COMPARISON OF DYNAMIC LOADS TO SPACE INSTRUMENTS, DEPENDING ON THE STAGE OF DEVELOPMENT

Swen Ritzmann(1), Heiko Jahn (2)

(1) Astro- und Feinwerktechnik GmbH Albert-Einstein-Strasse 12 D-12489 Berlin Germany
phone +49 30 6392 1170 fax +49 30 6392 1002 Email s.ritzmann@astrofein.com

(2) I-BN GmbH Paul-Linke-Ufer 8E D-10999 Berlin Germany
phone +49 30 616543-0 fax +49 30 616543-17 Email heiko.jahn@i-bn.de

ABSTRACT
At begin of a space project, test requirements for scientific instruments will be derived by coupled load analyses using a very coarse model, or by statistical energy method. Application of these requirements for the qualification of the instrument cause very high loads, which never will occur during real lift off. To solve this problem tailoring of excitation by notching has been established. In case of notching, using interface-force as notchlimit is the best solution. These notchlimits can be derived by Finite-Element-Analyses or by application of the Semi-Empirical Method, developed by NASA/JPL.
To get an impression, how these calculated limits match the interface loads occurring during lift off, shakertests as well as Finite-Element-Analyses for a demonstration example have been done, covering component test and system test instrument on spacecraft interface. The derived data will be compared and analysed.

INTRODUCTION
In the last years, force notching has been used very often for secure space instruments against overtesting during component tests. The difficulties using the force limited vibration approach consists in the stipulation of Limits. In common cases the Limits will be derived by methods introduced by NASA/JPL (Scharton 1997). These methods always will produce very conservative values for Force Limits compared to the Loads arising during Lift-Off. The conservative nature of these Limits is caused by the underlying theory. As a quick way to get Force Limits the Semi-Empirical Method has been established. But how are these loads in relation to real loads?
In the frame of a project raised by DLR, donated by BMBF, for a demonstration model Interface-Forces at different levels of development and integration have been investigated.

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1. DEMONSTRATION MODEL

This demonstration model simulates an electronic box located on an instrument bay of a satellite. The instrument bay consists of an honey-comb plate. For thermal reasons the instrument is connected through an interface plate to the instrument bay. Fig. 1 shows the system consisting of electronic box and honey-comb plate, forming the instrument bay.

The honey-comb plate is clamped at its corners. The honey-comb plate is this part of the satellite, which will take part at the system resonances of the system instrument and interface-structure.

To be able to measure the force, force gauges are located between electronic box and interface plate as well as at the connection points of the honey-comb plate to the ground.

The force gauges between electronic box and interface plate will give the Interface-Force whereas the remaining force gauges give the System-Force.

The electronic box (see Fig. 2) consists of the base-plate and two side-walls. Three electronic plates are attached to the side-walls. The remaining side-walls and the cover are omitted, to be able to see the dynamic behaviour of the electronic plates. This structure represents the instrument.

2. START OF THE PROJECT

At start of a space project, test requirements for dynamic excitation of instruments during component tests will be determined. At this stage only the predicted mass and Centre of Gravity (CoG) of the new instrument are known. For demonstration reasons a typical test specification (see table 1) will be used for the demonstration model.

<table>
<thead>
<tr>
<th>Frequenz in Hz</th>
<th>PSD in g²/Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>+3 dB</td>
</tr>
<tr>
<td>50</td>
<td>1.0</td>
</tr>
<tr>
<td>500</td>
<td>1.0</td>
</tr>
<tr>
<td>2000</td>
<td>-6 dB</td>
</tr>
<tr>
<td>overall</td>
<td>29 g RMS</td>
</tr>
</tbody>
</table>

Table 1: Test Specification for Demonstration Model

This specification may have been derived by Statistical Energy Analyses (SEA) of the coupled satellite and instrument model.

3. QUALIFICATION OF THE INSTRUMENT

The qualification of the instrument will be done at vibration shaker. Fig. 3 shows the set up for the out-of-plane direction.

The electronic box (see Fig. 2) consists of the base-plate and two side-walls. Three electronic plates are attached to the side-walls. The remaining side-walls and the cover are omitted, to be able to see the dynamic behaviour of the electronic plates. This structure represents the instrument.

For the component the responses in Fig. 4 have been measured.

At the first resonance of \( f = 242 \text{ Hz} \) an Interface-Force of \( F = 4900 \text{ N} \) occurs. The amplification of acceleration is \( Q = 40 \).
4. SIMULATION OF THE COUPLED SYSTEM SATELLITE-INSTRUMENT

As described above the system in Fig. 1 can be seen as the vibrating system involved in the system resonances instrument-satellite. For this system tests and Finite-Element-Analyses (FEA) have been done. Fig. 5 shows the test set up for this system.

And Fig. 6 shows the corresponding FEA-model. The excitation for test and calculation has been set to that level, which generates an acceleration level at component interface equal to the test specification for component.

In Fig. 7 the calculated and measured acceleration responses at component interface and on the top electronic plate are drawn.

It has to be noted that the acceleration level at component interface is comparable to the level specified for test requirements (black curve).
5. COMPARISON OF INTERFACE-FORCES

Now the Interface-Forces can be compared. On one side we have the Interface-Forces occurring during Component test. On the other side we have the Interface-Forces occurring in the simulated system test satellite instrument. In both tests the acceleration at the connection points of instrument are comparable. Fig. 8 shows the accompanying forces.

Fig. 8: comparison of Interface-Forces component test system test

The Interface-Force from component test (4900 N) is significantly higher than the real Forces (1020 N), which has been simulated in system test.

6. CALCULATED FORCE LIMIT

Based on the measured data during component test the following Force Limit can be derived.

The Semi Empirical Method states, that

\[ S_{FF} = C^2 \cdot M_0^2 \cdot S_{AA} \]  

(1)

- \( S_{FF} \) interface force PSD
- \( C \) semi empirical factor
- \( M_0 \) total mass (squared for PSD)
- \( S_{AA} \) acceleration PSD

up to the first resonant frequency. After that frequency the Force Limit falls off following the remaining residual mass.

In case of this demonstration model the value of \( C \) will be chosen as \( C=2 \), because of the mechanical impedance of structure of the interface.

For a component mass of 2.8 Kg a Force Limit of 3000N²/Hz will be derived.

Fig. 9 shows the values for Interface-Forces and the calculated Force Limit.

Fig. 9: Interface-Forces and Force Limit

The Force Limit covers the Interface-Forces occurring in system configuration.

7. NEW DEVELOPMENTS FOR FORCE CONTROL

The Demonstration Model was made for good conditions to measure the interface force. But instrument interfaces often not usable for fixing force gages. Also the interface with force gages can change the dynamic behaviour of the test item.

To solve this problem for the test wit an instrument according Fig. 10 a compensation of the death mass of the adapter plate was developed and successful tested.

Fig. 10 instrument interface

The force for the instrument with the test set-up according Fig. 11 is the difference of the complex force measured and the force driven by the mass of the adapter plate.

Fig. 11 force gages between shaker and adapter
The force driven by the mass of the adapter plate is the mass multiplied by the adapter acceleration. The measured force and acceleration of the adapter plate must be used for an online calculation. For this online calculation a fast µcontroller system with two input channels and a output channel is needed. The output is the calculated force of the instrument.

ASTRO has developed and tested this instrumentation in cooperation with KISTLER Instruments Germany. That’s a easy way to include force measurement into the test setup. For more information please contact the author.

8. CONCLUSION

The calculated Force Limit securely covers the force values, which occurred during system test and which will be predicted for occurring during flight.

The demonstration model shows the different loads for system test and component test and the changes in the dynamic behaviour.

In the shown example the possible reduction of input level is very small, because of the large mass of the stiff support structure for the electronic plates. To take into account such adverse conditions for the masses in the considered vibrating system, much more investigations have to be done. A possible solution can be the extraction of the stiff mass of the instrument from the active vibrating system.

The new force measurement method shows an easy way to include force measurement into the test setup.

9. REFERENCES


AUTHORS’ BIOGRAPHIES

Ritzmann:
Studies of Telecommunications
20 years experience in vibrational testing
expert in testing of scientific instruments dedicated to space flights
presently head of the Test and Quality Assurance department

Jahn:
Studies of Design
20 years experience in Finite-Element-Analyses, especially in dynamic analyses
presently head of the I-BN GmbH office in Berlin
APPENDIX

Fig. 4: acceleration and force response component test

Fig. 7: acceleration responses for the vibrating system
Fig. 8: comparison of Interface-Forces component test system test

Fig. 9: Interface-Forces and Force Limit