FORCE LIMITED VIBRATION TESTING OF CASSINI SPACECRAFT COSMIC DUST ANALYSER

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ABSTRACT

In vibrational testing the test items are often overtested because of the discrepancies between the mechanical impedances and the force capabilities of the mounting structure and the vibration shaker. For the vibration tests of the Cosmic Dust Analyser the Force Limited Method was used to avoid overtesting. To use this method different equipment is required from other used in conventional testing methods. This includes force gages, fixtures and a special test controller. This is the description of the practical aspects of using the Force Limited Method.

1. INTRODUCTION

The objective of this test was to verify the design of the specimen to withstand the loads during launch and cruise. During this qualification test the specimen had to accept sine vibration, random vibration and half sine shock. Because of the high loads and the weak design a new notching method was used which gives the possibility to limit the excitation to levels, expected for flight.

2. DESCRIPTION OF THE TEST ITEM

The Cosmic Dust Analyser (CDA) is a scientific Instrument intended to fly with the CASSINI - Mission.

The CASSINI - Mission is an international venture involving NASA, the European Space Agency (ESA), the Italian Space Agency (ASI), and several separate European academic and industrial partners for exploration of Saturn and its atmosphere.
The Structure of the CDA can be divided into three main parts, which are the cylindrical sensor, the main electronics box and the turntable allowing 270° rotation around one axis. The baseline for the first design was to be mounted on a turntable provided by the CASSINI orbiter for several payloads.

This baseline was changed by removing the turntable from the spacecraft and so the CDA was equipped with its own turntable without changing the existing design of the sensor and the mainbox.

For this reason the CDA is not well-suited to withstand the dynamic loads during launch.

When we look at the expected loads, we see that these loads are very high.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 - 20 Hz</td>
<td>9.5 mm 0 to peak</td>
</tr>
<tr>
<td>20 - 50 Hz</td>
<td>15.0 g</td>
</tr>
<tr>
<td>50 - 100 Hz</td>
<td>10.0 g</td>
</tr>
</tbody>
</table>

Tab. 1: sine vibration qualification level

<table>
<thead>
<tr>
<th>frequency (Hz)</th>
<th>20 - 50</th>
<th>50 - 600</th>
<th>600 - 1000</th>
<th>1000 - 2000</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>demand</td>
<td>+9 dB/Oct.</td>
<td>-10 dB/Oct.</td>
<td>0.08 g²/Hz</td>
<td>-11 dB/Oct.</td>
<td>11.8 g_rms</td>
</tr>
</tbody>
</table>

Tab. 2: random vibration qualification level

On the other hand we saw from the structural analysis that the first seven natural frequencies are in the range up to 100 Hz. That means that even the sine vibration is very dangerous for this structure.

For these reasons we saw problems for qualification of the CDA-structure.
3. DESCRIPTION OF THE TEST METHOD

To solve this problem we could use the Force Limited Method for vibration control. By using this method, the acceleration input to the instrument under test is automatically notched at the equipment resonances by limiting the shaker force to values predicted for flight. This notching is based on the fact that the mechanical impedance of payloads and of mounting structure are typically comparable for lightweight aerospace structures. To use this method you have to know the vibrational forces at mounting structure - test item interface. Because there were no flight data, a prediction was made using the Frequency Shift Method. This method needs data for effective masses to set force limits for vibration tests. The effective masses were derived by Finite Element calculations, based on a Finite Element Model of the CDA by Mr. Grünagel, department YMD, ESA-ESTEC. These force limits were verified by interface force data, measured during acoustic tests of the CASSINI spacecraft Development Test Model.

These effective masses had to be included in a spreadsheet provided by JPL (see figure 2).

![Spreadsheet for force limit calculation](image)

In this sheet you have to insert the acceleration spectrum specification and the assumed damping coefficient. In the second part, the data from the spacecraft side has to be inserted, provided by Finite Element calculation of the spacecraft interface. And in the third part you have to insert the modal dates, got from the Finite Element Analysis of the instrument.

The data you have to insert are the total mass of instrument, the modal mass as % of total in each frequency range and the number of modes in each frequency range.
An example for a completed sheet for the x-axis test can be seen in figure 3.

![Completed Sheet for CDA x-axis](image)

### 4. DESCRIPTION OF THE TEST AND TEST PROCEDURE

To be able to compare the real force during the vibration test with the force limit, you have to measure the force at the interface of the instrument to the fixture. The use of four force gages is recommended. Since the instrument has eight mounting points, an adapter ring is necessary to mount the instrument over its eight mounting points on the four force gages. The adapter ring has to be as lightweight as possible, because this weight will distort the forces which appear at natural frequencies. In this test we got a weight for the ring of 0.6 Kg whereas the weight of the instrument was about 16 Kg.

Triaxial force gages were used to be able to measure in each of the three perpendicular test axes.

The test assembly for the CDA-test is shown in fig. 4.

The total force, used for comparison with the force limit, was derived by summation of the four gages in the direction of shake.

To use this limiting method in real-time, the vibration controller must have at least two independent reference channels, first one for controlling the required acceleration function and the second one for limiting the input, using the measured force. High quality controller are capable of this. Since the controller used did not support those
independent channels, a flat force limit was used, which was scaled into a pseudo-acceleration. This pseudo-acceleration was compared by the controller with the acceleration reference spectrum. To do this the controller has to be able to use two or more channels for control at the same time by peak control. The scaling was done by changing the input sensitivity of the force gage amplifier, so that the force limit seems to be at the same level as the acceleration reference spectrum. Finally, the controller was prepared to use two input channels for controlling in peak mode.

Fig. 4: Testassembly for the CDA vibrational test in-plane of mounting points. Here you see the shaker with the slip-table. On top of the slip-table there is the fixture-plate with the four force gages and the adapterring. On top of the adapterring the eight mounting points of CDA are clearly visible.

In this way, it is only possible to use force limits with a linear function of frequency. But in the actual test-specifications the acceleration spectrum had a linear part between 50 and 500 Hz and in this range the overloads occurred. So it was possible to use it. In other cases you have to use a spectrum shaper to form a desired force function.

The real test procedure was as follows:

The first step was calculating the effective masses of the instrument. Before the test, a fixture and procedure checkout was accomplished with a mass simulator of the CDA. The test had to be done in three perpendicular axis. The first axis was done by mounting the fixture on the shaker, the other ones by means of a slip table. After mounting the CDA over the adapter ring and the force gages on the fixture a resonance survey was done to derive the resonance frequencies and the qualification factor. These data were compared with the results of the Finite Element Analysis.

Then a low level random vibration run was made at -18 dB. During this run the forces at the interface were monitored (see fig. A1). After evaluation of the results of the frequency survey and the low level random vibration, the force limit was derived and the scale factor for the force gage amplifier was calculated.
The next run was a low level random vibration at the same level. But during this run the force limit control was activated. By means of this run the force limit and the scale factor were proved and the effect of the force limited control on the drive signal for the shaker was monitored (see fig. A2).

After this, the real qualification random test was carried out.

For the sine qualification no on-line control was used because of the absence of an automatic notching feature in the controller and the insufficient experience with the scaled pseudo-acceleration control in conjunction with the fast, six octave per minute, sweep rate.

Here the measured force was compared off-line to the calculated force limits and to the equivalent rigid body acceleration design limits. The drive signal for the shaker was notched by hand and the notch-level was verified by the measured test data.

5. GOALS OF THIS METHOD

Figure A1 shows the measured spectrum of the first low level random test of the CDA. You can see the high quality factor of acceleration response (green color) at about 85 Hz. At the same frequency the force curve (red color) has a peak. Because of no scaled input the force function is shifted on this diagram in y-axis. After scaling, the force limit controlled run was done and the figure A2 shows this spectrum. In this diagram the quality factor of the acceleration response is obviously lower, the force limit is scaled to the pseudo-acceleration level and the excitation signal (black color) shows a negative peak at the resonance point. It is obvious that the vibration control at the resonance point changes from acceleration to force control. The achieved notch is about 10 dB.

The diagram of the real random test (see fig. A3) shows that the achieved notch is about 12 dB.

6. CONCLUSION

Both the sine and random vibration tests of the CDA instrument in three axes were successfully completed in three working days. The achieved notches by using the Force Limited Method are a good way to avoid overtesting. Because of the weak design of the instrument, these notches were essential to the successful completion of the test without damage to the CDA structure.

This method is a good expansion of existing test procedures, because the real conditions are reproduced more exactly. Those notches are based on the real behavior of the interface between spacecraft and instrument.
REFERENCES


"General Specification for Environmental Testing (Assembly Level), Spec.-No.: TS515526, Jet Propulsion Laboratory, 1991

APPENDIX

Fig. A1: CDA first low level random test x-axis
Fig. A2: CDA low level random test x-axis with force control
Fig. A3: CDA random test x-axis qualification level with force control