half of the maximum.

The control curve ~~can~~ was able to meet the requirement of the Test.

The control curve is shown in figure 19, which serial number is AMS- Z.017 b) b)

b) Sine-burst test: the test level was 12g(17Hz). The steps were -20dB, -12dB, -9dB, -6dB, -3dB, –-2dB, -1dB, -0.5dB, 0dB. All of these tests were finished without any interruption. In the full level test, the maximum drive current of one amplifier is 450A（the full drive current is 500A. After this test, -0.5dB test was ~~finished~~ done twice~~) again~~.

The control curve is shown in figure 20, which serial number is 998.015

8.2 Pre-test in horizontal direction

8.2.1 Install simulator

Two test fixtures were used to simulate the formal test in December, 2002. The

horizontal fixture is made of 4 pieces. ~~which~~ The total mass is 200kg, the other is used in AMS-01 dynamic test which mass is 830kg.

In fact, the total mass of ECAL system with four linkers is about 792kg.

8.2.2 Pre-test loading factors

a) Random pre-test: according to the formal test condition, the random test was run. The control curve is shown in figure 21,which serial number is AMS- XZ.002

The control curve ~~can meet~~was able to meet the test requirement.

b) Sine-burst test, the test level was 12g(17Hz). The steps were -20dB, -12dB, -9dB, -6dB, -3dB,~~–~~ -2dB, -1dB, -0.5dB, 0dB. All of these tests were finished without any interruption. In the full level test, the maximum drive current of one amplifier is 500A （the full drive current is 500A）. After this test, 0dB test was ~~finished~~ done again.

The control curve is shown in figure 22, which serial number is 998.024

8.3 Summary on the Pre-tests

In conclusion, these equipment and instruments in BISEE that are described in this document can meet the requirement of ECAL system dynamic test.

9 Check-up for system quality before formal test

Before the formal tests, the check-up for the system quality is necessary. The results are listed in table 9.

Table 9 Check-up table

Test	ECAL environment test		
Item	Content	Result	Inspector
Test staff	Qualification for test	Meet requirement	Xiang Shuhong
Documents	Test procedure	OK	Xu Lanju
	Test qualification outline	OK	
	Test record table	OK	
	Test plan	OK	
Equipments	Control system	In good condition and in the period of efficiency	Xu Lanju Han Xiaojian Xiao Jinghua
	Amplifier system	In good condition and in the period of efficiency	
	Shaker system	In good condition and in the period of efficiency	
	Measurement system	In good condition and in the period of efficiency	
Safety	Power	OK	Zhou Derong
	Fireproof	OK	
Environment of the chamber	Temperature	17℃~22℃（the detail data in every day recorder）	Zhu Zihong
	Relative Humidity	30%~40% （the detail data in every day recorder）	
	Cleanliness class	Lower than 100,000 degree（the detail data in every day recorder）	
The protection of trouble in the test	OK		Yang Song
The condition of ECAL system	OK		Lu Yusheng
Final approval for test	Xiangshuhong		

10 Formal test

10.1 Random vibration test in X direction

On January 21, 2003, the pre-tests were finished.

The shaker is ready for the horizontal tests.

The ECAL system is installed on the shaker (Figure 6 is shown system in X direction).

Four control accelerometers are located on the joints between the ECAL and USS-2 respectively.

Figure 14 is the sketch map of the location of 4 control accelerometer points.

Figure 15 shows one control accelerometer at the system. The location of the control points in Y and Z direction test are as the same as these in X direction.

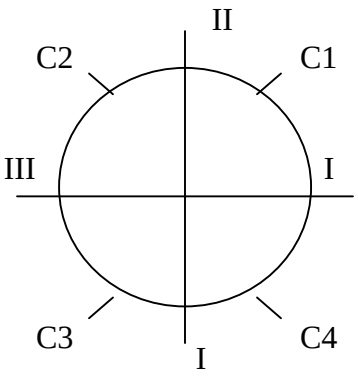


Figure 14: sketch of the location of 4 control accelerometer points.（topview）

After the measurement cables are connected and the ~~bolt~~-checking of the bolt torque is finished (the torsion moment is 90Nm), the random test is started according to the technique requirement of the X direction test. The procedure is as follows:

a. 0.1 g sine-sweep test to check the measurement system and the test facility;
b. The first dynamic characteristic Check Test (0.25 g);
c. Random test (3.1 grms);
d. The second dynamic characteristic Check Test (0.25 g);

In the test with 0.1g for checking measurement system, there are two bad channels. The technicians checked these two channels carefully. They ~~find~~ found these channels

can’t be repaired. So after ~~discussed~~ discussion with experts of LM and IHEP, A7z and E4z ~~are~~ were cancelled.

All tests in X axis are finished without any interruption. The control curves ~~are right~~were correct. ~~The control result~~ and ~~meets~~ met the requirement. The measurement result is valid. The measurement data in the first and in the second characteristic class test overlaps. The result of test evaluation ~~is~~ indicated that there ~~is~~ was no~~t~~ damage ~~with~~ to theECAL structure~~.~~and there was no change to~~The~~ the bolt torque ~~of bolt checking shows no changes~~.

The natural frequency of the system in X direction ~~is~~ is roughly 88 Hz.

The maximum acceleration and strain response values of the ECAL system in the X direction are shown in table 10.

Table 10 the value of some measurement points

Measurement point	Value
A22x	3.5293 grms
A31x	4.1739 grms
E14s(45°)	33.973 με
E3y	25.966 με

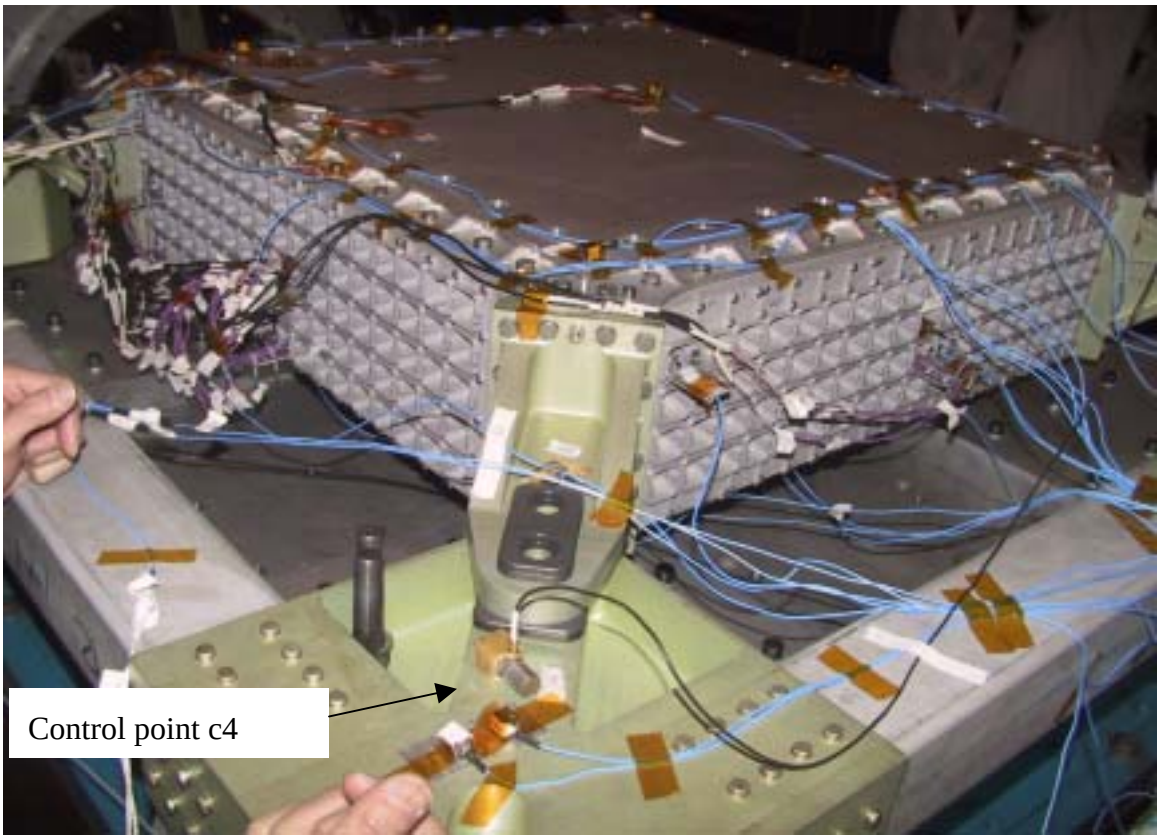


Figure15 control point C4

10.2 Random vibration test in Y direction

On January 22, 2003, the shaker is ready for the horizontal tests. The ECAL system is installed on the shaker. Four control accelerometers are located on the joints between the ECAL and USS-2 respectively. After the measurement cables are connected and the ~~torque of~~ bolt torque ~~checking~~ checks are finished, the random test is started according to the technique requirement in Y direction test. The procedure is as follows:

a. 0.1 g sine-sweep test to check measurement system and test facility;

b. The first dynamic characteristic Check Test (0.25 g);

c. Random test (~~3.1~~2.3 grms);

d. The second dynamic characteristic Check Test (0.25 g);

All tests in Y axis are finished without any interruption. The control curves are right. The control result meets the requirement. The measurement result is valid. The measurement data in the first and the second characteristic class test overlaps. The result of test evaluation shows that there is no damage ~~with~~ to the structure. The torque

~~bolt~~-check~~ing~~ for the bolts ~~torque~~ shows there are no changes ~~with~~ to the torque values.

The natural frequency of the system in Y direction is roughly 86 Hz.

The maximum acceleration and strain response values of the ECAL system in Y direction are show in table 11.

Table 11 the value of some measurement points

Measurement point	Value
A5z	4.5681 grms
A32y	3.8022 grms
E14y	31.72 με
E7z	28.003 με

10.3 Random vibration test in Z direction

On January 22, 2003, the shaker is ready for the vertical test. The ECAL system is installed on the shaker. Four control accelerometers are located on the joints between the ECAL and USS-2 respectively. After the measurement cables are connected, the measurement system and the torque ~~value of~~ for the bolt~~s~~-~~checking~~ checks is finished, the random test is started according to the technique requirement of Z direction test. The procedure is as follows:

a. 0.1 g sine-sweep test to check the measurement system and the test facility;
b. The first dynamic characteristic Check Test (0.25 g);
c. Random test (3.2 grms);
d. The second dynamic characteristic Check Test (0.25 g);

All tests in the Z axis are finished without any interruption. The control curves are right and the control result meets the requirement. The measurement result is valid. The comparison of measured responses in the first and in the second characteristic class test shows that there are a shift that value is about 1.5 ～ 2 Hz, which is less than 3%, and can be acceptable. The natural frequency of the system is from 66Hz to 64.1Hz. The result of the test evaluation is that there ~~are~~ is no damage ~~with~~ to the structure. The torque ~~of bolt~~-check~~ing~~ for the bolts shows ~~the value meets the requirements~~that there is no change to the torque values.

The natural frequency of the system in the Z direction is roughly 66 Hz.

The maximum acceleration and strain response value of the ECAL system in the Z direction are shown in table 12.

Table 12 the values of some measurement points

Measurement point	Value
A6z	5.3377 grms
A24z	5.0832 grms
A31z	4.1668 grms
E14x	94.05με
E6z	57.674με

10.4 Sine-burst test in Z direction

On January 24, 2003, the shaker is ready for vertical test. The ECAL system is installed on the shaker. Four control accelerometers are located on the joints between the ECAL and USS-2 respectively. After the measurement cables are connected, the measurement system and the ~~torque~~ of bolt torque-check~~ing~~ is finished, the sine-burst test is started according to the technique requirement of Z direction test. The procedure is as follows:

a. 0.1 g sine-sweep test to check measurement system and test facility;
b. The first dynamic characteristic Check Test(0.25 g);
c. Random test(12g,17Hz);
d. The second dynamic characteristic Check Test(0.25 g);

During Sine-burst test in –3dB, which is 70% maximum level, there is a over-flow protection in the amplifier system. After the system is regulated, other tests in Z axis are finished without any interruption. The control curves are right and the control result meets the requirement. The measurement result is valid. The measured response in the first and in the second characteristic class test overlaps. The result of test evaluation is that there ~~are~~ is no damage ~~with~~ to the ECAL Structure. The bolt torque ~~of bolt~~-check~~ing shows the value meets the requirement~~ shows that there is no change to the torque values..

The maximum acceleration and strain response value of the ECAL system in Z direction are show in table 13

Table 13 the value of some measurement points

Measurement point	Value
E14x	255.5με

Data curves of A18z and A20z are a little abnormal. After analysis, it is caused by the cables connection of accelerometers. After checking, the ECAL system is normal.

10.5 Sine-burst test in X direction

On January 25, 2003, the shaker is ready for the horizontal test. The ECAL system is installed on the shaker. Four control accelerometers are located on the joints between the ECAL and USS-2 respectively. After the measurement cables are connected, the measurement system and the ~~torque~~ of bolt torque-check~~ing~~ is finished, the Sine-burst test is started according to the ~~technique~~ requirement of X direction test. The procedure is as follows:

a. 0.1 g sine-sweep test to check the measurement system and the test facility;
b. The first dynamic characteristic Check Test (0.25 g);
c. Random test (12g, 17Hz);
d. The second dynamic characteristic Check Test(0.25 g);

During Sine-burst test in –3dB, which is 70% maximum level, there is the impact between ECAL and USS-02, the control system stopped and the test interrupted. After the system was checked carefully, the Spacer Plates between ECAL and USS-02 had ~~glided~~ slipped obviously. And the surfaces of the Spacer Plates had visible imprints, which are shown in figure 16 and figure 17. The ~~torque~~ of bolt torque-check~~ing~~ showed the torque value were ~~changed, which values were~~ reduced from 90Nm to 60Nm～80Nm. The control curve is shown in figure 25 and figure 26, which serial number is 998.030. The test verifies one of the test objectives, ~~which~~ that the Spacer Plates can move in the sine-burst test. After discussion with experts of LM, the technical condition for the preload has been amended. The torque value (Max.) has been changed from 90Nm to

~~200Nm~~200Nm, which is shown in the technical requisition (see Appendix 6). After the system is regulated, other tests in X axis are finished without any interruption. The control curves are right and the control result meets the requirement. The measurement result is valid. The measured responses in the first and in the second characteristic class test overlaps. The result of test evaluation is that there ~~are~~ is no damage with ECAL structure. The torque of bolt-checking shows the value are changed, which are reduced from 200Nm to168Nm～180Nm. After careful observation, there ~~are~~ was no ~~slide~~ sliding ~~can~~ could be seen. The test results are valid.

The acceleration response value of the ECAL system in X direction is about 13g .

The maximum strain response value of the ECAL system in X direction is shown in Table 14.

Table 14 the value of some measurement points

Measurement point	Value
E14s	356με

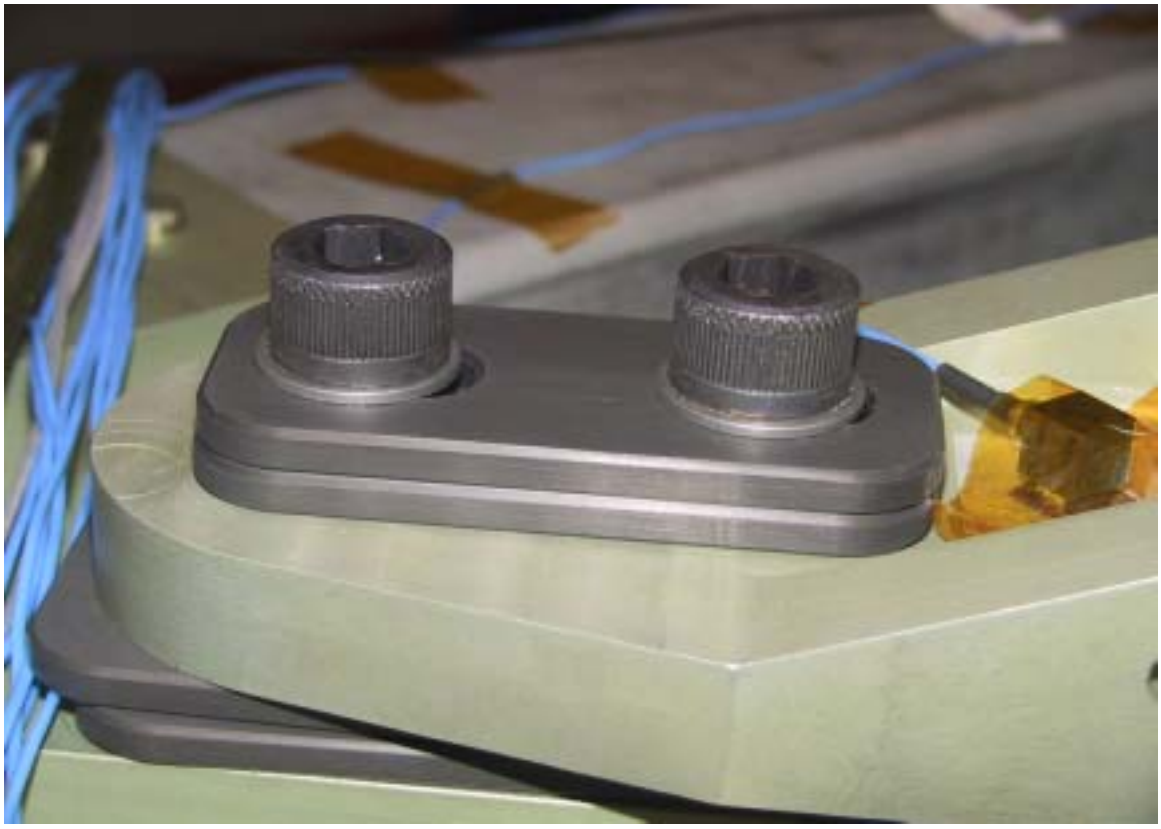


Figure 16　the glided Spacer Plates

图 17　imprints on the Spacer Plates

10.6　Sine-burst test in Y direction

On January 25, 2003, the shaker is ready for the horizontal test. The ECAL system in Y direction is installed on the shaker. Four control accelerometers are located on the joints between the ECAL and USS-2 respectively. After the measurement cables are connected, the measurement system and the torque for bolt torque-check~~ing~~ is finished, the sine-burst test is started according to the ~~technique~~ requirement of Y direction test. The procedure is as follows:

a. 0.1 g sine-sweep test to check the measurement system and the test facility;
b. The first dynamic characteristic Check Test (0.25 g);
c. Random test (12g,17Hz);
d. The second dynamic characteristic Check Test (0.25 g);

All tests in Y axis are finished without any interruption. The control curves are right. The control result meets the requirement. The measurement result is valid. The measured responses in the first and in the second characteristic class test overlaps. The result of test

evaluation concludes that the structure has no change. The ~~torque~~ of bolt torque-check~~ing~~ shows the values meet the requirement.

The acceleration response value of the ECAL system in the Y direction is about 12g.

The maximum strain response value of the ECAL system in the Y direction is shown in table 15. There is zero-moving in E10s in the test.

Table 15 the value of some measurement points

Measurement point	Value
E14s	230με

11 Test result

11.1 Control Result

The control results are shown in Appendix 2.

11.2 Measurement Result

The measurement results are shown in Appendix 3.

11.3 Bolts Torque Checking Table

The torque values of connection bolts are shown in Appendix 4.

11.4 Environment of the chamber

The record of the chamber environment is shown in Appendix 5.

11.5 Requisition of the technical condition for preload

The amendment for technical condition for bolts torque is shown in Appendix 6.

12 The evaluation of the test results

During January 20~25, 2003, the Space Qualification Tests for AMS02/ECAL Structure were carried out on the 16T vibration shaker system in BISEE, which include the Random Vibration Tests and the Sine-burst Tests. The testing has met the Space Requirements (refer to **3. Reference Documents**), the measurement data are correct and valid. The comparison of the sine sweep results-before and after the random vibration tests and the sine-burst, tests shows that the dynamic behavior of the AMS-02/ECAL Structure is not changed. We conclude that the AMS-02/ECAL Structure has been qualified by the random vibration tests and the sine-burst tests.

The test is successful for AMS-02/ECAL Space Qualification.