CHAPTER 7

DYNAMIC RESPONSES OF MICRO-SATELLITE

Dynamic Analysis is an analysis that enables us to analyze structures subject to time dependent loads. All structures can exhibit resonant behavior when they are excited at, or close to one of their natural frequencies, and such excitations cause large amplitude oscillations. Therefore, it is necessary to ensure in the design of the structure that the excitation frequencies and natural frequencies are not close to each other.

When sine and random vibration analysis are performed, the model is "shaken" at the point or points where the model interfaces with the launch vehicle. The satellite considered has 12 mounting points with the launch vehicle through the interface ring. Thus, these 12 points are connected down to what is called the shaker point. This shaker point is where the sine and random excitation input are applied. From this input, responses can be obtained at any location on the finite element model.

7.1. SINUSOIDAL ANALYSIS

Sinusoidal vibration is periodically varying time dependent motion which is described by amplitude (displacement, velocity or acceleration), frequency and phase angle. Sinusoidal analysis was conducted to determine accelerations, displacements and stresses on the structure submitted to the sinusoidal spectrum described in Table 7.1.
The frequency response analysis uses three separate input spectrums, one for each of the three orthogonal axes. This is done because the launch vehicle, PSLV, has different sine vibration loading environments in different directions. The inputs represent the sine vibration being input to the instrument through the spacecraft. In this analysis the modal frequency response method was used. This method uses the mode shapes of the structure to reduce the size of the system of equations to be solved by uncoupling the equations of motion and consequently making the numerical solution more efficient. The frequency range of sinusoidal response analysis was spanned up to the frequency of the higher normal elastic mode already calculated by the modal analysis. The damping was applied to each mode separately in order to maintain the equations of motion uncoupled. Sine vibration can be directly measured for any applied frequency, since only one frequency occurs at a time. Using this analysis the accelerations at any node on the finite element model was determined.

<table>
<thead>
<tr>
<th>Table 7.1 Sine vibration test levels</th>
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<tbody>
<tr>
<td><strong>Frequency range</strong></td>
</tr>
<tr>
<td>(Hz)</td>
</tr>
<tr>
<td>Longitudinal axis</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Lateral axis</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Sweep rate</td>
</tr>
</tbody>
</table>

The sinusoidal analysis is carried out with ‘1g’ base sine excitation given in X, Y and Z directions and the responses are obtained at 50 locations in the spacecraft.
The Figure 7.1 shows the location of the node 10342 in the bottom deck and Figures 7.1.1 and 7.1.2 show the response of the node 10342 in the bottom deck for base sine excitation of ‘1g’ given in X and Z directions.

![Figure 7.1 Location of the Node 10372 in Bottom Deck](image)

![Figure 7.1.1 Response of Node 10372 for 1g base sine excitation in X direction](image)
Figure 7.1.2 Response of Node 10372 for 1g base sine excitation in Z direction

The Figure 7.2 shows the location of the node 37054 in the middle deck and Figures 7.2.1 and 7.2.2 show the response of the node 37054 in the middle deck for base sine excitation of ‘1g’ given in X and Z directions.

Figure 7.2 Location of the Node 37054 in Middle Deck
Figure 7.2.1 Response of Node 37054 for 1g base sine excitation in X direction

Figure 7.2.2 Response of Node 37054 for 1g base sine excitation in Z direction
The Figure 7.3 shows the location of the node 60143 in the top deck and Figures 7.3.1 and 7.3.2 show the response of the node 60143 in the top deck for base sine excitation of ‘1g’ given in X and Z directions.

**Figure 7.3 Locations of the Node 60143 and Node 62471 in Top Deck**

**Figure 7.3.1 Response of Node 60143 for 1g base sine excitation in X direction**
Figure 7.3.2 Response of Node 60143 for 1g base sine excitation in Z direction

The Figure 7.4 show the location of the node 70003194 in the solar panel and Figures 7.4.1 and 7.4.2 show the response of the node 70003194 in the solar panel for base sine excitation of ‘1g’ given in X and Z directions.

Figure 7.4 Location of the Node 70003194 in Solar panel
Figure 7.4.1 Response of Node 70003194 for 1g base sine excitation in X direction

Figure 7.4.2 Response of Node 70003194 for 1g base sine excitation in Z direction
The Figure 7.5 shows the location of the node 22752 in the cross web and Figures 7.5.1 and 7.5.2 show the response of the node 22752 in the cross web for base sine excitation of ‘1g’ given in X and Z directions.

**Figure 7.5 Location of the Node 22752 in Cross Web**

**Figure 7.5.1 Response of Node 22752 for 1g base sine excitation in X direction**
Figure 7.5.2 Response of Node 22752 for 1g base sine excitation in Z direction

The Figure 7.6 shows the location of the node 70884 in the vertical web and Figures 7.6.1 and 7.6.2 show the response of the node 70884 in the vertical web for base sine excitation of ‘1g’ given in X and Z directions.

Figure 7.6 Location of the Node 70884 in Vertical Web
Figure 7.6.1 Response of Node 70884 for 1g base sine excitation in X direction

Figure 7.6.2 Response of Node 70884 for 1g base sine excitation in Z direction
The Figure 7.7 shows the location of the node 44445205 in the interface ring and Figures 7.7.1 and 7.7.2 show the response of the node 44445205 in the interface ring for base sine excitation of ‘1g’ given in X and Z directions.

Figure 7.7 Location of the Node 44445205 in Interface Ring

Figure 7.7.1 Response of Node 44445205 for 1g base sine excitation in X direction
Responses are taken about 50 locations in bottom deck, middle deck, top deck, cross webs, vertical webs and solar panels of the microsatellite and it was found that the response is highest in the top deck. The amplification factor obtained from the response curves of the base sine excitation at the resonant frequencies are low and does not have critical structural problem. The bottom deck is the closest to the excitation point and consequently it presents with the lowest levels of acceleration. The same accelerations grow with the distance from the base, achieving the highest values, among the three deck plates, cross webs and vertical webs, and in the top deck.
7.2 RANDOM VIBRATION ANALYSIS

Random vibration is the vibration containing all frequencies whose instantaneous magnitude cannot be explicitly defined. Random vibration contains non periodic or quasi-periodic components and thus an exact value at a future time cannot be predicted. The instantaneous magnitude is specified by probability distribution functions giving the mean square value that lies within a specified frequency range.

Random vibration analysis was conducted to determine the accelerations, displacements and stresses on the structure subject to the random excitations described in Table 7.2. The random analysis was performed as a post-processing step after frequency response analysis. The frequency analysis is used to generate the transfer function and obtain the power spectral density (PSD) response from the PSD input. As output of this analysis, the program gives the response PSD, autocorrelation functions, number of zero crossings with positive slope per unit time, and RMS (root mean-square) values of response acceleration.

The purpose of performing a random vibration analysis is to create a component test level specification. With the finite element model of the micro-satellite, a random vibration analysis was performed to predict acceleration responses from 20 Hz to 2000 Hz. This response is in turn used as a template to derive a test level specification.
Table 7.2 Random vibration test levels

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSD (g²/Hz)</td>
</tr>
<tr>
<td>20</td>
<td>0.002</td>
</tr>
<tr>
<td>110</td>
<td>0.002</td>
</tr>
<tr>
<td>250</td>
<td>0.034</td>
</tr>
<tr>
<td>1000</td>
<td>0.034</td>
</tr>
<tr>
<td>2000</td>
<td>0.009</td>
</tr>
<tr>
<td>gRMS</td>
<td>6.7</td>
</tr>
<tr>
<td>Duration</td>
<td>1min/axis</td>
</tr>
</tbody>
</table>

Figures 7.8.1 and 7.8.2 show the response of the Node 10372 in bottom deck for random excitation in X and Z direction.

Figure 7.8.1 Response of Node 10372 in bottom deck for random excitation in X direction
Figure 7.8.2 Response of Node 10372 in bottom deck for random excitation in Z direction

Figures 7.9.1 and 7.9.2 show the response of the Node 37054 in middle deck for random excitation in X and Z direction.

Figure 7.9.1 Response of Node 37054 in middle deck for random excitation in X direction
Figure 7.9.2 Response of Node 37054 in middle deck for random excitation in Z direction

Figures 7.10.1 and 7.10.2 show the response of the Node 60143 in top deck for random excitation in X and Z direction.

Figure 7.10.1 Response of Node 60143 in top deck for random excitation in X direction
Figure 7.10.2  Response of Node 60143 in top deck for random excitation in Z direction

Figures 7.11.1 and 7.11.2 show the response of the Node 70003194 in solar panel for random excitation in X and Z direction.

Figure 7.11.1  Response of Node 70003194 in solar panel for random excitation in X direction
Figure 7.11.2  
Response of Node 70003194 in solar panel for random excitation in Z direction

Figures 7.12.1 and 7.12.2 show the response of the Node 22752 in cross web for random excitation in X and Z direction.

Figure 7.12.1  
Response of Node 22752 in cross web for random excitation in X direction
Figure 7.12.2  Response of Node 22752 in cross web for random excitation in Z direction

Figures 7.13.1 and 7.13.2 show the response of the Node 70884 in vertical web for random excitation in X and Z direction.

Figure 7.13.1  Response of Node 70884 in vertical web for random excitation in X direction
Figure 7.13.2  Response of Node 70884 in vertical web for random excitation in Z direction


Figure 7.14.1  Response of Node 44445205 in interface ring for random excitation in X direction
Figure 7.14.2  **Response of Node 44445205 in interface ring for random excitation in Z direction**

The Figure 7.15 shows the stress plot of micro-satellite structural components obtained for the random vibration input in X direction and the Figure 7.16 shows the stress plot of micro-satellite structural components obtained for the random vibration input in Z direction.

**Bottom Deck - 0.081 Mpa**  
**Middle Deck - 0.072 Mpa**
Top Deck - 0.062 MPa
Cross Webs - 0.061 Mpa

Vertical Webs - 0.020 Mpa
Solar Panels - 0.025 Mpa

Interface Ring - 0.26 Mpa

Figure 7.15 Stress plot of micro-satellite structural components for random excitation in X direction
Bottom Deck - 0.06 MPa
Middle Deck - 0.028 Mpa
Top Deck - 0.016 Mpa
Cross Webs - 0.059 Mpa
Vertical Webs - 0.017 Mpa
Solar Panels - 0.011 Mpa
Random responses are taken at 50 locations in bottom deck, middle deck, top deck, cross webs, vertical webs and solar panels of the micro-satellite and it was found that the response is highest in the top deck similar to sinusoidal excitation. The bottom deck is the closest to the excitation point and consequently it presents with the lowest levels of acceleration. The same accelerations grow with the distance from the base, achieving the highest values, among the three deck plates, cross webs and vertical webs, and in the top deck. The maximum stress values are obtained in the interface ring due to the random excitation in both X and Z direction. The obtained stress values of all the micro-satellite structural components are well within the limit and based on this evidence it was decided that no structural problem was created due to the random excitation loads developed on the micro-satellite structure. All stresses resulting from the PSD random vibration acceptance levels excitation demonstrates ample Margin of safety for the design.