The phenomenon of resonance may occur during a space rocket launch. Therefore, modal tests are common practice to measure resonance frequencies which should be excluded from the range of operating conditions, or at least minimized. Therefore, it is necessary to identify resonance frequencies and then either to exclude them from the range of operating conditions, or to implement measures to minimize resonant phenomena. Internationally, modal tests are mandatory, while in Russia the requirements for the formation of such normative documentation are only being developed. The paper describes the non-contact method of experimental modal analysis to measure the resonant vibration of a lens case for spacecraft. The method we applied involves a three-component laser vibrometer in the frequency range of 30-400 Hz. The results obtained show the amplitude-frequency response (AFR) and vibration modes of the object under the loads. A technique for performing experimental modeling of the processes of rocket and space technology for further verification of the mathematical model is developed.

Keywords: modal analysis, finite element methods

1. Introduction

Resonant phenomena play an important role in developing space-rocket equipment (SRE). A significant number of space-rocket equipment malfunction are associated with fatigue failure of the parts under the alternating stresses caused by vibroacoustic loads. In order to prevent vibration breakdowns, it is necessary to analyze the eigen frequencies and vibration modes of the SRE components. In this regard, the issue of creating modal analysis technology is of great importance and interest, since it improves the accuracy and efficiency of vibroacoustic testing and reduces the implementation time.

According to the research of the Experimental Mechanics Community [1], the determination of the dynamic characteristics of spacecraft and their components can be divided into two categories: strength analysis and analysis of the satellite structural stiffness. The purpose of strength analysis is to confirm the integrity and performance of the components under vibration loads, comparable to those which appear during the flight. The dynamic analysis of the satellite structural stiffness poses the task of determining its modal parameters (eigen frequencies and vibration modes, as well as damping at these frequencies). The objectives of determining modal parameters are the following:

1. Determining the resonance frequencies;
2. Verifying the accuracy of the mathematical finite element model and its elements;
3. Determining the value and change of modal parameters of remote elements having a significant spatial extent [2, 3, 4].
Rodionov L. et al suggest that finite element model and experimental modal verification should be used for improving pump vibroacoustic performances [5,6]. In [7,8] the authors describe in detail the contactless laser vibrometry method as applied to the carbody surface using the three-component laser scanning vibrometer to verify the vehicle finite-element model. Paper [9] presents a research on diagnostic parameters using the Doppler Effect laser vibrometer for monitoring conditions of lightweight aircraft engine blades made of composite materials in flight. In [4,10] the authors describe modeling of the size-stable platform. However, to the best of our knowledge, few researchers have addressed the problem of a lens case.

In this paper we present an example of determining the resonance frequencies and of verifying the mathematical finite element model. The object of the study is the lens case designed for spacecraft. The method of the investigation involves a three-component laser vibrometer in the frequency range of 30-400 Hz. This study shows the amplitude-frequency response (AFR) and vibration modes of the lens case under loads. The technique is designed for verifying the spacecraft component mathematical model.

2. Methods

A selected lens case is modelled by using FE methods and CAE techniques. The model is developed to characterize the major case structural dynamic behaviours such as eigen frequencies and corresponding mode shapes. The simulation of the dynamic behaviours is carried out by MSC. Nastran [11, 12]. The search of eigen frequencies is carried out in the frequency range from 30 to 400 Hz. The lens case is made from composite material and the composite’s properties such as density and Young’s modulus have been used for the structure of the CAE model. This lens case has been modelled using element type «Plate». «Normal Modes» has been chosen as a type of analysis.

Search of the lens case for its resonance frequencies is performed using a Polytec PSV-400 laser vibrometer. After the scanning process is completed, the results of vibration measurement of all fragments are put together. Then transfer functions from "Polytec Scanning Vibrometer" software are imported into "LMS Test.Lab" to calculate the modal parameters.

The advantage of this method provides a higher accuracy pattern due to a greater number of vibration detection points produced by scanning laser vibrometer.

The eigen frequencies of the component structure are identified by determining and recording the maximum values on the vibration velocity graph from the test report.

Modal analysis makes it possible to determine:
- the amplitude-frequency characteristics (by vibration velocity) at points on the surface of the component;
- the amplitude-frequency response averaged over the surface of the component (by vibration speed);
- the vibration form of the component which corresponds to each value of the eigen frequency.

The test procedure for the lens case is shown in Figure 1. The lens case was suspended on rubber bands without being secured to the floor.

A vibration exciter is used as a source of excitation, fixed at the point with maximum displacement when vibrations are generated. The vibration exciter in both cases of fixing is set equally to minimize the discrepancy under the experimental conditions.

A review of the received modes using the Test.Lab (Modal Analysis) software allows to identify stable poles, which are analyzed in accordance with the "modal phase collinearity" (MPC) and "maximum phase deviation" (MPD) indicators.

The experiment was carried out in cooperation with SRC "Progress" within the framework of the project on developing hi-tech products in accordance with the decree of the Government of the Russian Federation of 09.04.2010, №218.
3. Results

As a result of scanning the object from 30 to 150 Hz, the 6 harmonics of the case have been identified: 77.5; 100.2; 110.3, 119.4, 130.2 and 148.5 Hz. Figure 2 shows the frequency response of the structure after processing the data in the software. The solid line shows the data from Polytec software without being processed by the TestLab.

![Phase portrait](image)

Figure 2. Experimental amplitude-frequency characteristic of lens case

Phase portrait is presented in Figure 4. If the phase of object oscillation crosses zero, this frequency is eigen.
Then the values of the object eigen frequencies and the vibration forms at these frequencies have been determined. The simulation of the experiment in MSC.Nastran has also been performed in the frequency range from 30 to 150 Hz. Figure 4 shows a comparison of the first vibration form obtained from the experiment and the simulation one.

As shown in Figure 4 simulation mode is identical to experimental mode. The same results have been found for other modes.

Table 1 compares the first six values of the object eigen frequencies obtained from the experiment and the simulation.
Table 1. Comparison of theoretical and experimental values of eigen frequencies

<table>
<thead>
<tr>
<th>Mode number</th>
<th>Experiment (Hz)</th>
<th>Simulation 1 (Hz)</th>
<th>Δ (%)</th>
<th>Simulation 2 (Hz)</th>
<th>Δ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>77.5</td>
<td>73.9</td>
<td>4.87</td>
<td>80.3</td>
<td>3.61</td>
</tr>
<tr>
<td>2</td>
<td>100.2</td>
<td>99.1</td>
<td>1.11</td>
<td>107.8</td>
<td>7.58</td>
</tr>
<tr>
<td>3</td>
<td>110.3</td>
<td>110.6</td>
<td>0.27</td>
<td>120.2</td>
<td>8.98</td>
</tr>
<tr>
<td>4</td>
<td>119.4</td>
<td>117.9</td>
<td>1.27</td>
<td>128.2</td>
<td>7.37</td>
</tr>
<tr>
<td>5</td>
<td>130.2</td>
<td>124.7</td>
<td>4.41</td>
<td>135.6</td>
<td>4.15</td>
</tr>
<tr>
<td>6</td>
<td>148.5</td>
<td>144.6</td>
<td>2.70</td>
<td>157.2</td>
<td>5.86</td>
</tr>
</tbody>
</table>

Parameters

| E, MPa        | -                | 45000             | -     | 53200             | -     |
| m, kg         | -                | 40.98             | -     | 40.98             | -     |
| ρ, kg/m³      | -                | 1550              | -     | 1550              | -     |

4. Conclusions

The data presented in this study demonstrate an example of determining the resonance frequencies and of verifying the mathematical finite element model.

We conclude, therefore, that:

1) The proposed method of modal analysis of space-rocket equipment components allowed us to determine the eigen frequencies of the object and verifying the accuracy of the mathematical finite element model.

2) The results obtained are consistent with the result of finite element modeling of the structure in the considered frequency range.

The results indicate the overall correctness of the finite element models. In comparison with experimental data discrepancy of the simulation results does not exceed 9%, which indicates the correctness of the finite element models.

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