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Introduction

This technote describes the random vibration response of the SPIRE instrument and its impact on the specification of the random vibration test for the BDA. The note proposes at the end a notching strategy and input levels for the SPIRE instrument.

The first part of the note provides for a background of the problem by listing some results of the random vibration analysis carried out on the SPIRE finite element model issue 6. The instrument and its dynamics and the responses of the BDAs (JPL detectors mounted inside the instrument) are briefly discussed. See for more information the document " BDA analysis 2001-July.doc" distributed earlier by e-mail. The second part gives the results of the proposed notched input. Then the conclusions are given. The document ends, as said above with the proposed random input for the instrument.

Instrument description

The instrument FPU is a mono-coque structure at Level-1 temperature ("4 K"), attached at three locations to the Level-2 ("10 K") Herschel Optical Bench (HOB). Its main modes are at 120 - 180 Hz where basically the box is rocking on its mount. Modes are very clear, with a significant percentage of effective mass (over 60% for each mode).

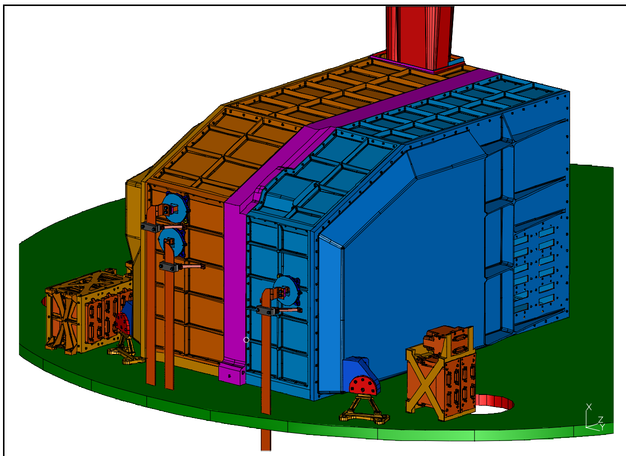

Fig. 1a: SPIRE outside view

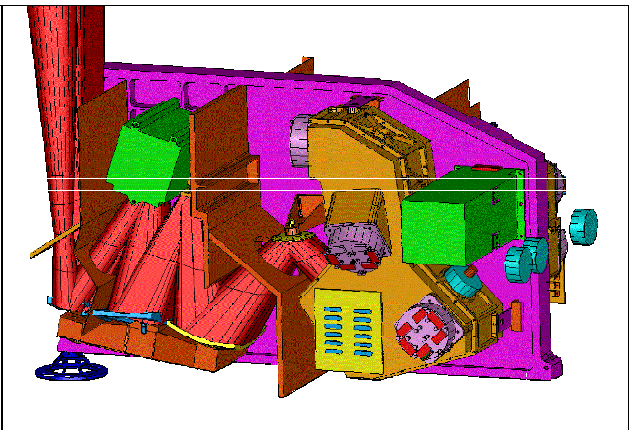

Fig 1b: SPIRE inside view photometer side
(with 3 BDAs visible light magneta, with red connectors)

Inside the mono-coque shell the SPIRE Optical Bench (SOB) is mounted, carrying on either side the photometer (pictured above) and the spectrometer. On each side, a Level-0 ("2 K") detector box, carrying the Bolometer Detector Assemblies (BDAs), is mounted on the SOB. The detector boxes are statically determined mounted on the SOB using thin walled tubes to insulate them thermally from the SOB.

As a mechanical system, it consists effectively of stacked resonators where each subsequent resonator has a higher eigenfrequency, compared to the one 'below' (closer to the HOB). The main resonators are the mono-coque shell, rocking on its feet (120 Hz), the optical bench (150 Hz), the detector box (190 Hz) and last (in this case) the BDA (lowest mode 220 Hz). The detector box is mounted on the edge of the SOB to minimise amplification of the SOB. There is not much choice in modifying the frequencies because they are the outcome of a delicate balance between thermal and structural requirements. It should be pointed out here that the detector box itself has several modes above 200 Hz. The 190 Hz quoted is the detector box rocking on its suspension.

First analysis

As a first step we applied the required input as specified in the IID-A issue 1.1, which defines the un-notched input at the base of the instrument as pictured in figure 2. (The listed g-rms values in the corner suffer from small numerical errors but are close to the real value.)

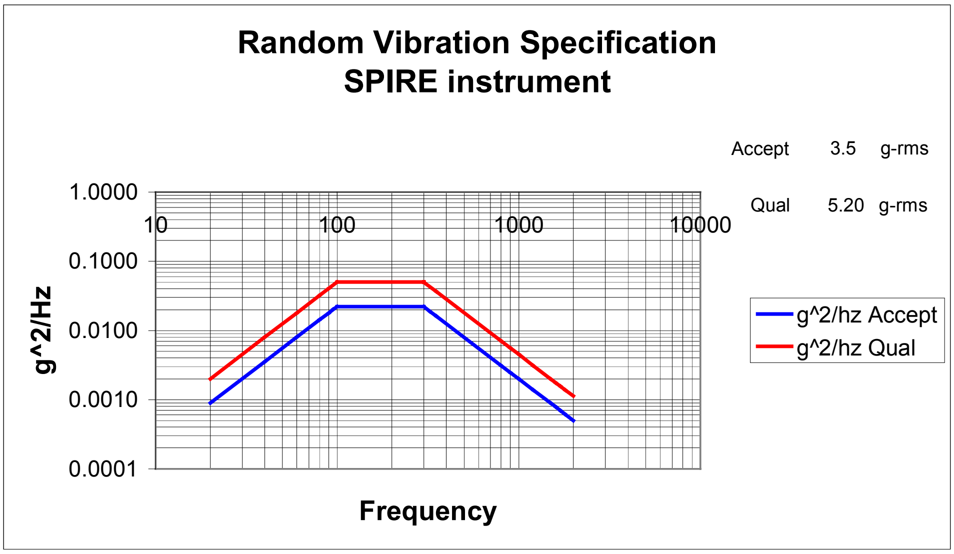

Figure 2: Random spectrum definition for all 3 directions (x, y and z)

This spectrum was taken as input for a random vibration analysis, together with the above mentioned FE. The results of this analysis served as input for the definition of the inputs for the various subsystems, the BDA being one of them.

In figure 3 the response of the 5 BDAs due to this input is given. Please note the following the units used to produce this graph are unusual, due to a software constraint. The units are all in SI, so $(m/s^2)^2$/Hz for the psd (divide by 9.807^2 to translate to g^2/Hz) and m/s^2 for the rms (divide by 9.807 to translate to g-rms)

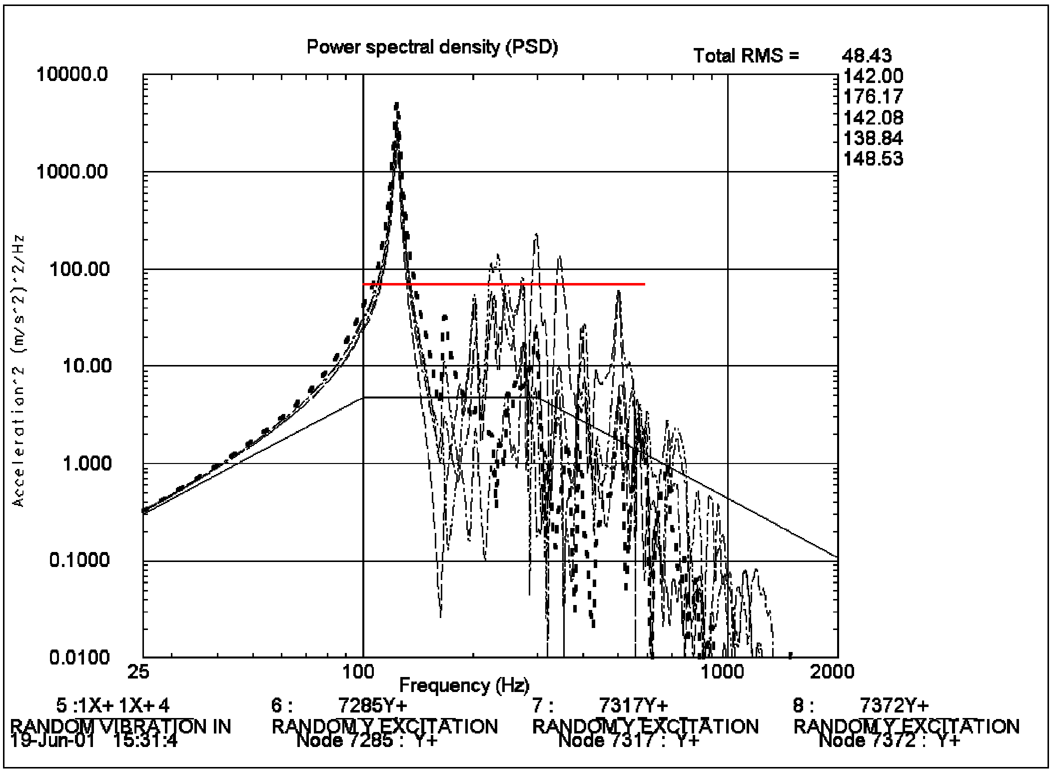

Figure 3: Response at the base of the BDA due to un-notched input given in figure 2

The red line represents the proposed plateau (with +6 dB/oct ramp up and -6dB/oct for the ramp down) for the qualification level BDA input. This is just the Y response to the Y input, the other responses show similar behaviour. The g-rms levels for the various directions, due to the various inputs (not shown here) reach levels of 25 g-rms for X and Z. This is equivalent to 75 g static input in the time domain. However, the BDAs have resonance's in the range of 200 to 400 Hz. Applying the Miles equation (giving the equivalent quasi-static response at resonance) the BDAs will reach levels in the range of 200 g equivalent acceleration. This will undoubtedly break the BDAs. One should note that the BDA will break during their individual sub-system qualification test, the coupled strength analysis with the instrument has not yet been performed. The current design is capable of withstanding accelerations less than 100 g.

Second analysis

Looking at the overall interface force response of the instrument as a whole it can be identified that the instrument at its own resonance's exceeds the equivalent quasi-static acceleration for the instrument itself as defined in IID-A. Based upon this a notch has been defined in the random vibration input for the instrument protect the instrument against over-testing. Baseline here is to notch the input for the instrument at it resonance such that the Newton-rms doesn't exceed 1/3 of the equivalent quasi-static load. Applying this notch a second analysis has been carried out with the results illustrated in figure 4.

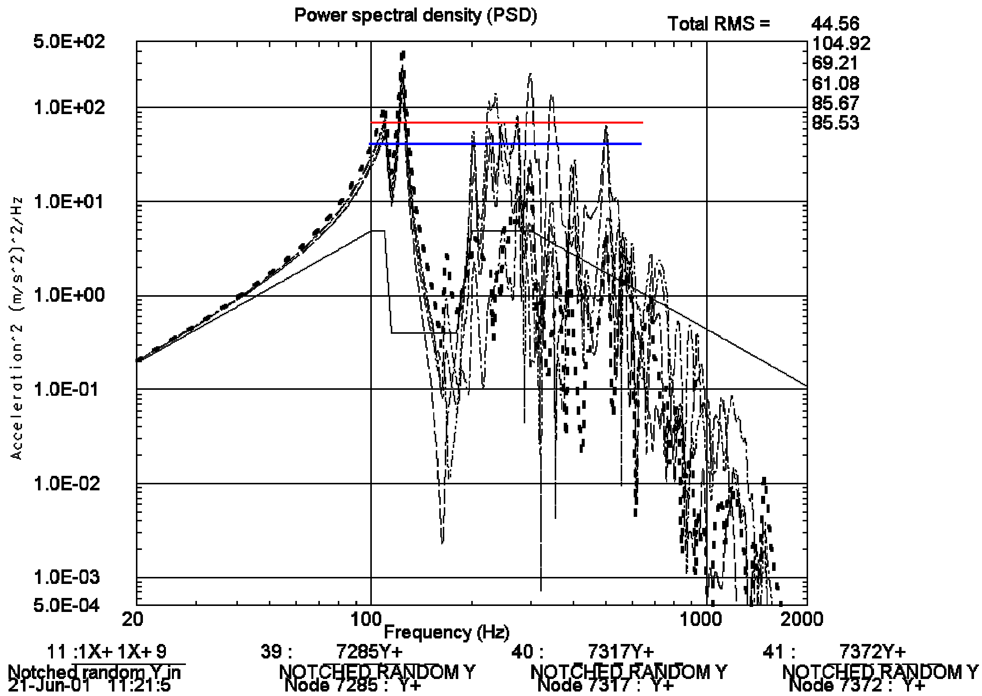

Figure 4: Response at the base of the BDA due to notched input given in the same figure (solid black line)

The red line represents again the proposed plateau (with +6 dB/oct ramp up and -6dB/oct for the ramp down) for the qualification level BDA input (now also included the flight level in blue). The g-rms levels for the various directions, due to the various inputs (not shown here) reach levels of 20 g-rms. This is equivalent to 60 g static input in the time domain. However, (again) the BDAs have resonances in the range of 200 to 400 Hz. Applying the Miles equation (giving the equivalent quasi-static response at resonance) the BDAs will reach levels in the range of 200 g equivalent acceleration. This will undoubtedly still break the BDAs. Again note that the BDA will break during their individual sub-system qualification test, the coupled strength analysis with the instrument has not yet been performed.

Conclusions

- The current random vibration specification for the instrument results in
  - unrealistic high interface forces for the instrument;
  - very high responses for the BDA.
- The BDA can not withstand the specified input during their sub-system test.

Based upon notching the second analysis results in:

- acceptable interface forces for the instrument;
- overall reduction in response;
- still high input for the BDA, resulting in unacceptable input levels for the BDA sub-system test.

Based upon these conclusions we decided to allow the BDAs to notch their input at resonance during the sub-system qualification test. However, we cannot allow an overall decrease in input for the BDAs. The design margins are very critical, and the current response of the instrument, even with notched input, produces high loads for the BDAs. This is due to three factors:

(i) the input at the base of the instrument;
(ii) the high frequency response of the instrument (between 200 and 600 Hz);
(iii) the main eigenfrequencies of the BDA are between 200 and 400 Hz.

Proposal

In order to reduce the required input for BDA sub-system testing the following approach is proposed by the SPIRE Project.

- The design of the Level-0 detector boxes will be examined and revised if possible to reduce the high frequency input (by stiffening them to reduce modes between 200 and 600 Hz). This will help, but it is unlikely that a major reduction of BDA responses can be achieved.

- JPL will look in detail, based upon input from MSSL (loads from coupled analysis, evaluating every detector separately) into the margin of safety for the detectors. To ensure these are sufficient, this should give larger margin compared to an overall input definition for the detectors.

- We ask ESA/Atrium to reduce the random vibration input above 200 Hz as much as possible.

The last point is very important since we squeezed out all possible margin already and are at the moment still left with an equivalent quasistatic input for the BDA at sub-system level testing of 100 g, both in the time domain (overall g-rms) as well as at the BDA resonance (Miles)

Proposed change of random vibration requirement.:

1. Allow the instrument to notch, based upon equivalent quasi-static acceleration interface forces
2. Define the required un-notched input as follows:

- 20 - 100 Hz Ramp up at +6 dB/oct.
- 100 - 200 Hz 0.05 $g^2\ Hz^{-1}$
- 200 - 300 Hz 0.03 $g^2\ Hz^{-1}$
- 300 - 2000 Hz Ramp down at -6 dB/oct.

Appendix A Applied notches, I/F force information

Using the un-notched input taken from IID-A issue 1.1 the interface forces were calculated at the base of the instrument. They are pictured in figure A-1 and listed in table A-2.

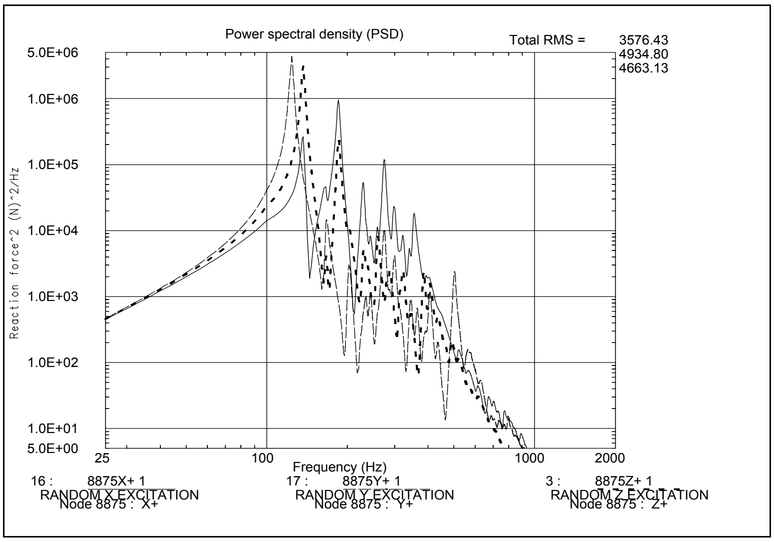

Figure A-1: Un-notched I/F force for the three orthogonal directions

Input direction	kN-rms resp. (un-notched)
X	3.6
Y	4.9
Z	4.7

Table A-2

The equivalent quasi-static forces are 7.5 kN, 5.2 kN and 5.2 kN respectively (for this FEA and with an input of 20, 14 and 14 g respectively). We should not exceed the equivalent quasi static interface force with the random time based response. We should therefore not exceed: 2.5 kN in X and 1.7 kN in Y or Z direction. Forces being N-rms are divided by 3 to take into account the 3-sigma variation of the force in the time domain. In order to scale the input for the instrument to obey this boundary condition we notch the primary mode in each excitation direction (modes with significant effective mass > 10% of instrument mass). The resulting interface force is pictured in figure A-3 (compare with figure A-1)

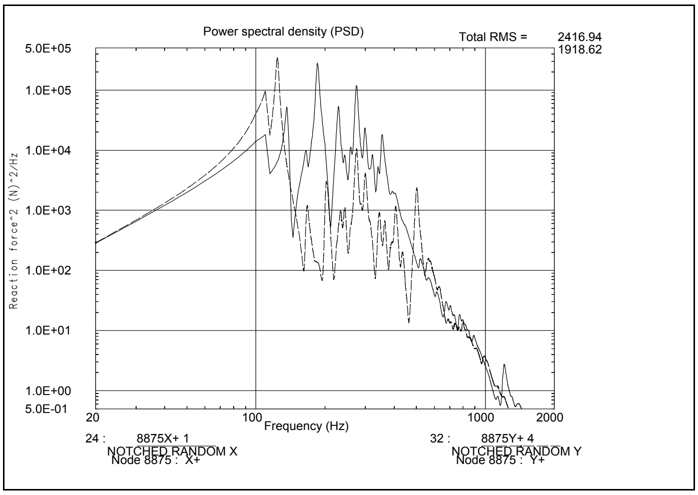

Figure A-3: Notched X and Y -input X=2.4 kN Y=1.9 kN (rms)