ICSV14

Cairns • Australia

9-12 July, 2007

14th International Congress on Sound & Vibration

VIRTUAL VIBRATION TEST AND VERIFICATION FOR THE SATELLITE

XIANG Shu-hong, LIU Chuang, Yan Tingfei

Beijing Institute of Spacecraft Environment Engineering,
Yard 1 Road Huayanbeili Chaoyang Beijing 100029, China
xshxsh638@sohu.com

Abstract

The vibration test is import in the satellite development. The virtual vibration test can prefigure the test result. It can be used for the test design and the structure modification of the satellite

Firstly, the finite element model (FEM) is established for the shaker by the stepping up method. The method solved the problem that is the building FEM of the shaker's complex structure and the computer simulate analysis of dynamic response. The shaker has been separated into several substructures. The FEM is established and the model test is made for every substructure. The FEM is modified by the experimental data. The shaker's FEM is constructed via the modified substructures.

Secondly, the virtual vibration test is realized based the virtual simulate and prefigurative technology. The computer simulation of shaker and the realization of vibration control test are solved by this technology. Though the numerical force spectrum at the exciting points, the simulate test is completed with table-board control.

Finally, connecting the FEM of some satellite, a virtual vibration test of shaker and satellite is made. The virtual vibration platform for satellite has been built. The numerical results agree well with those from the true vibration test.

1. INTRODUCTION

Currently, the satellite engineering structure design is still lord with experiment verification. The most structure dynamic problem must do vibration experiment, and whether passing the vibration check is the standard of accepting the product.

Sometimes, though the combined structure of the rocket and satellite had passed the shaker testing, but the problems may still appear in the launching. On the other hand, though the combined structure hadn't passed the shaker testing, but the launching test was succeed.

So some vibration testing results are not really reliable and can't be the only criterion of the engineering structure design. It may induce some hidden problems. The simulation of the shaker testing may be a useful method to avoid the serious result for these hidden problems. Along with the development of the structure design, the computer simulation of the shaker testing gradually becomes a new application technique.

The virtual vibration test can prefigure the test result. It can be used for the test design and the structure modification of the satellite.

The research of the virtual vibration test is very difficult. The main problems have the FEA model of the complicated structure, the damp model of the satellite structure and vibration control test, etc.

2. SIMULATION PROCESS OF THE VIRTUAL VIBRATION TEST

The computer simulation of the shaker test has three essentials: system, modal and computer. The most key technique is that the accurate mathematical model of the shaker is set up. Generally the theories FEA model of the shaker is impossible to set up. So the test model is used. Equally, by the experiment of the parts, the theory analyzing and synthesizing of the system, the model of the shaker is established. For example, a satellite engineering structure is usually composed of many sub-structures. These sub-structures are designed and produced in the different dept., and the model of the satellite usually has several ten thousand degrees of freedom. It is very difficult that using the ground experiments data to verify, modify and simulate this complicated model. So the sub-structure experiments model method is used. This method includes four steps:

1) Build the sub-structure primary model;
2) Do the dynamic tests of the sub-structures;
3) Analyze the relativity of the test result and the calculation result;
4) Modify the universal sub-structure model.

The simulation of the shaker testing has two steps in approach. The first step is to predigest the structure and build the FEA model to ensure that the numerical value of the model is right. The second step is basis the fact experiment data to modify the FEA model in order to make the FEA model accord with the dynamic characteristic of the reality structure and get the true analysis result of the model. Figure 1 is the flow chart of modeling the shaker and satellite. Figure 2 is the detailed flow chart of simulation testing of the table-control vibration.

Model testing data is a criterion of the mathematic model improvement, and the FRF of the vibration testing can be used to check whether the model is right or not. But the FRF error will directly infect the result of model refinement, and influence the precision of the simulation analysis.

Model improvement usually includes two steps, one is the model diagnosis and the other is the model updating. About the model diagnosis, firstly we should study the modal shape relativity of calculating and testing and use the model shapes and energy distribution to diagnose the regions of leading error and the parameters that should be modified. Then we can adjust the local nodes and elements of the error area to form the new analysis model and ascertain these parameters value. We should make the number of the updated parameters fewer, or else the process is very complex and difficult.

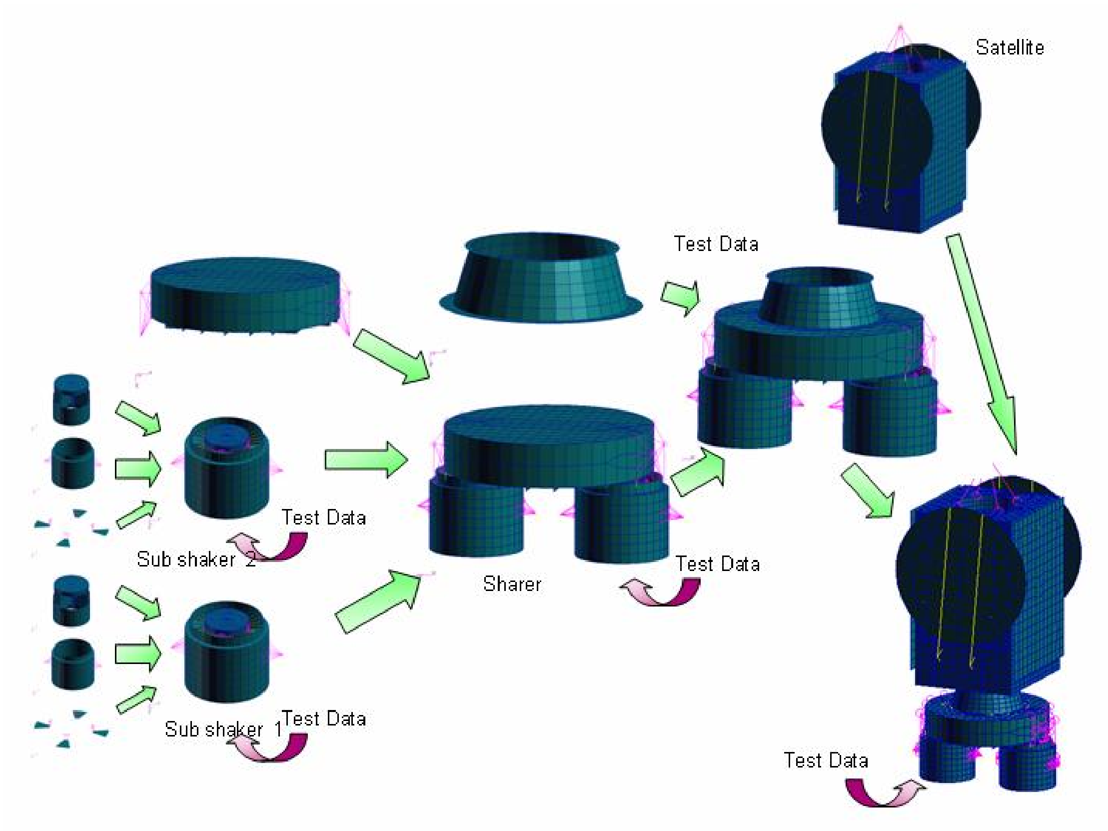

Figure 1. The main chart of modeling the shaker and satellite

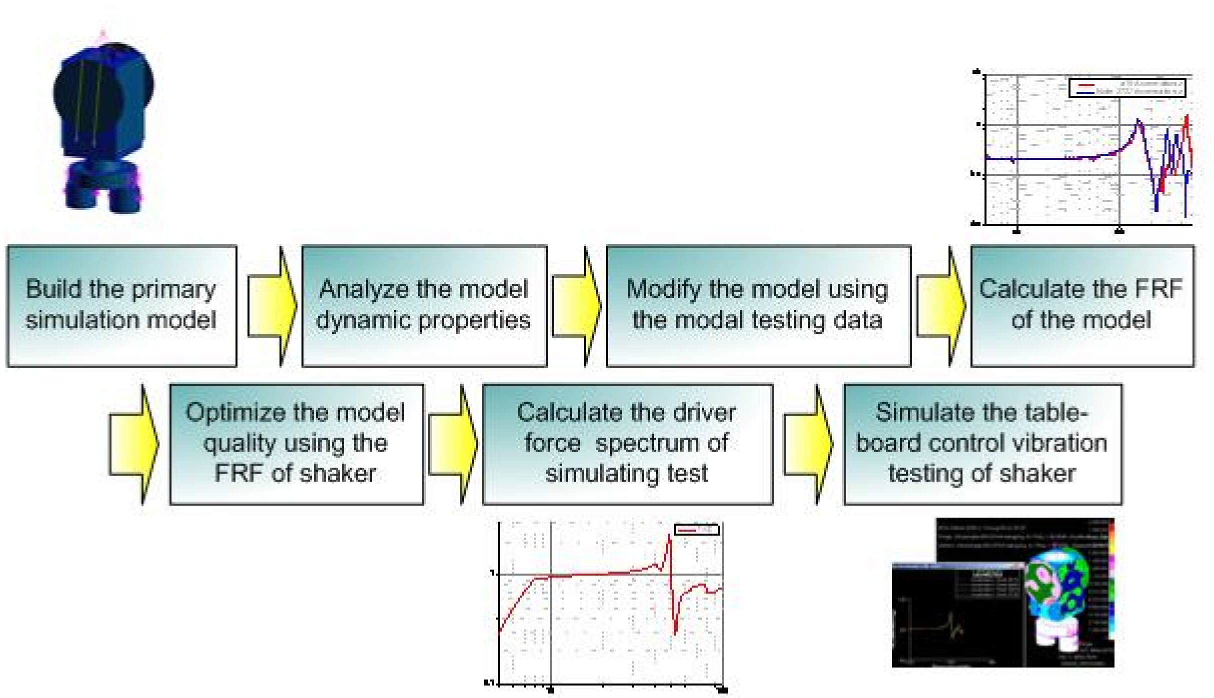

Figure 2. Detailed flow chart of the virtual table-control vibration testing.

Due to the limit of the existing model improvement software, we have to associate the hand refinement method with the FEM software to do the simulation analysis of the shaker. The detailed method is as follows. Dividing the FEA model into several groups and selecting one updated parameter in each group. In general, we should choose the material constants, structural thickness and characteristic length as the parameters to be refined. For the shaker system, there are two steps to improve the mathematic model. Firstly, use the original mathematic model to calculate structural modal frequency and modal shape. Compare the obtained results of calculation with those extracted results from test to make them coincide with each other. In this step, we modify the stiffness matrix and mass matrix mostly. Secondly, we may complete the second mathematic model improvement by comparing the FRF curves calculated with those measured. During this process, we may not only consider the frequency of peak value but also take into account the curve shape whether it is a ascend trend, descend trend or equal trend to make the key points achieve the requirement value of frequency response spectrum.

3. SIMULATION METHOD OF TABLE-BOARD CONTROL VIBRATION TESTING

The method of table-board control vibration testing is to control the measured response of a single point or four points' average in sine sweeping testing denoted by $a(f)$ equal to the accelerator spectrum of vibration test. However, to simulate the FRF response of FEM model, the accelerator spectrum of vibration testing $a(f)$ can't be acted on the model directly because of the characteristic of simulation theory. A practicable process is introduced following.

Supposed current-driving spectrum is $I(fT)$, accelerator response spectrum of measured point is $a(f_iT)$, and the powering force of shaker is *F*. The relationship of these quantities is：

$$F_T(f)=[QL]I_T(f)=G_TI_T(f)\,,G=QL \tag{1}$$

In which: *Q* is the magnetic field strength, *L* is the cable length, *I(f)* is the exciting current of shaker, and *G* is a force constant. Appling the exciting current of shaker *I(f)* and accelerator response spectrum in each measured point $a(f_iT)$ to the Equation (2) can get the FRF $H(f_iT)$ of structure in each measured point:

$$H(f_{iA})=a_{iA}(f)/F_A(f)=a_{iA}(f)/[G_AI_A(f)]=A(f_{iA})/G_A \tag{2}$$

In which: *i* is measured point, *T* is the quantity of actual vibration test. The Equation (2) shows that FRF $H(f_iT)$ of measured point is 1/*G* times of $a(f_i)/I(f)$ which is the ratio of current-driving function $I(f)$ to the accelerator response $a(f_i)$. So the $H(f_iT)$ can be used as the reference to the second model improvement.

When simulating an actual test, the boundary condition is a constant force spectrum $F_1(f)$ acted on the bottom of shaker armature parts, the response $a(f_iA)$ of each node is calculated, and the calculated FRF $H(f_iA)$ can be written as:

$$H(f_iA)=a(f_iA)/F_1(f) \tag{3}$$

In which: *i* is the node number, *A* is the quantity of simulating test, the aim of model improvement is to make the result $H(f_iA)$ of virtual testing equal to the $H(f_iT)$ of actual testing.

Equally, when the force acted on the bottom of the armature parts is $F_2(f)$, the response of single point controlling or the four points controlling average is $a(fA)$. Assuming the structure has a good linear characteristic, when giving the Sine sweeping accelerate spectrum $a(f)$, the exciting force spectrum $F_2(f)$ is calculated following:

$$F_2(f) = F_1(f) * a(f) / a(fA) \tag{4}$$

If given force spectrum $F_1(f)$ 、 single point or four points average spectrum $a(fA) = \frac{1}{4}\sum_{i=1}^{4} a(f_i A)$ 、 and acceleration condition spectrum $a(f)$ of Sine sweeping testing, the force spectrum $F_2(f)$ is calculated for Equation (4).

The true test FRF $H(f_i T)$ of each measured point is used as the reference of the second simulation model improvement to make the virtual results of $H(f_i A)$ close to the true result of $H(f_i T)$. So the criterion of the FEM model increasing stand or fall is whether the virtual test spectrum $I(fA)$ is equal to the true test spectrum $I(f)$.

4. VIRTUAL TESTING ANALYSIS

With the modified FEM model of the shaker and satellite, Figure 3 is the calculated curve of current-driving spectrum $I(f)$. Figure 4 is the actual test curve of current-driving spectrum $I(f)$. Figure 5 shows acceleration response curves of the typical points (5-100Hz). From these figures, it can be found that the simulation result is almost equal to the actual test result in the low frequency (below 50Hz), but occurring to great difference in high frequency. In fact, this accords with the true test results of shaker, because the shaker is difficult to be controlled in high frequency range.

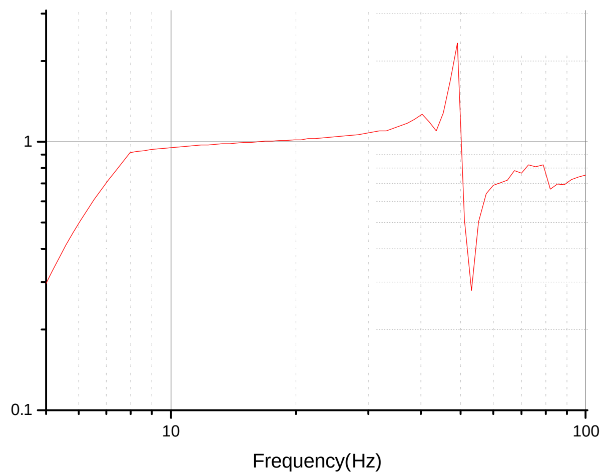

Figure3 The $I(f)$ curve of virtual testing

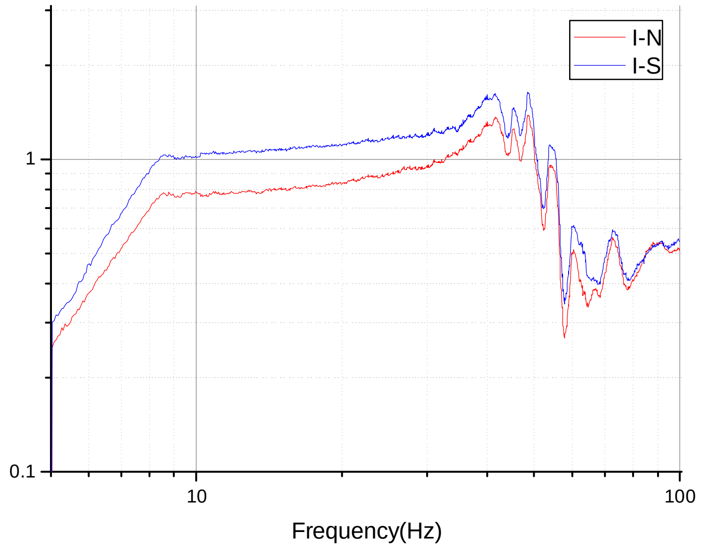

Figure4 The $I(f)$ *curve of true vibration test*

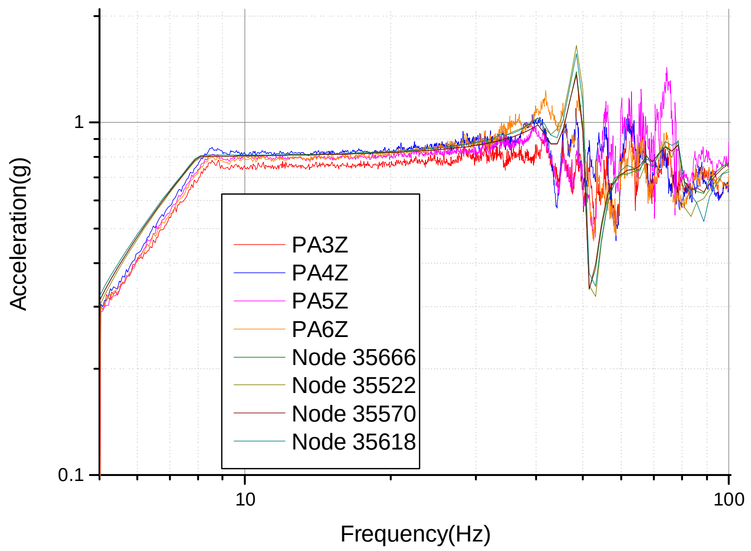

Figure5 The acceleration response curves of the virtual testing vs. the true testing

6. SUMMARY

In this paper, the computer simulation process of the virtual vibration test is proposed and the simulation result of the shaker and satellite is introduced. The FEM is established for the shaker by the stepping up method. In order to make the FEM model of the shaker equal to the actual physical model, two steps are taken: first the mass matrix and stiffness matrix of FEM model are modified by comparing the modal analysis result of FEM model with the modal testing data of the shaker; secondly the damping coefficients、boundary conditions and connection conditions of FEM model are modified two times by comparing the FRF curves of simulation

$H(f_i A)$ with the measured FRF curves of the shaker $H(f_i T)$. Applied the above process to the shaker FEM model and the satellite model, the example of the acceleration response simulation shows a good result comparing with the vibration test result below low frequency. And it shows that the modification process is practicable.

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