ANALYSIS OF VIBRATION MODELLING VALIDITY OF SPACE-BORNE ROBOTIC SYSTEM

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Abstract

Space-borne equipment requires especial strength for vibration load, which takes place during carrier vehicle launch at the stage of passing through dense atmosphere. To check the unit performance capabilities with different adverse impacts the series of test operation is usually taken – thermal chamber test, centrifugal machine test, etc. To check the structural strength with vibration impact the series of examinations are taken on vibration table: the unit is located the same way it would be located in the carrier vehicle and exposed by 3-axes vibration impact in specified frequency range (0 to 2000 Hz or 0 to 3000 Hz). Vibration acceleration produced in different parts of unit is controlled with accelerometers. In such a way mechanical amplitude-frequency curve, resonance frequencies and peak accelerations can be determined.

Keywords: vibrations; validating; modelling; simulation; finite element analysis (FEA)

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1. Introduction

Despite the sophisticated operation test techniques vibrations, provided by rocket blastoff are taken as random probability process. For vibration simulation levels of exposure for different frequency ranges are taken. This data is represented as tables with levels of vibration acceleration spectrum density by frequency components. Table 1 data is contributed by “S.P. Korolev Rocket and Space Corporation “Energia”. Table shows spectral density of vibration acceleration at different stages during flight stages of carrier vehicle Soyuz.

Flight stage	Frequency, Hz							Exposure time, s
	20	50	100	200	500	1000	2000	
	Spectral density of vibration acceleration, g ² /Hz							
Launch	0,0100	0,0100	0,0100	0,0250	0,0250	0,0125	0,0065	60
	0,0100	0,0100	0,0100	0,0100	0,0040	0,0020	0,0010	240
Autonomous flight	0,0020	0,0020	0,0020	0,0020	0,0020	0,0020	0,0010	300
Mated with ISS	0,00020	0,00020	0,00025	0,00025	0,00030	0,00020	0,00010	300 (Y/Y)

Table 1. Spectral Density of Vibration Acceleration

In line with all-Union State Standard it is available to replace random probability vibration test by equivalent sine wave vibration. RTC test engineering department uses sine wave vibration table. All space-borne units as well as major part of all units, developed by RTC, take the vibration test. However the unit can be damaged or destroyed, providing additional financial and time expenditures for unit reengineering and new parts production.

Modern computer simulation tools allow to evade unit destruction and unit rebuild expenditures if one is not strong enough for specified vibration impact.

2. Experiment description

Along with need to simulate certain situation with specified initial conditions, the question arises of how to precise forecast for vibration distribution and for levels of appearing vibration accelerations could be. To answer this question a simple experiment with beam structure was produced. Its results are shown below.

Fig. 1. (a) beam structure (model); (b) beam structure (photo)

There are known cases of another experiments, aimed on CAE-methods validation [1, 2, 3]. Construction was made the way it is possible to measure vibration accelerations in different parts of construction with evidently different Young's modulus to get different resonance frequencies distribution. It was expected to take measures in six different points, but since of measurements on vibration table, used in experiment, were taken simultaneously from four accelerometers, the experiment with equal impacts were provided twice.

Fig. 2. (a) measure points (case 1); (b) measure points (case 2)

Stand basement during vibration test was fixed with 4 screws on reference platform. Figures 2 (a) and 2 (b) shows accelerometers mount places by crosses.

Reference impact for physical test is vibration with 1 mm amplitude within 5 to 50 Hz frequency range and acceleration peak of 5 g within 50 to 2000 Hz frequency range. For computer simulation reference impact was considered as constant amplitude impact of stand basement with 5 g peak acceleration within 0 to 2000 Hz frequency range. For computer modelling discretization of frequency is 4 Hz (500 values).

3. Validation results

Results of experiment and modelling are shown below.

Fig. 3. (a) case 1 (experiment); (b) case 1 (modeling)

Fig. 4. (a) case 2 (experiment); (b) case 2 (modelling)

Absolute acceleration of points is shown in figure 3 (a) and 4 (a). Accelerations are demonstrated in sum of three axes with reference to coordinate grid tied to earth gravity field.

In computer simulation (figure 3 (b) and 4 (b)) relative accelerations of points on construction are shown. Accelerations are demonstrated in one axe and are referenced to coordinate grid tied to stand basement. For computation actualization vectors amplitudes sums w taken for every frequency and every point. After that 5 g value was added to make transition to coordinate grid tied to earth gravity field. Apart of that in computer simulation only absolute values of variation were calculated, i.e. computer simulation results had only positive values.

The result of conducted experiment primary correlation of data obtained from simulation with data collected in physical experiment.

Objective of experiment is computer simulation accuracy characterization.

Main difference between computer model simulation and real experiment is idealization of computer model. Frequency response function, obtained from computer simulation, shows vibration amplitudes for every frequency in steady-state. And conversely, from the physical experiment in transient. Established vibrations amplitudes are shown on amplitude-frequency curve, received from computer simulation. Whereas in contrast to computer simulation in real experiment vibration impact process is permanent and all accelerations in specified frequency band are sums of reference forced impact from vibration stand and dying-out oscillation from antecedent frequencies. Main result of this difference is vibration amplitude reduction within resonance frequencies in the real experiment. With frequency modulation speed increasing peaks become smoother. In other words construction doesn't catch frequency to oscillate with maximum amplitude because the frequency changes.

Detailed explanation of this effect can be found in general physics. In the part, dedicated to constrained oscillation dynamic problem of clamped beam while applying reference oscillation (harmonic input) to its base is considered. In linear model dowel will oscillate with gradually increasing amplitude and frequency of reference oscillation.

Key feature of this oscillation is smooth increasing of vibration amplitude to its maximum value (figure 5). This feature allows making consequence that clipping peak values during resonances pass through vibration table.

Fig. 5. Illustration of monochromatic vibration transient

Put in another way, when examined beam construction (fig. 1) is vibrating harmonically on resonance frequency for one part of construction the amplitude increases sharply.

But before construction reaches maximum amplitude value frequency modulation of reference impact occurs, that reduce amplitude value. Due to that fact the most precise data in experiment were obtained, when frequency modulation speed is minimal - at low frequencies.

Despite fundamental difference between simulation and real experiment frequency-amplitude curves, obtained in experiment and in simulation are nearly similar. On low frequencies (below 100 Hz) resonance frequencies of all parts of construction are similar. On frequencies above 100 Hz barely identified difference in frequencies appears, but in most cases resonance distributions are nearly similar.

The major difference at 100 to 500 Hz frequency band is lack of resonance on 232 Hz in real experiment, while it was obtained in computer simulation results.

There are no inverse mismatches – all resonances, found in real experiment were predicted by results of computer simulation.

Within 500 to 1000 Hz frequency band mismatches between computer simulation and real experiment are observed. Main difference is absence of some resonance groups in real experiment in spite of the fact that it was predicted by results of computer simulation. Most probably, narrow bands of amplitudes bursts can't be recognized against transient processes in system.

These groups of resonances do not constitute a danger for a system, because they can arise only with monochromatic longstanding impact, which is barely possible in real systems operation.

Within 1000 to 2000 Hz frequency band simulation result and real experiment are nearly similar. For deeper research extra experiments and further exploration required.

Overall, correspondence of frequency to amplitude curves is more precise within low frequencies range.

However it is concerned with rather not method of computer calculation, but with frequency modulation speed on vibration table, which is minimal within low frequencies range.

There is a reason to suppose that with frequency modulation speed decreasing the results of experiment and computer simulation is going to approach each other until the difference, caused by linearity of computer model, will appear significantly.

4. Vibration simulation at the design engineering stage

Results of experiment described above were put to use in real robotic system. [4]

The model of development space-borne manipulation system was uploaded to CAE-system and afterwards the vibration simulation was run. Simulation was conducted with 1 g acceleration amplitude in 0 to 300 Hz frequency band, discretization of frequency is 3 Hz (100 values).

Fig. 6. Number of points and axis directions

Specific manipulation system computer model is shown in figure 6. Points, where vibration acceleration was measured, are marked.

Results of simulation are curves of resonances frequencies for different parts of construction and of far higher surface tension map for different parts of construction.

Fig. 7. Vibration response of Specific Manipulation System (computer modelling result)

Fig. 8. (a) Surface tension level allocation (a) on 123 Hz; (b) on 237 Hz

Information about the most vulnerable for vibration parts of construction is valuable at the design engineering stage, because it provides an opportunity to remove weaknesses beforehand.

5. Conclusion

The main interest in design engineering of new unit is determination of fragile, in terms of mechanic, parts of construction. However, if simulation is not sufficiently reliable, there will be no benefit of it. Described experiment shows possibility to obtain sufficient similar results for simple beam construction in CAE-system. For vibration simulation of complex systems it is impossible to tell clearly how precise the resonance frequencies are determined.

In future it is expected to carry-out fully-featured simulation of specific manipulation system on supercomputer with full scale frequency range. However, resonance frequencies distribution is not so important as the allocation of surface tension.

From general considerations it is clear, that deformations, obtained in simulation are close to the real ones for deformation directions, but unreliably exaggerated for value. To explore relations between simulation and real deformation it is suggested to use results of supercomputer simulation.

It will be possible to compare the result of this simulation and experiment on vibration stand, when the manipulation system will be fabricated.

During results comparison the methodology of computer simulation will be adjusted to make more precise vibration test simulation possible before unit manufacturing.

A better reproducibility is also expected to be achieved in future.

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