**SUBJECT:** **Herschel/SPIRE Instrument Cold Vibration Test Report FM acceptance**


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# CHANGE RECORD

| ISSUE | SECTIONS | REASON FOR CHANGE |
|---|---|---|
| 0.1 | all | Draft Issue |
| 0.1b | | ESA comments added |
| 1.0 | | Photographs added, appendix A, C, D, E completed |
| 2.0 | 9 | Conclusions added |
| | 10 | Problem areas added |

# Table of contents

# 1. SCOPE

This document lists the acceptance test results of the cold vibration test of the Herschel SPIRE instrument flight model (FM). This model is the flight model with a few exceptions as listed in section 5. The CQM model was tested in April 2004 with the stainless steel supports for the instrument itself as well as for the detector boxes. The FM test started with an all CFRP support. Halfway during the Z-axis vibration testing the instrument cone had to be replaced by a stainless steel one.

# 2. DOCUMENTS

| | | |
|---|---|---|
| AD (1) | Instrument Interface Document, part A | IID-A, issue 3 |
| AD (2) | Technote 9 Random Vibration SPIRE February 2003 issue 3.doc | |
| AD (3) | Instrument Interface Drawing | 5264-300 sheet 1 to 7, issue 18 |
| AD (5) | As built status | SPIRE-RAL-DOC-002326 issue 2.2 |
| AD (7) | HERSCHEL : SPIRE STM QUALIFICATION | AIV-2003-027-VIB |
| AD (8) | TRR1 minutes of meeting | SPIRE-RAL-MOM-001958 |
| AD (9) | Cold vibration test plan | SPIRE-RAL-PRC-002524, issue 2.1 |
| AD (10) | Cold vibration test procedure | SPIRE-RAL-PRC-002539, issue 2.2 |
| AD (11) | SPIRE FPU Handling and integration procedure | SPIRE-RAL-PRC-001923 |
| AD (12) | Cryo-vibration test report SPIRE FM 1 | RP-CSL-CRYOV-05001, version 1 |

# 3. DEFINITIONS

## 3.1. Abbreviations

| | |
|---|---|
| AD | Applicable Document |
| BSM | Beam steering mirror |
| CQM | Cold Qualification Model |
| EM | Engineering Model |
| FM | Flight Model |
| ICD | Interface Control Document |
| PFM | Proto-Flight Model |
| STM | Structural Thermal Model |
| S/C | Spacecraft |
| TBC | To be confirmed |
| TBD | To be defined |
| TRB | Test Review Board |
| TRR | Test Readiness Review |
| TML | Total Material Loss |
| VCD | Verification Control Document |
| VCM | Volatile Condensable Material |

# 4. TEST PHILOSOPHY

The test item is the FM model of the SPIRE instrument as it will be flown, with the exception of the SMEC. The SMEC will be replaced at a later stage after which a workmanship cryo-vibration test may be performed. The instrument will be acceptance tested. That is at reduced levels compared to the CQM test and for shorter durations.

# 5. BUILD STANDARD

The instrument is the flight model with all parts up to flight standard with the exception of the SMEC. The SMEC will be replaced by the SMEC flight model at a later stage.
AD(5) As built configuration list applies.
Due to a degrading CFRP instrument main cone support the instrument mounting was changed between the Y and Z axis vibration.

| Axis | Instrument Cone | Drawing | A-frames | Drawing |
| --- | --- | --- | --- | --- |
| Y | CFRP 'A' | B3MD-00.20.022 | CFRP No3 and No4 | B3MD-00.20.017 |
| Z* | CFRP 'A' | " " | CFRP | " " |
| Z | Stainless | 5264-302-5 | CFRP | " " |
| X | Stainless | " " | CFRP | " " |

Table 5-1: Instrument support parts used during the test

# 6. TEST OBJECTIVES

- To acceptance test the SPIRE instrument.
- The test sequence was dictated by the cryo-vibration facility. It consisted of:
  - Cool down
  - complete Y-axis
  - shaker table/cryo-chamber rotation
  - complete Z-axis
  - warm up
  - reconfiguration
  - cool down
  - complete X-axis

After the sine vibration run in the Z axis it appeared the main structure response had degraded in such a way that it was decided to stop the test and inspect the instrument. Minor cracks were found in the CFRP instrument support cone. It was decided after an TRB meeting to replace the CFRP cone with the original stainless steel alternative as This was already qualified and the degradation to thermal performance was acceptable.

# 7. FIXTURE

The fixture for this cold vibration test was provided for by CSL

# 8. TEST REQUIREMENTS

## 8.1. SUMMARY

Resonance search, sine vibration test and random vibration tests were carried out in three axes. Resonance searches and intermediate random tests were performed in all three axes before the instrument was subjected to qualification runs.

## 8.2. Fixture qualification runs

Runs on just the bare fixture were carried out to prove that the fixture (and cold vibration facility) behaviour was suitable for the test. This was carried out before the instrument test. Test was successful.

## 8.3. Resonance search

A resonance search was performed between all major runs (qualification level), as the first and also as the last run in each axis.

## 8.4. Sine vibration test

See AD12 for all response curves.

The acceptance level sine testing was adjusted as not to exceed 1000 load cycles for the main structure and to accommodate the limitation of the shaker (stroke of ±1 mm)
As stated in AD (9) the acceptance levels are (here limited to the facility lower frequency 20 Hz and the 1000 maximum load cycles). Sweep rate was 4.0 oct/min. For each test the input was specified via the average response of the accelerometers located on the shaker table near the feet of the instrument.

**X axis**

| Frequency Range Hz | Acceptance level |
|---|---|
| 20 – 42.4 | +/- 1mm |
| 42.4 - 90 | 14.4 g (1000 cycles) |
| 90-100 | 6.4 g (remainder) |

Test sweep rate 4 Oct/min, the input was limited to the equivalent quasi static interface force.

**Y and Z axis**

| Frequency Range Hz | Acceptance level |
|---|---|
| 20 - 29 | +/- 1mm |
| 29 - 75 | 6.4 g (1000 cycles) |
| 75-100 | 4.8 g (remainder) |

Where applicable the input was limited to the equivalent quasi static interface force. For this, since no force cells were available for this test, accelerometer readings were used on or near the CoG of the instrument. During the X-axis sweep the SMEC response was capped to the specified input level since its first resonance is located at 110 Hz.

Note that the shaker system (including the cryostat) is responsible for some artefacts. One of these is a dip in the input at 50 Hz in the Y and Z-direction. After reconfiguring the shaker this artefact had shifted to 67 Hz (X axis).

**Achieved Levels and discussion X-AXIS**

The accelerometer at the top of the SPIRE optical bench was used as a control to limit the interface force to an equivalent 14.4 or 6.4 g static force where applicable. The number of maximum load cycles was limited to 1000. Based on the limitation of the CSL shaker (2 mm stroke maximum) maximum input could only be achieved at 42.4 Hz, continuing the maximum input to 90 Hz gives roughly 1000 cycles. After 90 Hz the input is lowered to 4.8 g with scaled limits accordingly. In order to protect the delicate spectrometer mechanism with a first resonance frequency at 110 Hz the the response of the top of the SMEC was limted to the input specification.

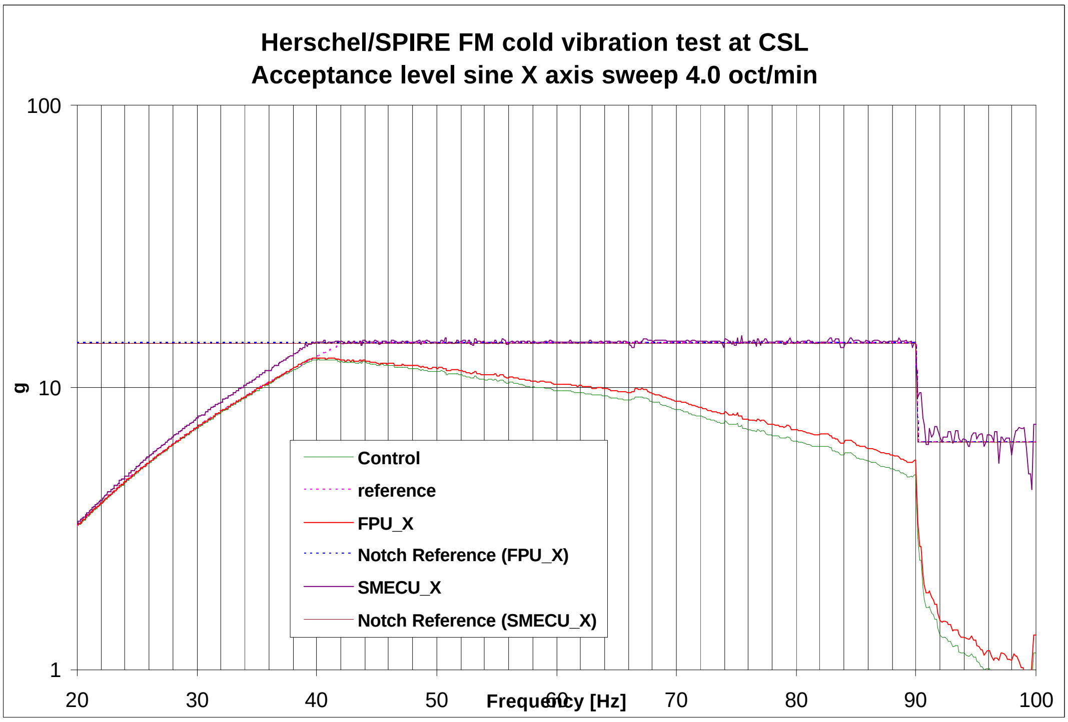



Figure 8.4-1 Achieved inputs for the X direction

Since during possible subsequent workmanship test no test instrumentation will be mounted internally the measured response of the FPU_X on the outside of the instrument will be used as a notch reference for future workmanship tests.

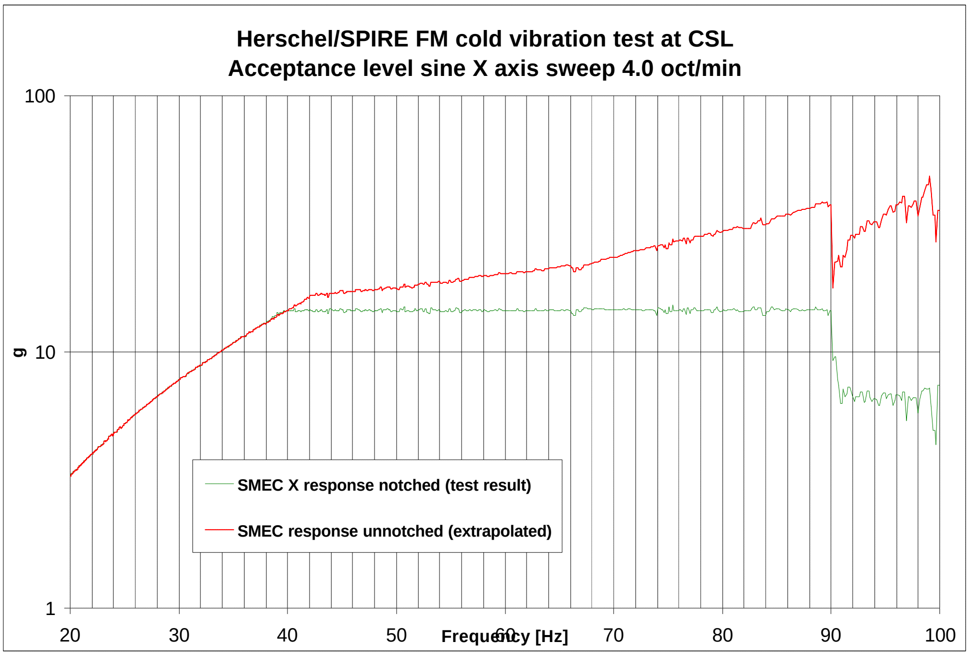



Figure 8.4-2 Measured and extrapolated X direction response of SMEC

Figure 8.4-2 shows the actual measured response (limited to the specified input, green bottom line) of the top part of the spectrometer mechanism and the extrapolated response of this mechanism if we had limited the response of the instrument just based on the CoG response. The SMEC response would have been too high, exceeding its qualified level of 20 g.

**Achieved Levels and discussion Y-AXIS**

A similar strategy was followed for the Y-axis. The Y-axis has a flat input of 6.4 g up to 75 Hz. Then it is lowered down to 4.8 g at 75 Hz and continued to 100 Hz. This was the first axis tested at CSL. Figure 8.4-3 shows the responses. The response of the CoG was limited to the specified input. The notch level for the CoG was set via the FPU_Y where the amplification factor between FPU_Y and CoG was taken into account.

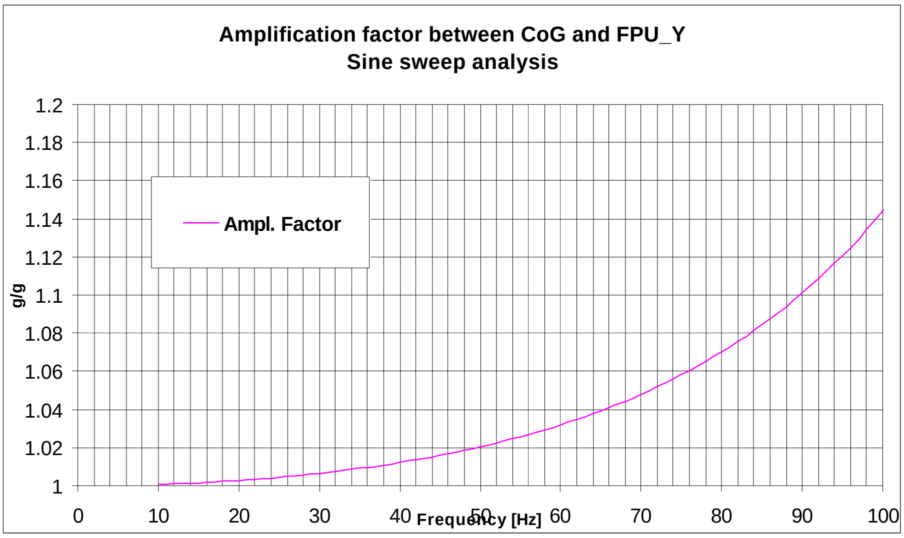



Figure 8.4-3: Amplification factor between CoG response and FPU_Y

The CoG response was limited to the specified input by notching the FPU_Y response to 6.7 g below 75 Hz and to 5.5 g above 75 Hz. The levels were set by the amplification as shown in figure 8.4-3.

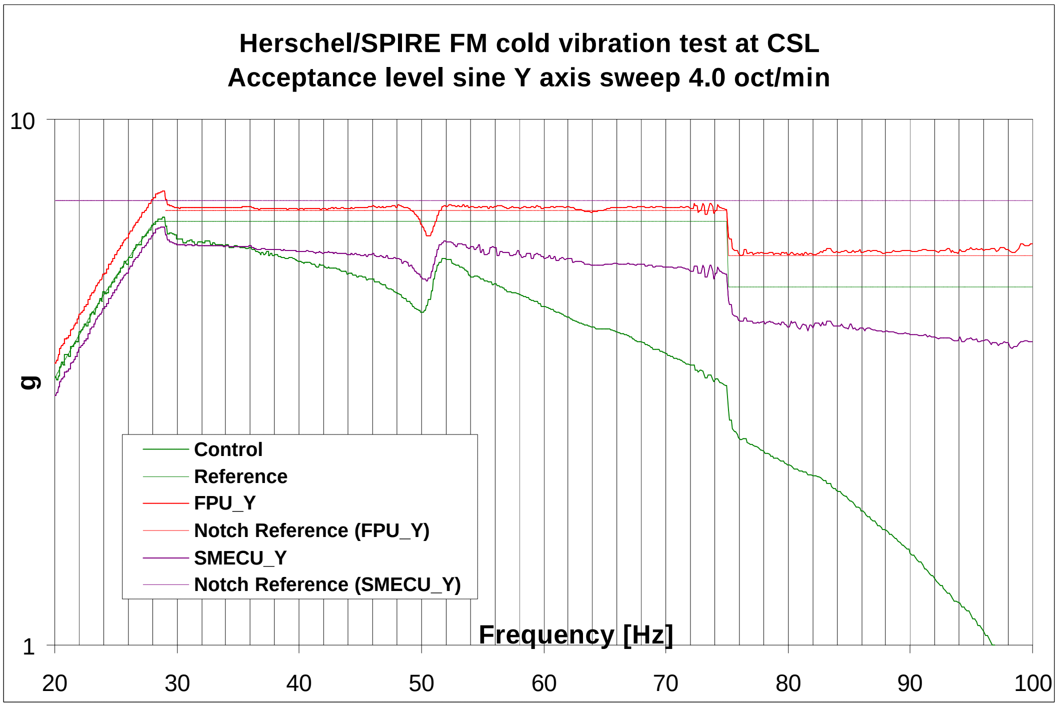



Figure 8.4-4 Achieved responses for the Y direction

Various points on detector boxes and SMEC.

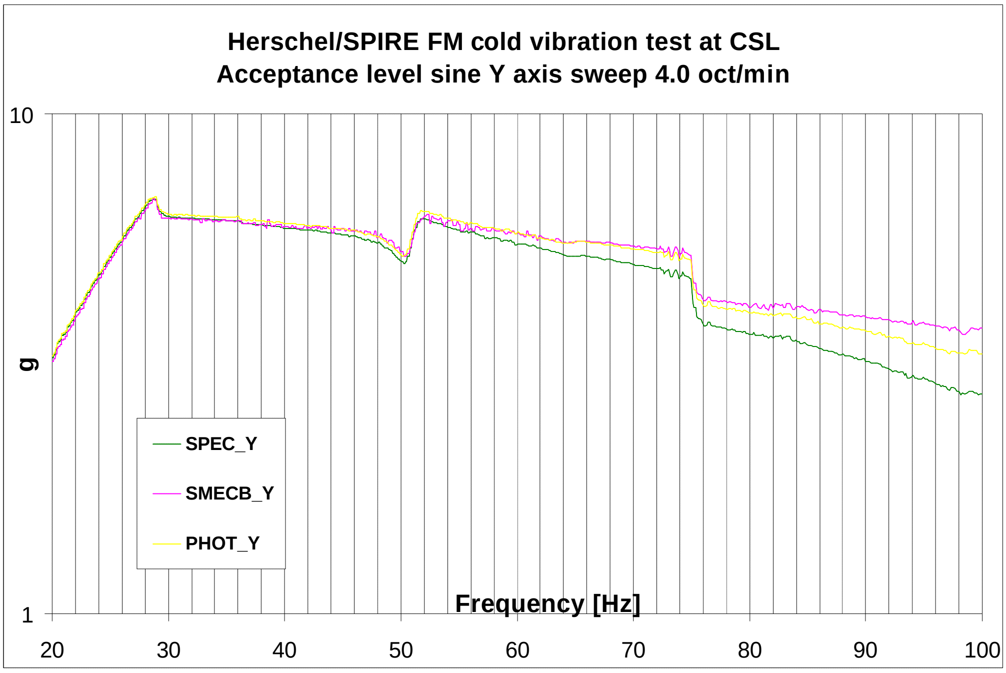



Figure 8.4-5 Achieved responses for the Y direction (continued)

**Achieved Levels and discussion Z-AXIS**

For the Z-axis the problem was to protect the Spectrometer mechanism. The SMEC_Z accelerometer showed during previous runs a significant amplification, shown in figure 8.4-6.

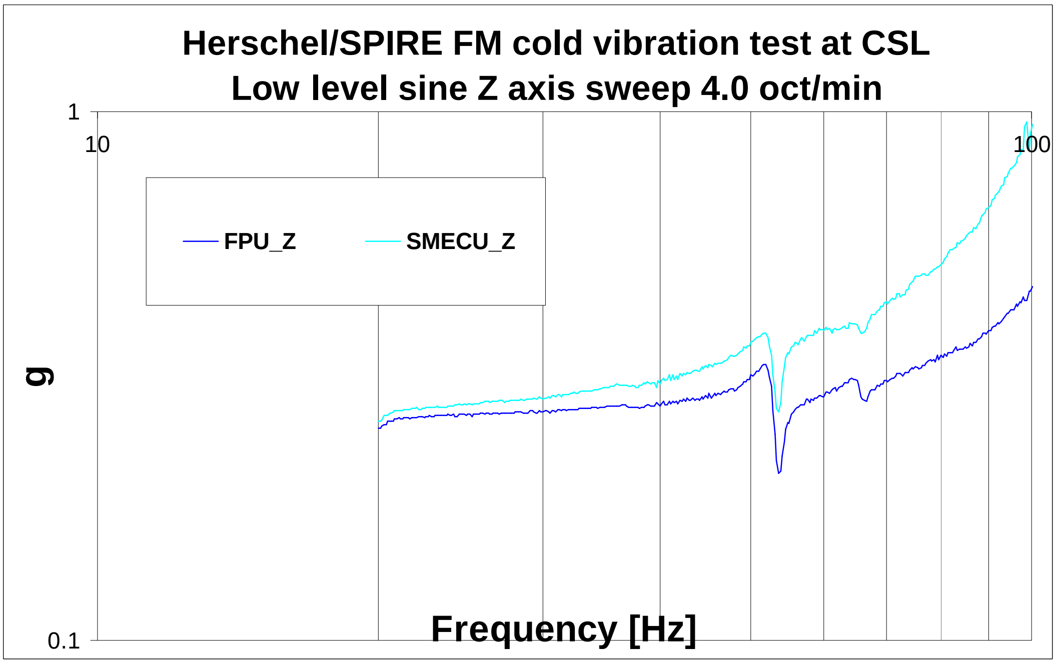



Figure 8.4-6 FPU_Z and SMECU_Z response (low level)

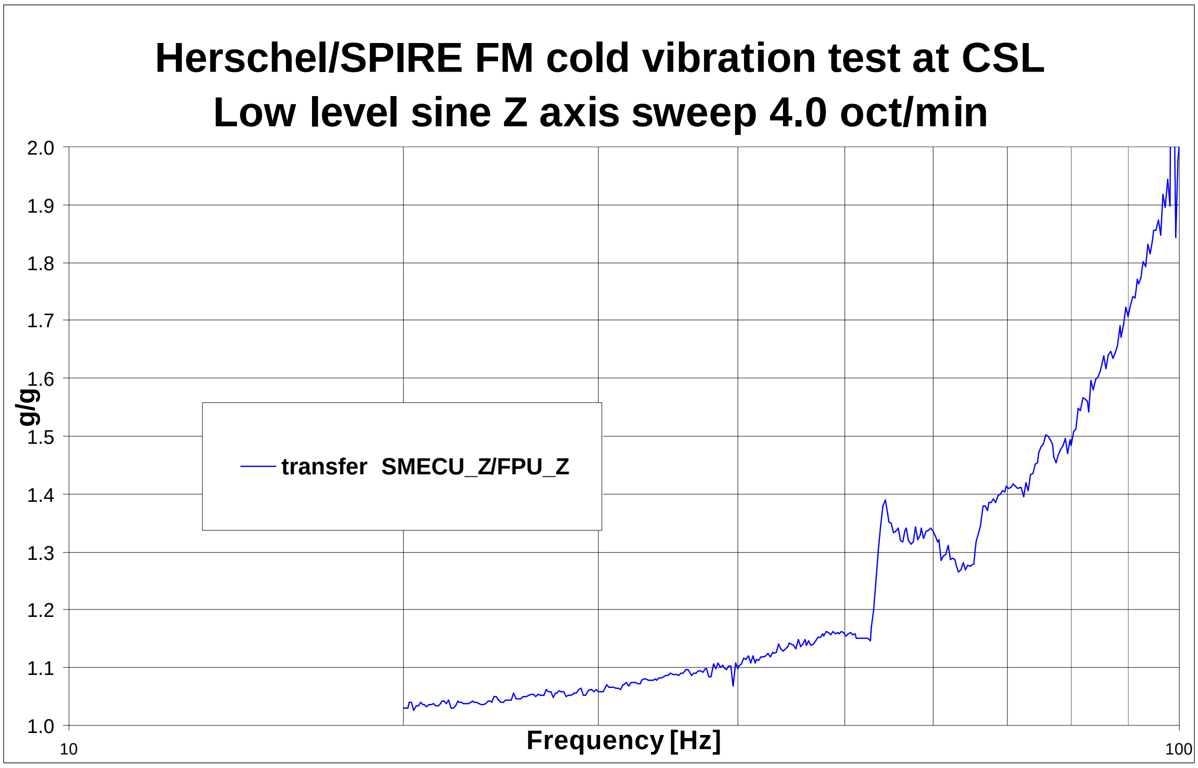



Figure 8.4-7 FPU_Z and SMECU_Z transfer function (low level)

After the first low level run the SMECU_Z signal was lost, in order to prevent subjecting the SMEC to loads higher than its acceptance levels the response of the FPU_Z was notched to protect the SMEC (indirectly) using the transfer function displayed in figure 8.4-6.

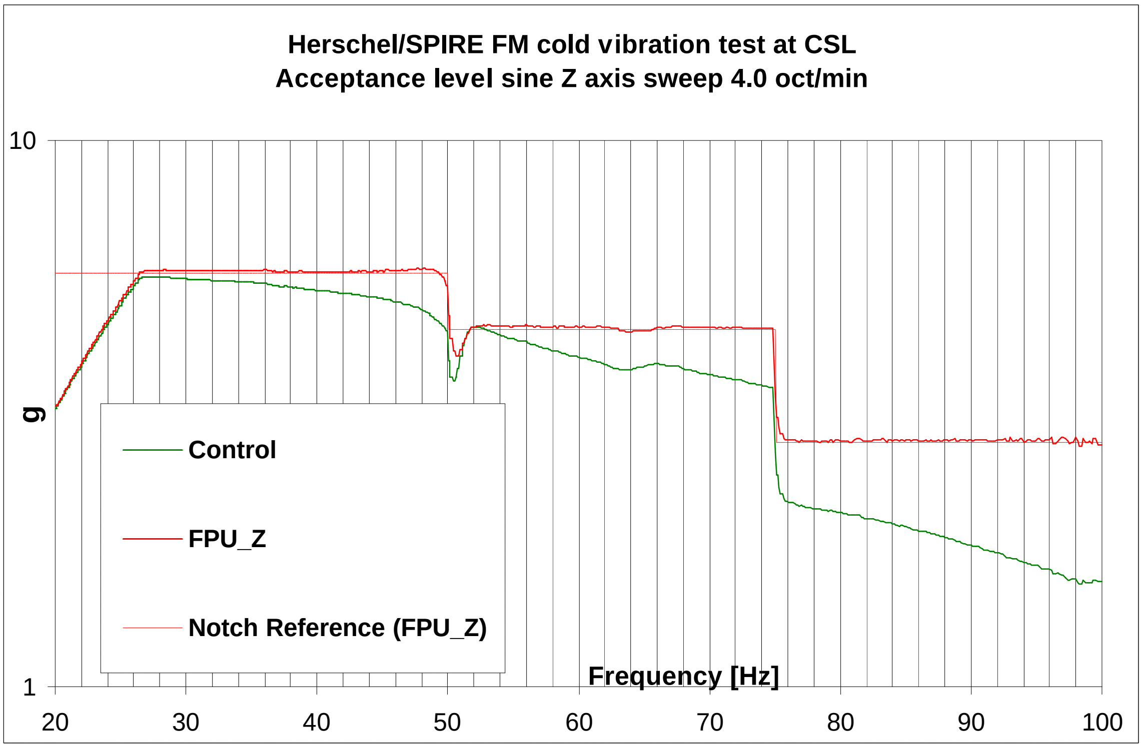



Figure 8.4-8 Achieved inputs for the Z direction

Figure 8.4-8 shows the achieved response of the FPU_Z. A third order interpolation function was used to approximate the transfer function (using the least square method), shown in figure 8.4-9. This was necessary (for this report) in order to display the achieved SMECU_Z response, based on this function. The interpolation needed to be carried out in order to account for different frequency samplings within the different recorded traces.

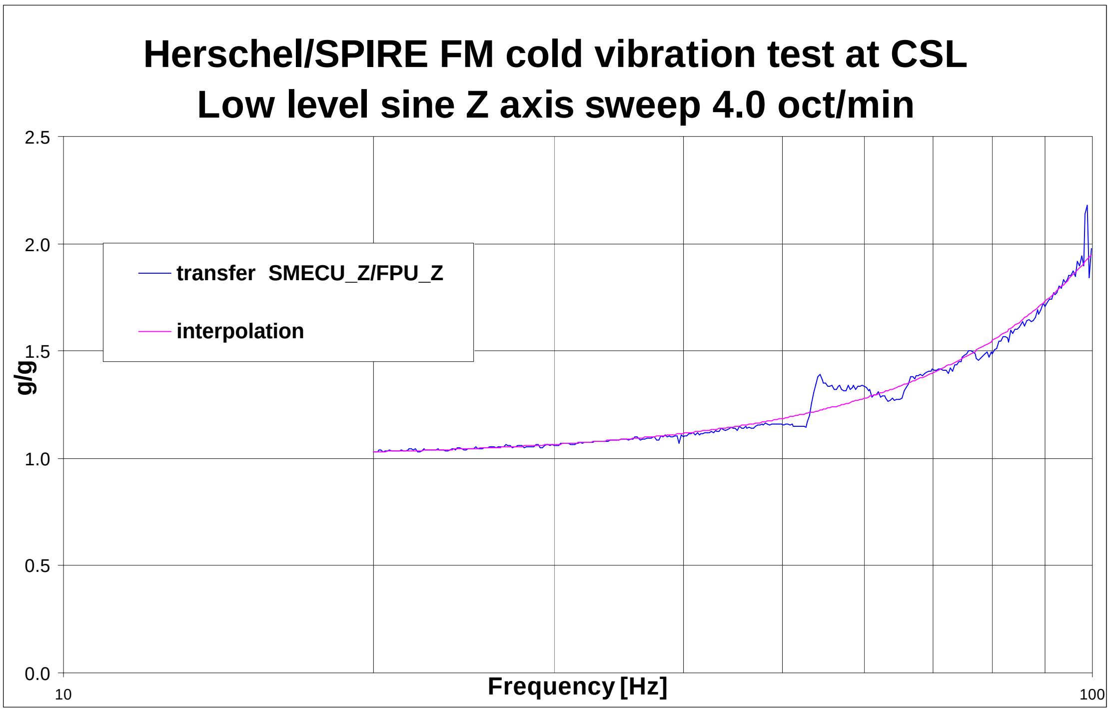



Figure 8.4-9: Transfer function and interpolation (required to scale functions with different frequency spacings)

The reconstructed SMECU_Z response is given in figure 8.4-10.

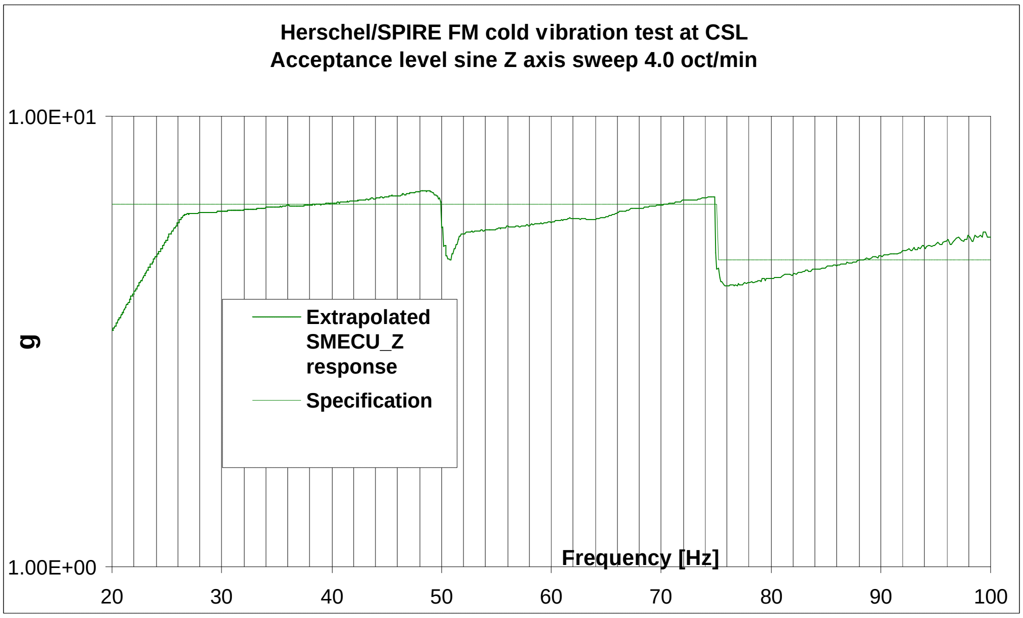



Figure 8.4-10 The reconstructed SMECU_Z response

The reconstruction in figure 8.4-10 shows that the SMEC did not exceed the acceptance level by more than 7% to 13%.

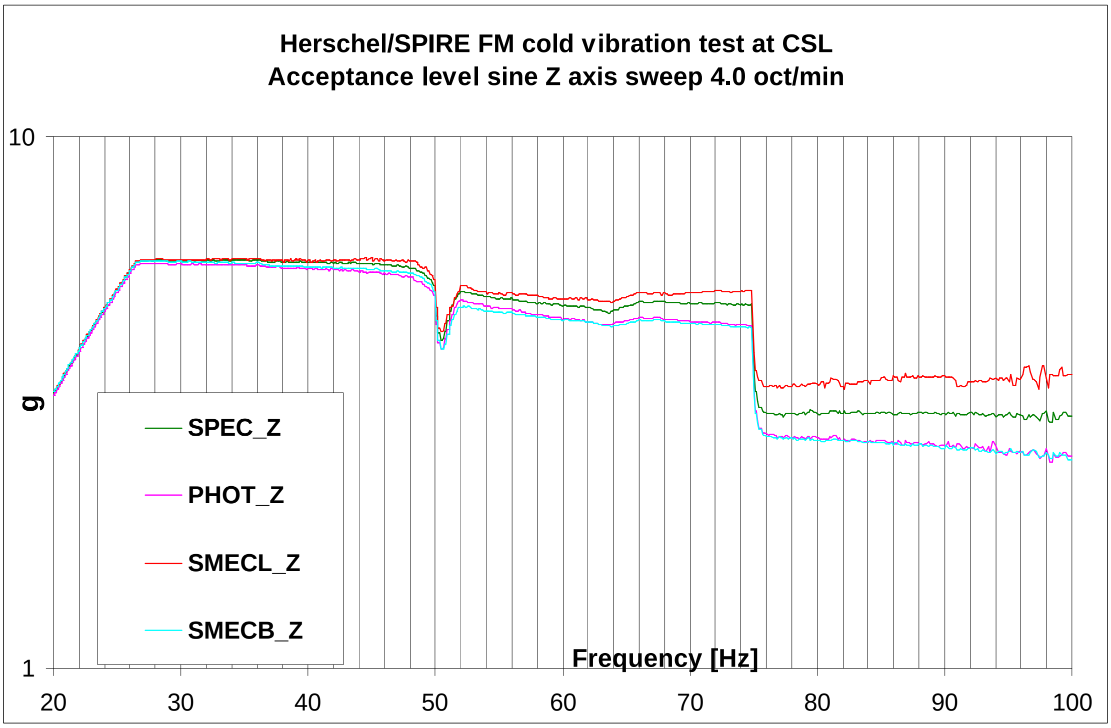



Figure 8.4-11 Achieved inputs for the Z direction (continued)

## 8.5. Random vibration test

See AD12 for all response curves.

As stated in AD(9) the acceptance levels were defined as follows.

**Y and Z axis**

| Frequency Range Hz | Qualification level |
|---|---|
| 20-100 | +3dB/Oct |
| 100-150 | 0.0128 $g^2$/Hz |
| 150-300 | 0.008$g^2$/Hz |
| 300-2000 | -12 dB/Oct |
| Global | 2.0 g-rms |

Table 8.5-1: Y and Z axis input definition for random acceptance

Test duration 1 minutes in each axis

**X axis**

| Frequency Range Hz | Qualification level |
|---|---|
| 20-100 | +3dB/Oct |
| 100-150 | 0.032 $g^2$/Hz |
| 150-300 | 0.0128$g^2$/Hz |
| 300-2000 | -12 dB/Oct |
| Global | 2.8 g-rms |

Table 8.5-2: X axis input definition random acceptance

Test duration 1 minute

**Input definition** (control)

For each test the input was specified via the average response of the accelerometers located on the shaker table near the feet of the instrument. For all tests this was the average over 3 accelerometers.

**Notching**

For all (but X-axis) random tests force notching was applied as well as notching on the responses of some of the components on the SPIRE optical bench.

**Force Notching**

Force notching was done indirectly via the instrument CoG response. As a minimum, a clear response should be present in the first mode indicating a significant amount of modal mass. Secondly notching on interface force is not allowed significantly beyond the first resonance frequency. In principle notching should be limited around the first eigenfrequency up to 1.5 times the first eigenfrequency (2.0 times if needed but not allowed to extend beyond twice the first eigenfrequency). When there is no clear first response mode present (effective mass spread out over the first few modes) indirect (by limiting the acceleration response) force notching is not allowed.

**Detector response notching**

Notching on the detector responses was performed indirectly, as was done during the CQM testing. The notching had to be done indirectly since it is not even close to practical to measure the detector responses directly. The notching was performed on a detector response as predicted by the miles equation. The internal (mechanical sensitive) part of each detector is a 300 mK Kevlar suspended stage with a mass between 0.1 to 0.3 kg.

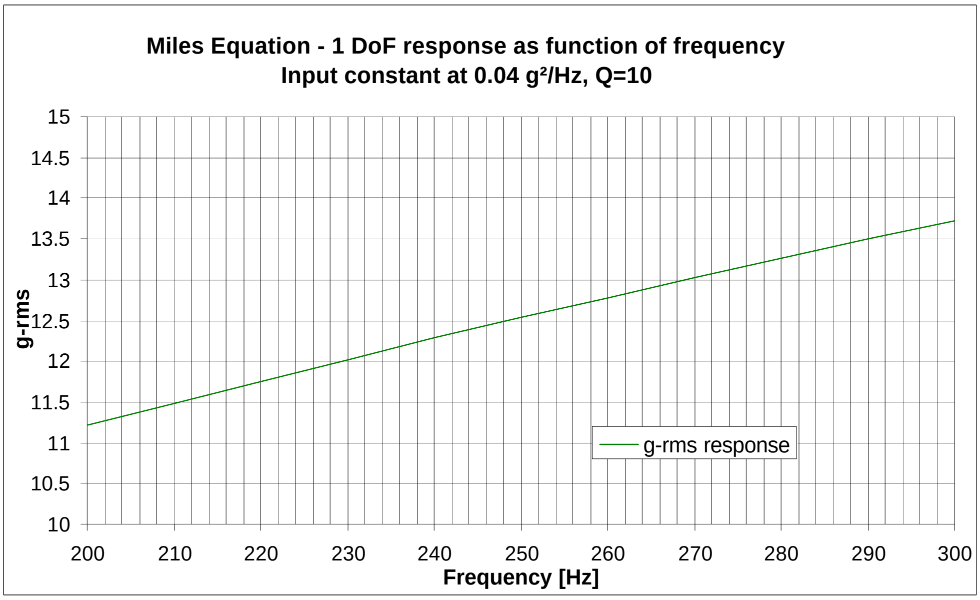



Figure 8.5-3: Miles response (as a function of frequency)

The graph shown in 8.5-3 shows extrapolated detector response as function of detector box response. The notching on detector response follows the curve shown in figure 8.5-3 limiting the response of the detector boxes to 0.04 $g^2$/Hz and indirectly the detectors to about 11 g-rms (1-sigma) where the detectors are qualified for 15 g-rms. The detectors have first resonances between 200 and 300 Hz. In the Z-axis a mistake was made where the input to the detectors was limited to 0.004 $g^2$/Hz, due to a wrong reference in a graph.

**Spectrometer mechanism**

The responses of the SMEC were measured directly and the responses were limited to around 8 grms. On top of that the quasi-static responses were limted to the input specification (which was important for the X-axis notching).

**Achieved Levels and discussion X-AXIS**

For the X axis it was decided not to notch on equivalent quasi-static interface forces since the overall response of the instrument at lower frequencies showed that the interface force would not exceed the equivalent QS-interface force (effective mass is spread out). The only notch applied was therefore to protect the detectors and the spectrometer mechanism.

Because in the future workmanship testing has to be performed without any accelerometers mounted on the inside of the instrument it was decided to actively notch on the FPU_X accelerometer only.

The notching applied on this accelerometer is to prevent over testing of the SMEC in particular. The SMEC has its first resonance frequency in the 110-120 Hz range. See figure 8.5-2 for comparison between FPU and SMEC_U response in X. The input is 0.25 g average over the three mounting points of the instrument.

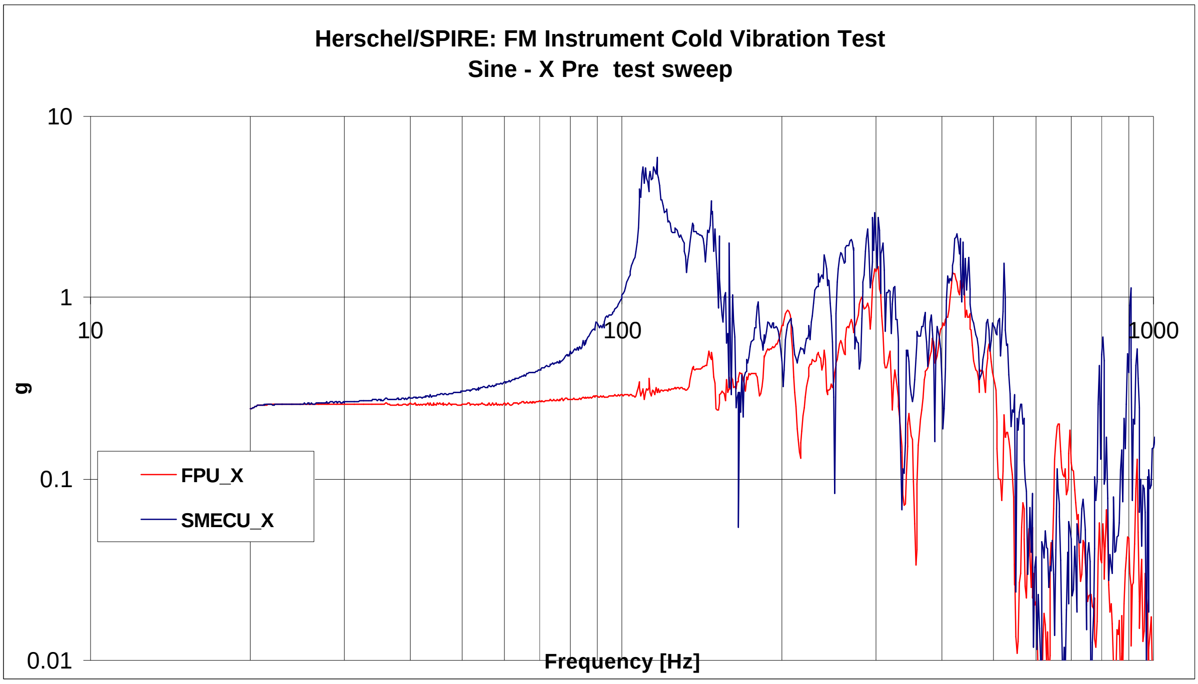



Figure 8.5-2: Filtered low level sine sweep response, note the (jagged) response of the SMEC between 110 and 120 Hz.

The SMECU_X response is strongly influenced by the play on the pinion that holds the moving part of the mechanism in place. As a result the response is not 'clean' and influenced by rattle/shockloads. Never the less, the first mode is clearly present and the loading of the SMEC as a result serious.

The low level random sweep gave the rms-levels listed in table 8.5-3.

| Frequency range | FPU_X (g-rms) | FPU_Y (g-rms) | FPU_Z (g-rms) | SMECU_X (g-rms) | SMECU_Y (g-rms) | SMECB_X (g-rms) | SMECB_Y (g-rms) | SMECB_Z (g-rms) |
|---|---|---|---|---|---|---|---|---|
| 20 - 300 Hz | 0.99 | 0.98 | 1.18 | 5.91 | 1.72 | 1.05 | 0.82 | 0.84 |
| 20 - 700 Hz | 1.09 | 1.02 | 1.21 | 6.76 | 2.05 | 1.10 | 0.89 | 0.88 |
| 20 - 2000 Hz | 1.11 | 1.11 | 1.26 | 9.04 | 4.51 | 1.83 | 3.33 | 2.37 |

Table 8.5-3: Measured g-rms levels (at -12 dB), calculated over different frequency domains

From table 8.5-3 it can be concluded that there is no need for force notching in X direction during random vibration, maximum response of the main structure will be below 5 g-rms. There is however significant cross-coupling in Y and Z potentially exceeding the qualification levels in Y and Z.

The SMEC responses show significant responses in both X and Y. The SMECU_X response will be between 25-30 g-rms if no notching is applied. In order to protect the SMEC and to comply with the maximum response level for the SMEC in any direction of 8 g-rms the response has to be limited for the acceptance run. Notching in the 115 Hz region (first eigenmode for the SMEC) would not reduce the response enough and the response of the SMEC had to be limited all the way up to 700 Hz to stay within limits.

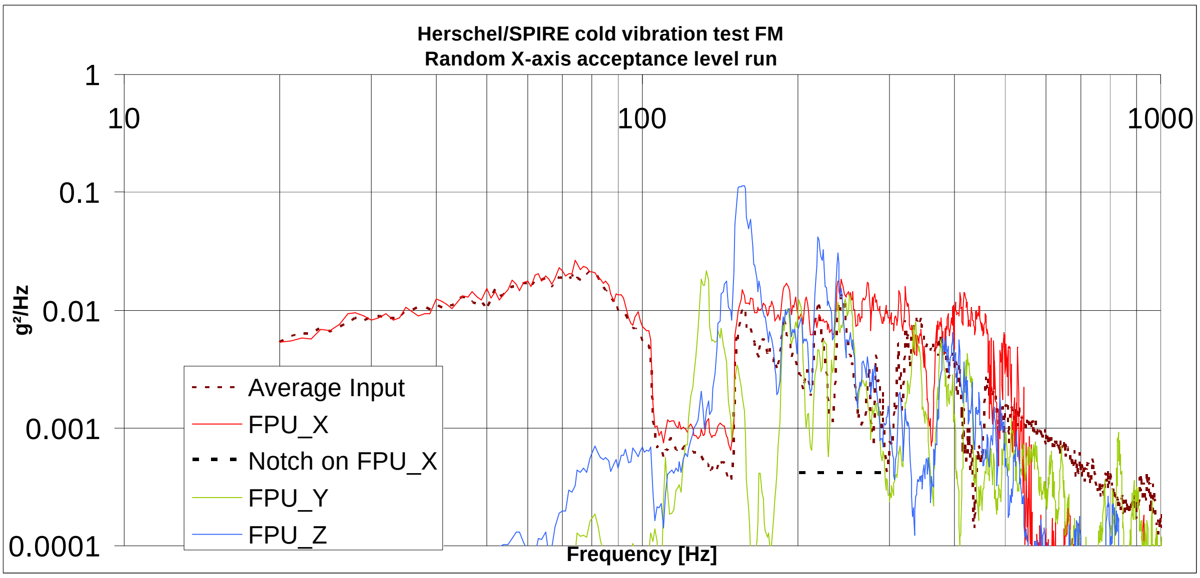



Figure 8.5-4 Achieved random responses in X main structure

Figure 8.5-4 shows the input and achieved levels for the main structure together with the applied notch. The notch was there to protect the spectrometer mechanism. As stated before, only responses on the outside of the instrument were limited for this axis only since the same control can be used during workmanship test.

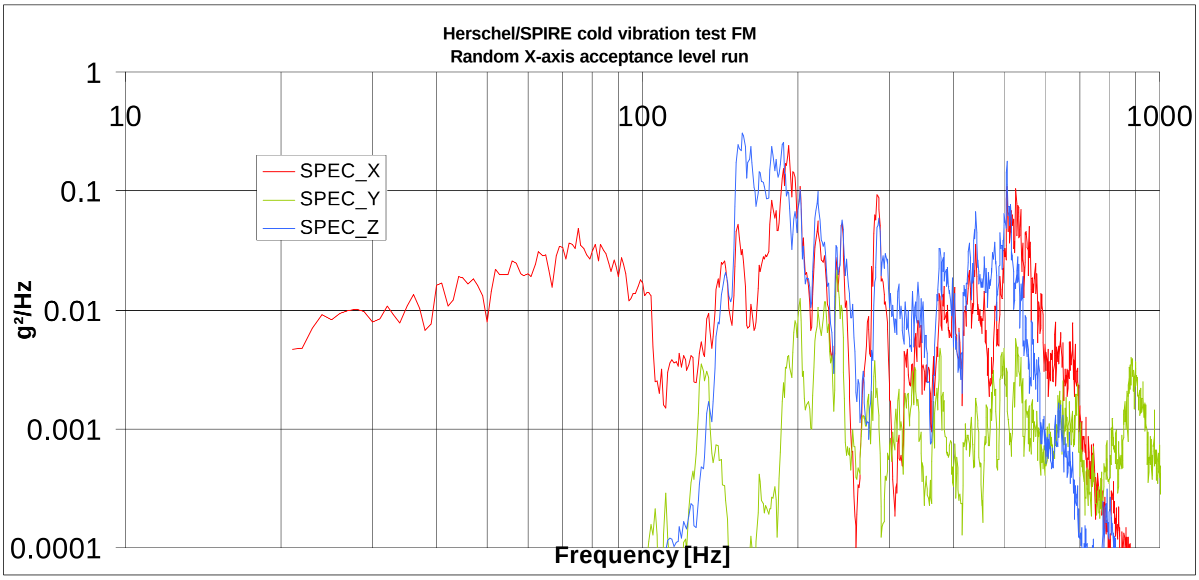



Figure 8.5-5 Achieved random input for spectrometer detector box

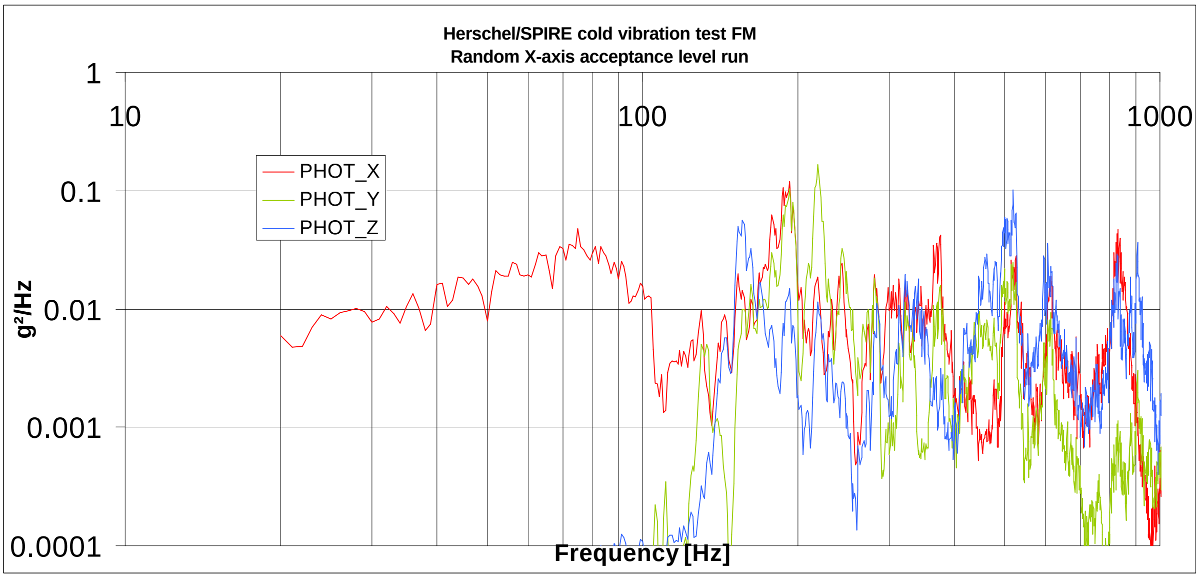



Figure 8.5-6 Achieved random input for photometer detector box

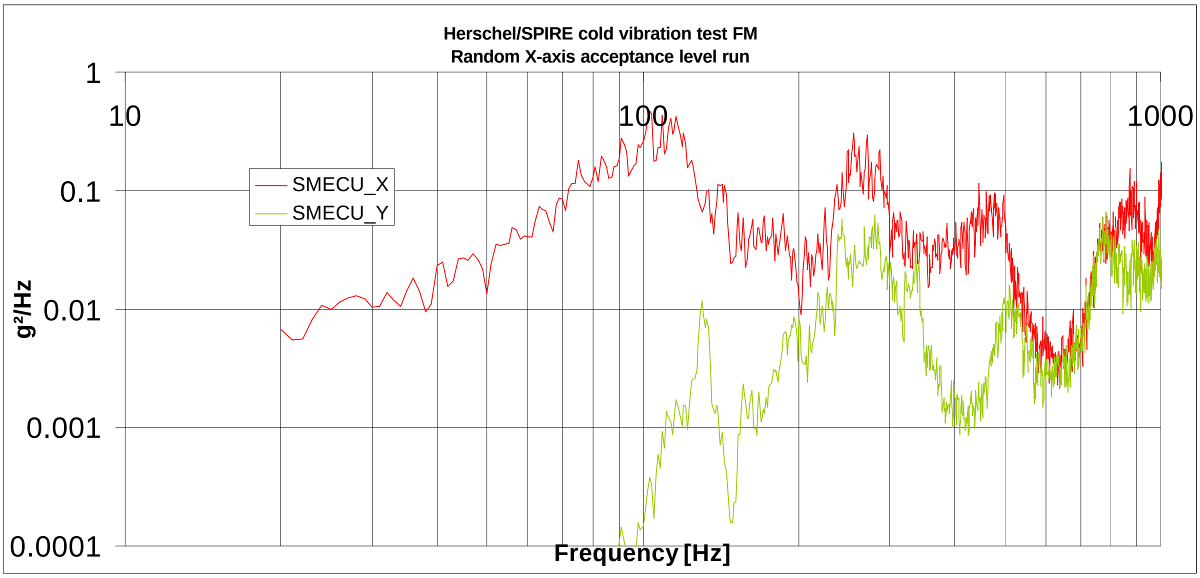



Figure 8.5-7 Achieved random input for the top of the spectrometer mechanism

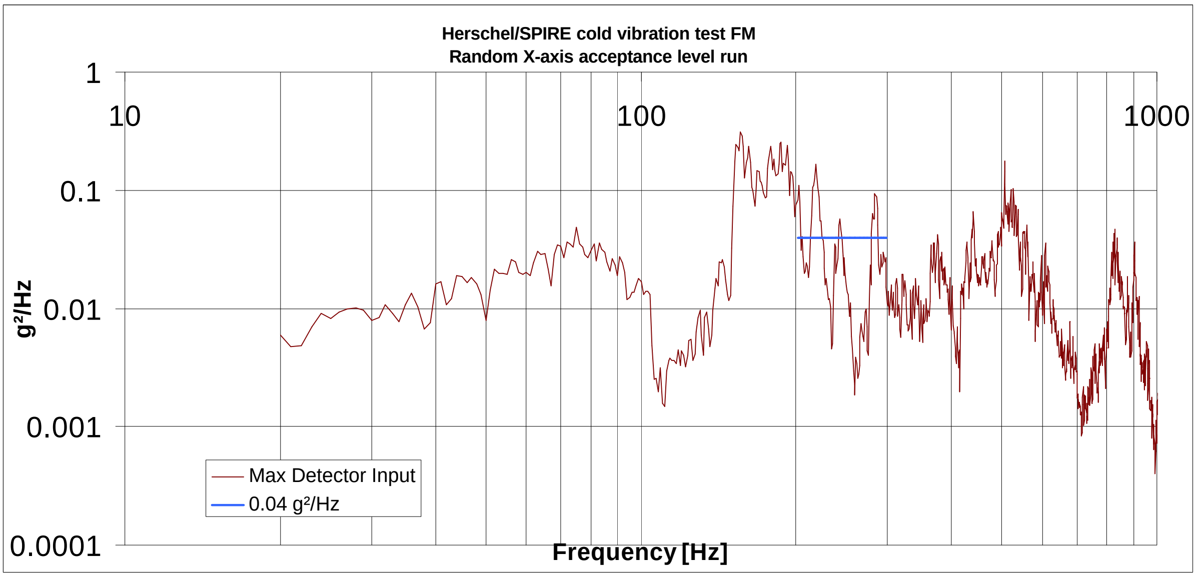



Figure 8.5-8 Maximum random input for (envelope) for the detectors

| | Control | | FPU_X | FPU_Y | FPU_Z | SPEC_X | SPEC_Z | SPEC_Y | PHOT_X | PHOT_Z | PHOT_Y |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20-300 Hz | 1.31 | | 1.68 | 0.85 | 1.54 | 2.78 | **3.20** | 0.69 | 2.15 | 1.06 | 1.85 |
| 20-700 Hz | 1.58 | | 2.07 | 1.05 | 1.64 | 3.55 | 3.95 | 0.98 | 2.66 | 2.34 | 2.23 |
| 20-2000 Hz | 1.63 | | 2.08 | 1.25 | 1.72 | 3.56 | 3.96 | 1.22 | 2.96 | 2.70 | 2.34 |
| | | | | | | | | | | | |
| | | | SMECL_X | SMECL_Y | SMECL_Z | SMECU_X | SMECU_Y | SMECU_Z | SMECB_X | SMECB_Y | SMECB_Z |
| 20-300 Hz | | | **3.46** | 1.57 | **4.21** | **5.28** | 1.63 | * | 1.62 | 0.78 | 0.99 |
| 20-700 Hz | | | 4.55 | 2.56 | **4.71** | **6.23** | 2.19 | * | 1.81 | 1.00 | 1.10 |
| 20-2000 Hz | | | 4.81 | 2.92 | **5.16** | **8.77** | 4.76 | * | 2.81 | 4.23 | 3.10 |

Table 8.5-9 Achieved g-rms over diffent frequency bands during X-axis vibration

**Achieved Levels and discussion Y-AXIS**

For the Y-axis a notch was implemented on the interface force as well on the spectrometer detector box to limit the input to the detectors at 0.04 g²/Hz. There was no need to limit the input to protect the SMec.

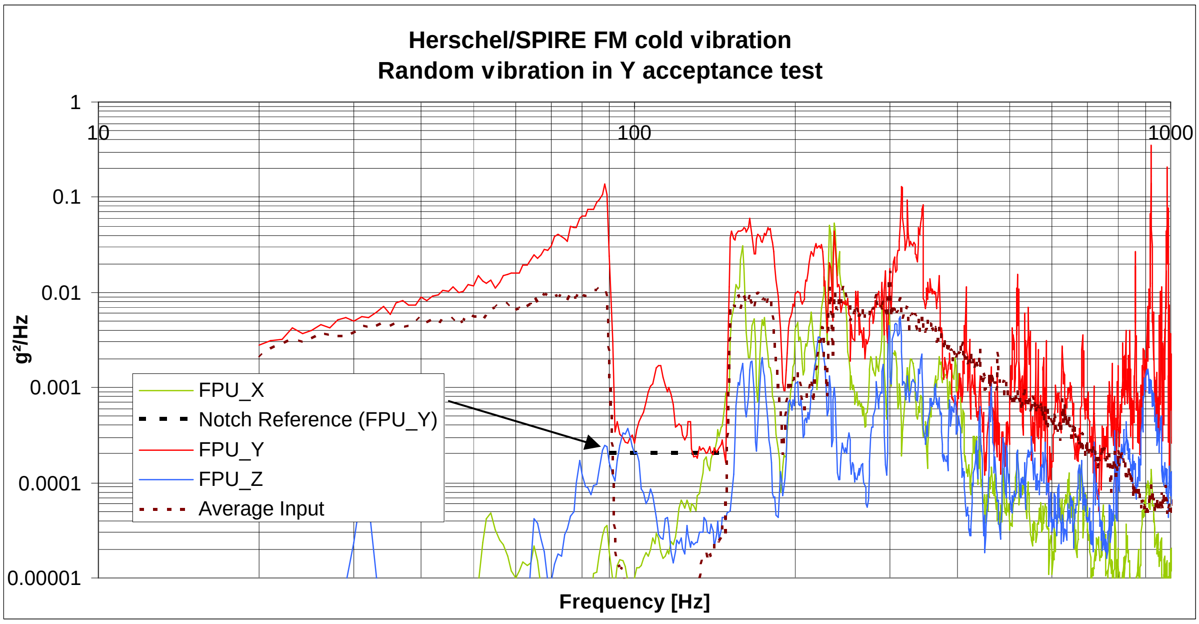



Figure 8.5-10 Achieved random responses in Ymain structure, arrow points to notch level

Figure 8.5-10 shows the FPY response with the FPU_Y response in 3-sigma well over the required 6.4 g equivalent.

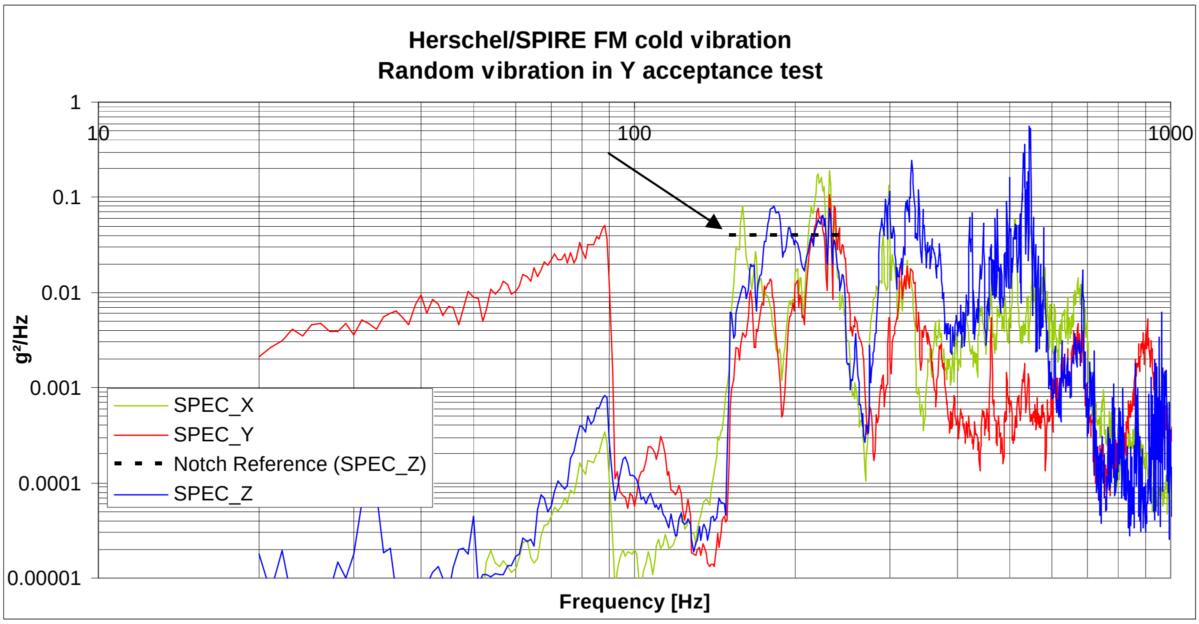



Figure 8.5-11 Y-axis response graph for spectrometer detector box, arrow points to notch level

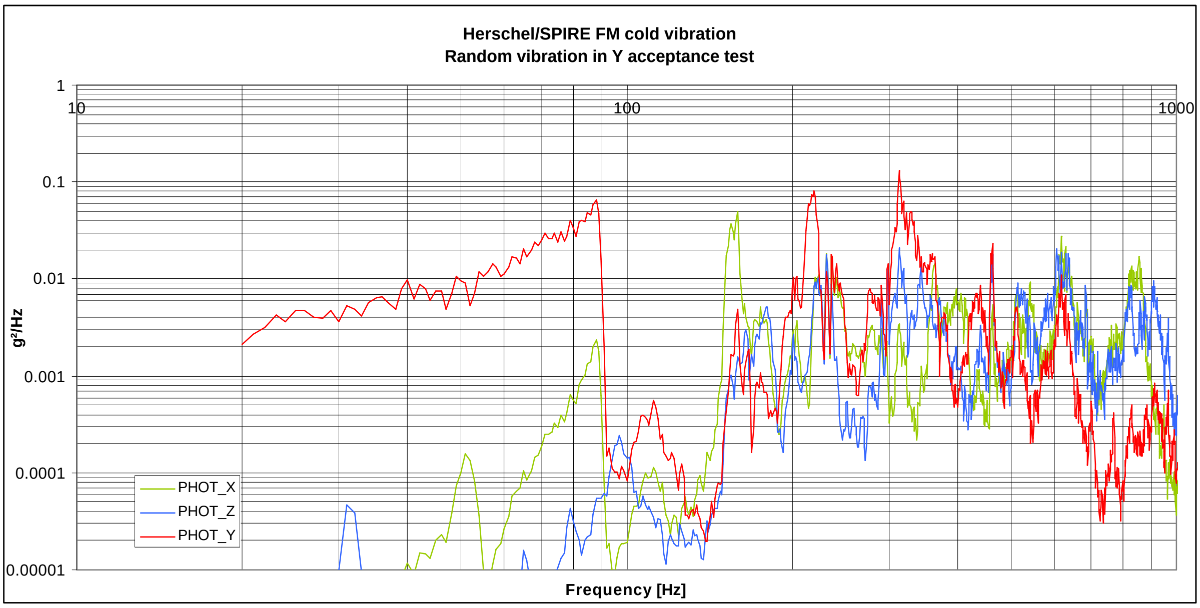



Figure 8.5-12 Y-axis response graph for photometer detector box

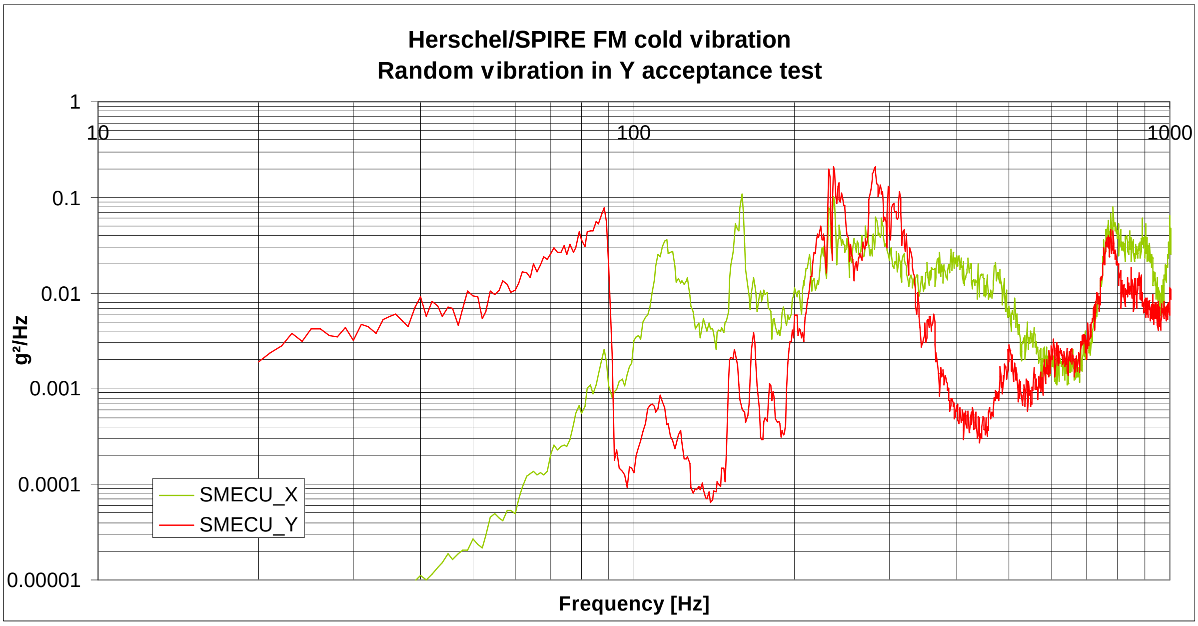



Figure 8.5-13 Achieved random input for the top of the spectrometer mechanism

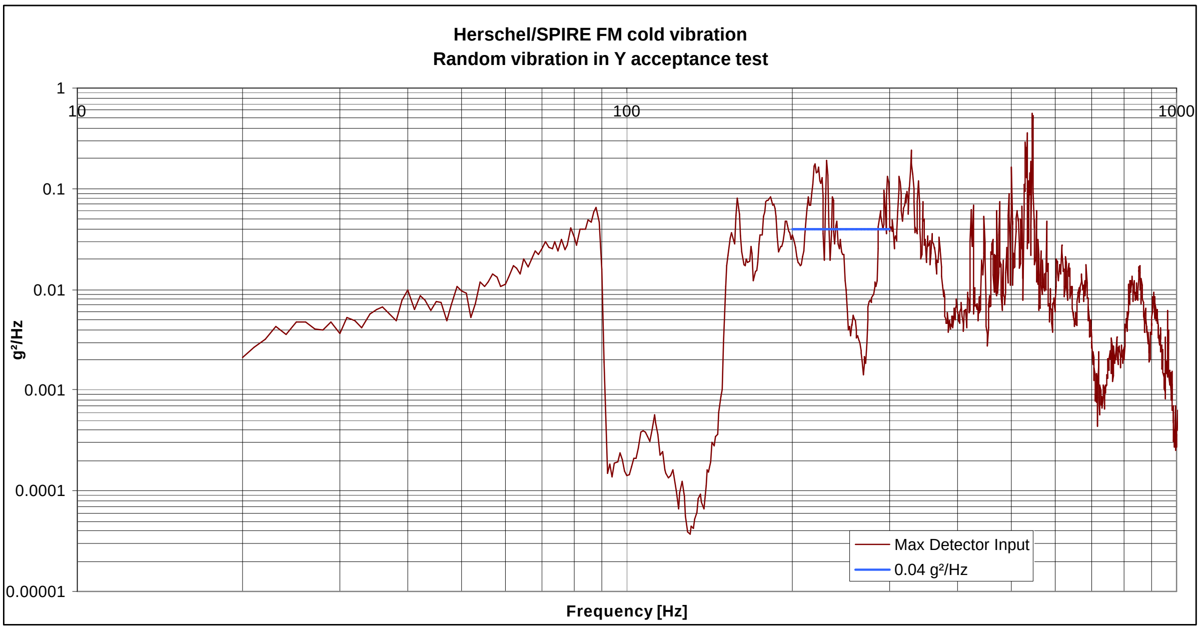



Figure 8.5-14 Maximum random input for (envelope) for the detectors

| | Reference | FPU_X | FPU_Y | FPU_Z | SPEC_X | SPEC_Y | SPEC_Z | PHOT_X | PHOT_Z | PHOT_Y |
|---|---|---|---|---|---|---|---|---|---|---|
| 20-250 Hz | 1.63 | 0.95 | 2.38 | 0.43 | 2.11 | 1.85 | 2.41 | 0.92 | 0.75 | 1.97 |
| 20-700 Hz | 1.79 | 1.00 | 2.64 | 0.52 | 2.61 | 1.98 | 3.89 | 1.54 | 1.47 | 2.30 |
| 20-2000 Hz | 1.80 | 1.02 | 2.98 | 0.64 | 2.63 | 2.08 | 3.91 | 1.79 | 1.73 | 2.36 |
| | SMECU_X | SMECU_Y | SMECB_X | SMECB_Y | SMECB_Z | | | | | |
| 20-250 Hz | 2.26 | 3.06 | 0.75 | 1.64 | 0.49 | | | | | |
| 20-700 Hz | 2.89 | 3.20 | 0.84 | 1.70 | 0.55 | | | | | |
| 20-2000 Hz | 4.79 | 4.21 | 1.53 | 3.37 | 2.15 | | | | | |

Table 8.5-15 Achieved g-rms over diffent frequency bands during Y-axis vibration

### Achieved Levels and discussion Z-AXIS

As for the Y-axis force notching was applied at the CoG but now between 120 and 170 Hz. Trying to achieve 2.1 g-rms up to about 290 Hz. The achieved level was 1.8 g-rms, slightly below the goal.

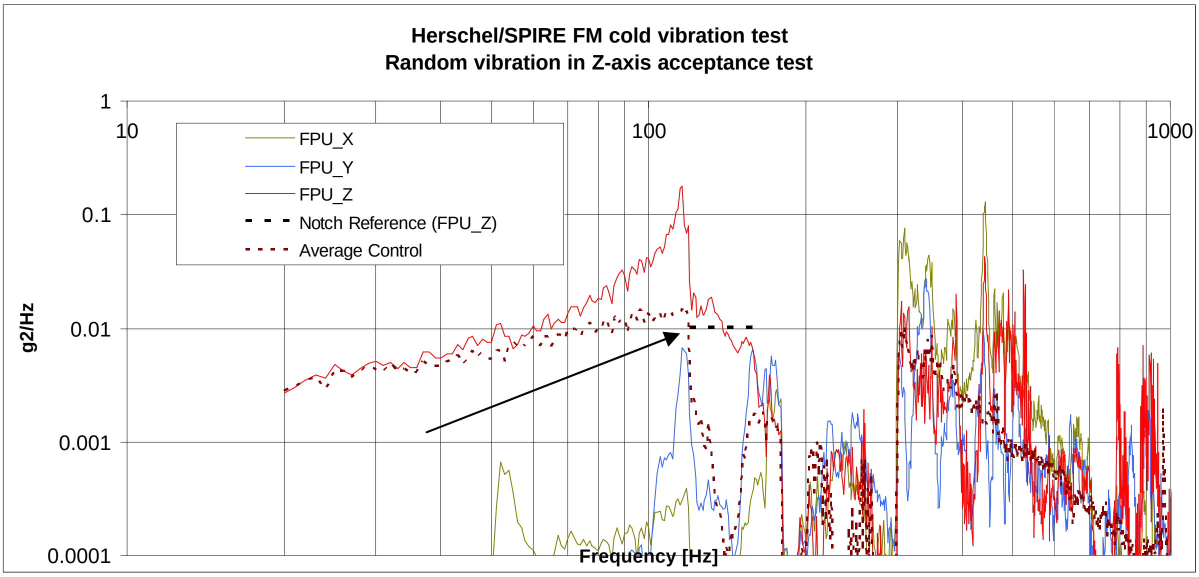



Table 8.5-16 Achieved random responses in Zain structure, arrow points to notch level

The detector box response was limited for botht the spectrometer and for the photometer detector box. During the assessment of the notching the wrong graph was used to set the notching levels for the detector boxes at 0.004 g²/Hz instead of  0.04 g²/Hz.

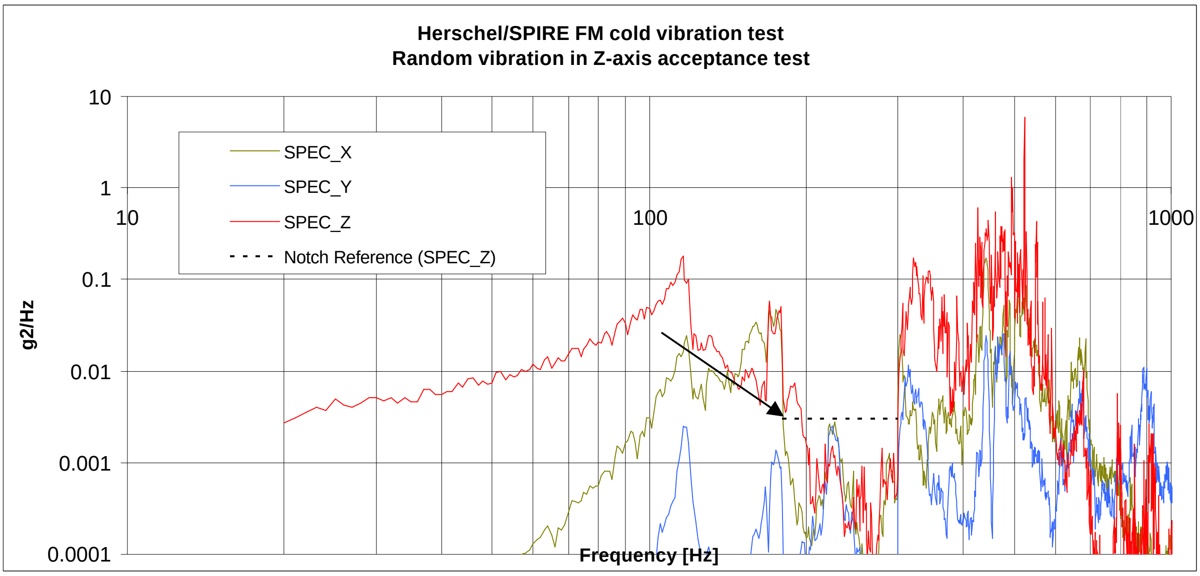



Table 8.5-17 -axis achieved spectrometer box levels

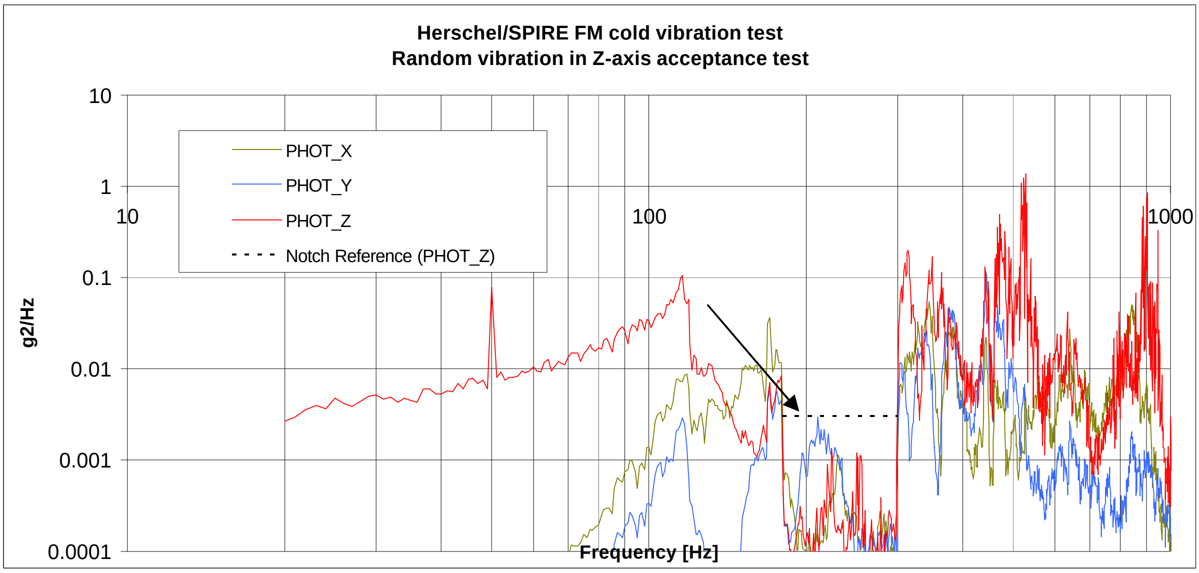



Table 8.5-18 Z-axis achieved photometer box levels

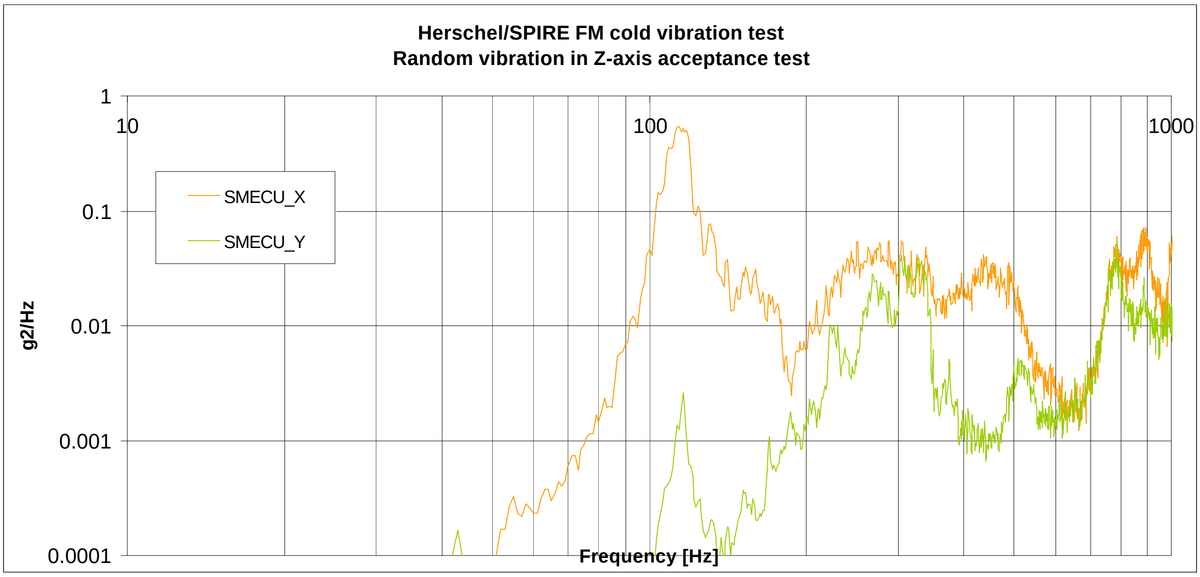



Table 8.5-19 Z-axis achieved photometer box levels

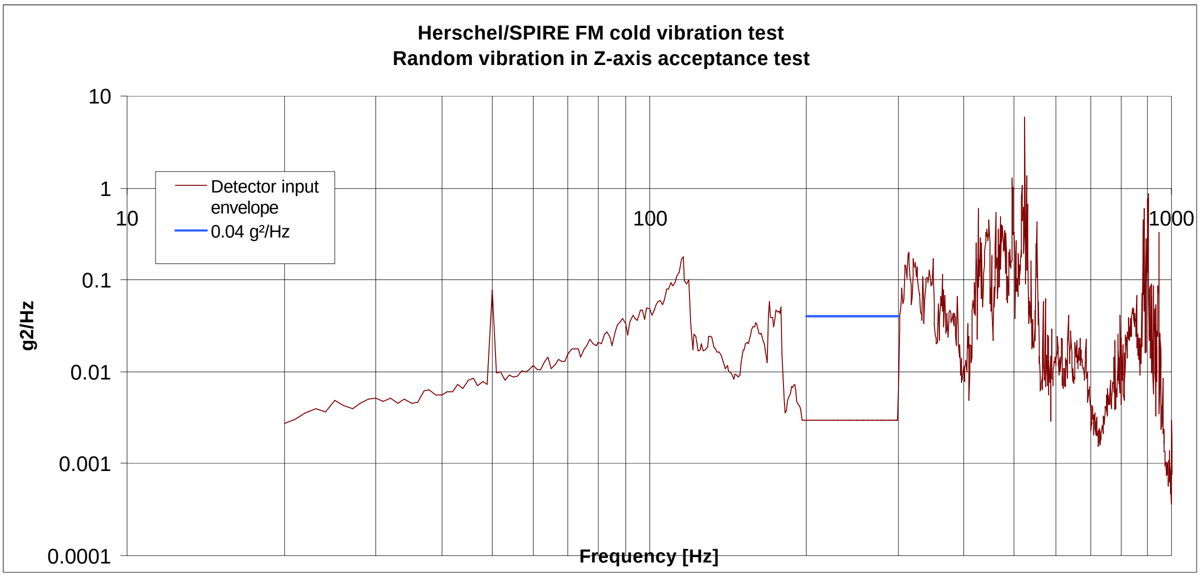



Table 8.5-20 Z-axis achieved detector input levels, too deeply notched between 200 ad 300 Hz

| | Control | FPU_X | FPU_Y | FPU_Z | | | |
|---|---|---|---|---|---|---|---|
| 20-300 Hz | 0.98 | 0.31 | 0.47 | 1.77 | | | |
| 20-700 Hz | 1.31 | 2.00 | 0.99 | 2.12 | | | |
| 20-2000 Hz | 1.34 | 2.03 | 1.27 | 2.29 | | | |
| | | | | | | | |
| | SPEC_X | SPEC_Y | SPEC_Z | PHOT_X | PHOT_Y | PHOT_Z | |
| 20-300 Hz | 1.18 | 0.26 | 2.04 | 0.79 | 0.41 | 1.58 | |
| 20-700 Hz | 2.78 | 1.19 | 6.32 | 1.87 | 1.86 | 5.03 | |
| 20-2000 Hz | 2.82 | 1.49 | 6.33 | 2.41 | 1.97 | 5.99 | |
| | | | | | | | |
| | SMECL_X | SMECL_Y | SMECU_X | SMECU_Y | SMECB_X | SMECB_Y | SMECB_Z |
| 20-300 Hz | 1.55 | 1.95 | 3.43 | 1.04 | 0.55 | 0.34 | 1.43 |
| 20-700 Hz | 2.68 | 3.15 | 4.20 | 1.75 | 1.14 | 0.73 | 1.68 |
| 20-2000 Hz | 2.91 | 3.31 | 6.13 | 3.55 | 1.87 | 3.21 | 2.76 |

Achieved g-rms over diffent frequency bands during Z-axis vibration

Overall the response level during the Z-axis has been slightly below the goal of 6.4 g equivalent on interface force.

## 8.6. Measurement of subsystem levels

N.A.

## 8.7. Post test inspection

On return to RAL an incoming inspection was carried out, and is documented in SPIRE-RAL-REP-002579. No anomalies were found.
The SMEC DM was removed and the CQM fitted for the next cold test campaign.

## 8.8. Main resonance frequencies found

| Main frequencies [Hz] | | |
|---|---|---|
| X-axis | | |
| Warm | Cold CQM | COLD FM |
| 176 | 158 | 145 |
| 206 | 193 | 205 |
| 219 | 212 | 207 |
| 314 | 300 | 300 |
| | | |
| Y-axis | | |
| Warm | Cold CQM | COLD FM |
| 122 | 129 | 112 |
| 197 | 210 | 206 |
| 249 | 228 | 218 |
| | | |
| Z-axis | | |
| Warm | Cold CQM | COLD FM |
| 137 | 148 | 141 |
| 202 | 205 | 194 |

8.7-1: Main frequencies

The listed frequencies are from the warm STM test, the cold CQM test and the cold FM test. There are a few things that are different between the warm and the cold STM test. First of all the instrument mass went up with about 12%, but this is countered by the increase in stiffness due to the lower temperatures (typically 5% to 10%). The rest is the influence of the coupled vibration with the CSL shaker, which in general lowers the frequencies or clusters modes. The cold FM test has again slightly lower frequencies due to the slightly more flexible A-frames. The original stainless steel A-frames (CQM) were replaced by CFRP re-engineered frames (FM).

# 9. CONCLUSIONS

The acceptance test of the SPIRE PFU was completed in all three axis.
Behaviour of the FPU was as expected.
Acceleration levels at several locations within the SMEC wer recorded.

# 10. PROBLEM AREAS

## 10.1. Damage to FPU cone mount.

After the sine vibration run in the Z axis it appeared the main structure response had degraded in such a way that it was decided to stop the test and inspect the instrument. Minor cracks were found in the CFRP instrument support cone. It was decided after an TRB meeting to replace the CFRP cone with the original stainless steel alternative as This was already qualified and the degradation to thermal performance was acceptable. NCR HR-SP-RAL-NCR-136 was raised

# 11. REJECTION AND RETEST

No test run was rejected or a re-test performed. Several attempts were made to continue an aborted low level sine-sweep. But because of the inherent problem of the shaker (flexibility of the table mounting) it was decided to accept sweeps up to 500 Hz as a minimum, but all sweeps were successful up to 2000 Hz.

During the Z-axis the FPU responses showed signs of degradation after the sine test. The test was aborted and the instrument warmed up. The CFRP cone showed small radial cracks around the top spigot and was replaced by a stainless steel cone (as used during CQM testing). The Z-axis acceptance test repeated the sine test and finished with the random tests following the test sequence, repeating the sine vibration test. The Z-axis was performed successfully.

# Appendix A – Intrumentation specification

The instrumentation consisted of two types of accelerometers. The first type is the cold-vibration accelerometers provided for by CSL. The second type warm-vibration accelerometers provided for by RAL. The warm-vibration accelerometers were not calibrated at the structure temperature at which we vibrated. However cold-vibration accelerometer readings (pointing in the same direction) were used during the test within the quasi-static frequency range as a reference for in-situ calibration.

- At each mounting point of the instrument (interface with vibration fixture for control, 3 tri-ax cold-vibration accelerometers in total)
- Top of the optical bench in instrument coordinates: FPU X,Y and Z (tri-ax co-aligned with S/C coordinates)
- On the photometer detector box PHOT X,Y and Z (tri-ax co-aligned with S/C coordinates
- On the spectrometer detector box SPEC X,Y and Z (tri-ax co-aligned with S/C coordinates
- At various locations on the spectrometer mechanism (SMEC), top of mechanism, base and bottom.

The SMEC accelerometers used were not cryogenic accelerometers and were calibrated in situ. During the test it appeared that the SMECU_Z malfunctioned as well as all the SMECB accelerometers.

The implemented instrumentation:

The numbering used during the tests was as follows (only accelerometers mounted in/on the instrument are listed):
Accelerometer allocation

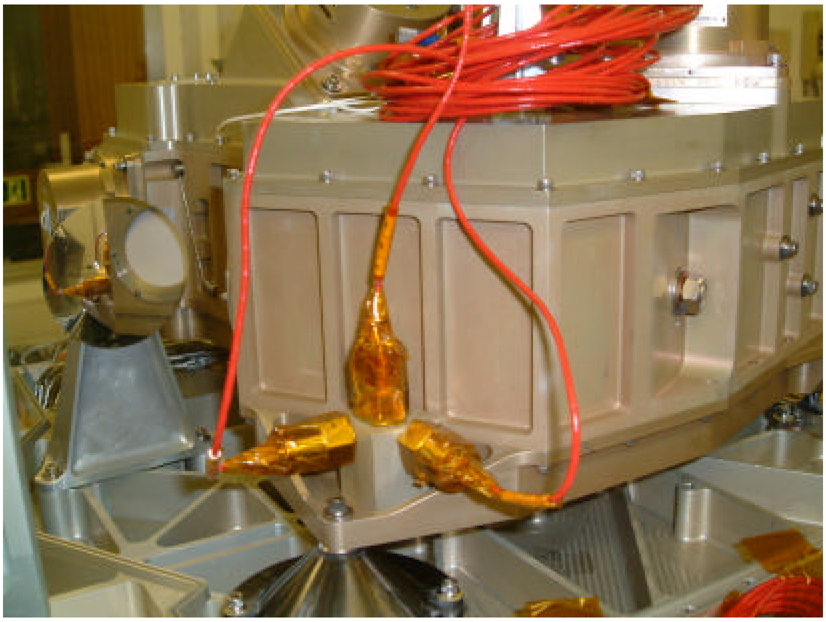
| **Channel No** | **Location** | **Type** | **Serial no** | **Code** | **Axis** | **Feed thro'** |
|---|---|---|---|---|---|---|
| F65 | Photometer detector box | 7724 | 12376 | PHOTX | X | 1 |
| F71 | Photometer detector box | 7724 | 12371 | PHOTY | Y | 2 |
| F53 | Photometer detector box | 7724 | 12373 | PHOTZ | Z | 3 |
| | | | | | | |
| F66 | FPU top of optics bench over cone | 7724 | 12372 | FPUX | X | 4 |
| F69 | FPU top | 7724 | 12381 | FPUY | Y | 5 |
| F52 | FPU top | 7724 | 13433 | FPUZ | Z | 6 |
| | | | | | | |
| F68 | Spectrometer detector box | 7724 | 13424 | SPECX | X | 7 |
| F73 | Spectrometer detector box | 7724 | 13416 | SPECY | Y | 8 |
| F54 | Spectrometer detector box | 7724 | 13414 | SPECZ | Z | 9 |
| | | | | | | |
| * | SMEC moving | 2222C | 32974 | SMECLX | X | 10 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | carriage 1.284pC/g | | | | | |
| * | SMEC moving carriage 1.606pC/g | 2222C | 32977 | SMECLY | Y | 11 |
| * | SMEC moving carriage 1.627pC/g | 2222C | 32976 | SMECLZ | Z | 12 |
| | | | | | | |
| * | SMEC top 1.262pC/g | 2222C | 32975 | SMECUX | X | 13 |
| * | SMEC top 1.692pC/g | 2222C | 26087 | SMECUY | Y | 14 |
| * | SMEC top 1.373pC/g | 2222C | AJC49 | SMECUZ | Z | 15 |
| | | | | | | |
| * | SMEC base plate 14.02 pC/g | 2272 | YG32 | SMECBX | X | 16 |
| * | SMEC base plate 1.618pC/g | 2222C | AADN7 | SMECBY | Y | 17 |
| * | SMEC base plate 1.306pC/g | 2222C | 32978 | SMECBZ | Z | 18 |
| | | | | | | |

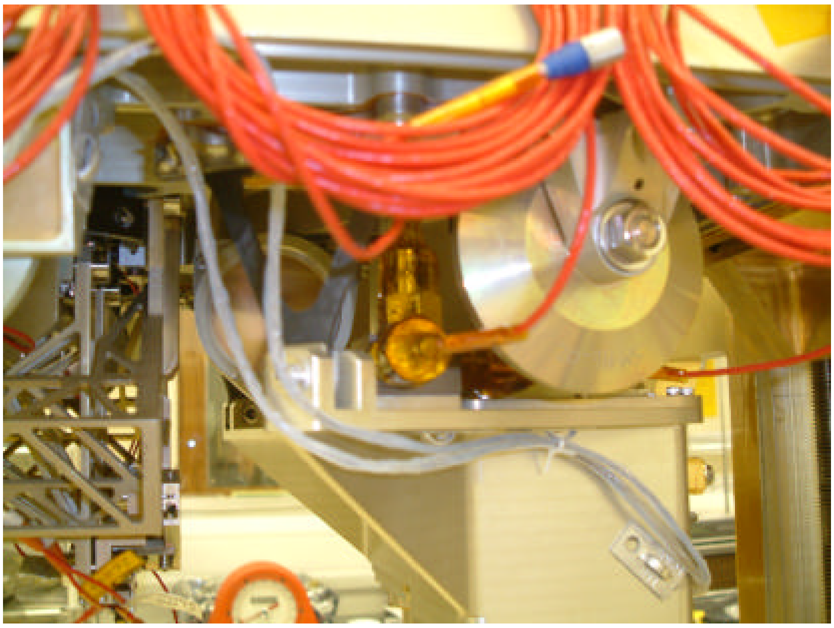
* are not cold-vibration accelerometers, they were calibrated during the tests

Not all accelerometers were working properly during all tests. Due to the extreme test environment and the routing between the accelerometer and the readout electronics this is not surprising.

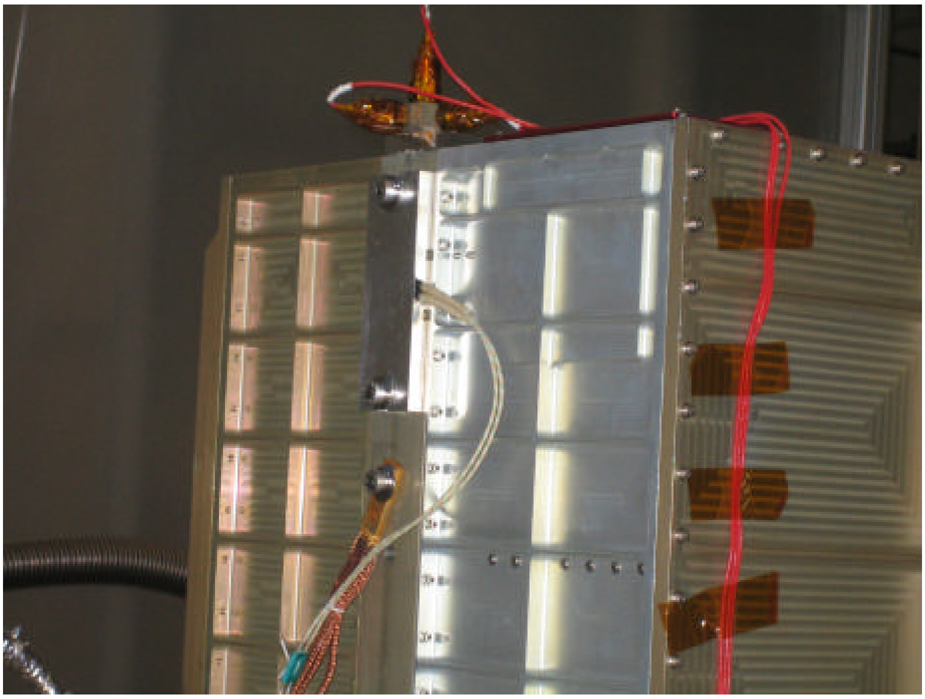
During the Y a Z axis vibration the SPECZ was not working properly (measuring in X) it was working properly during the X-axis vibration test.



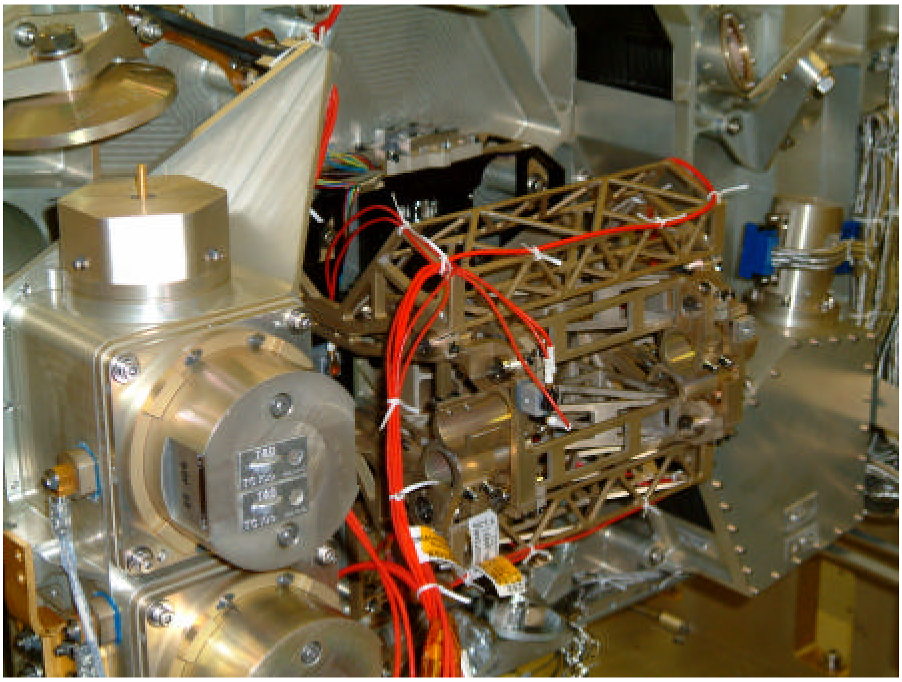
A-1: The triax on the photometer detector box



A-2: The triax on the spectrometer detector box

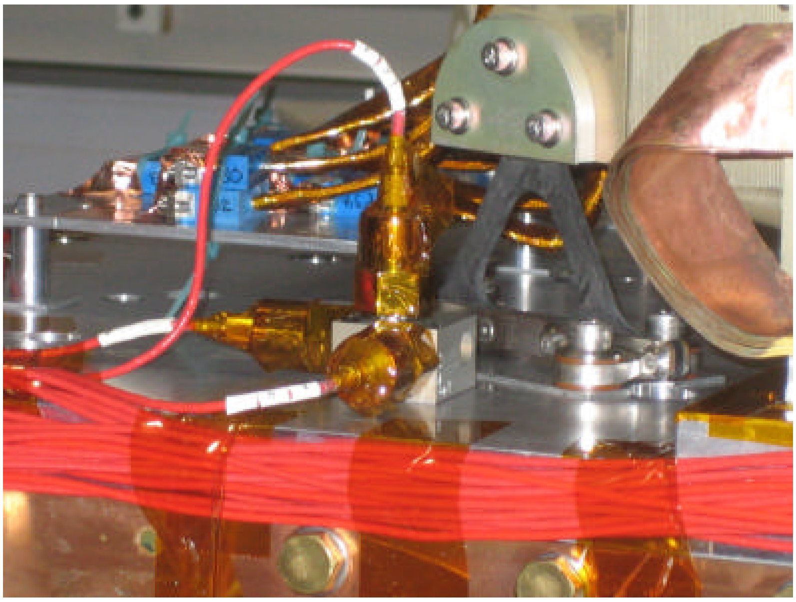


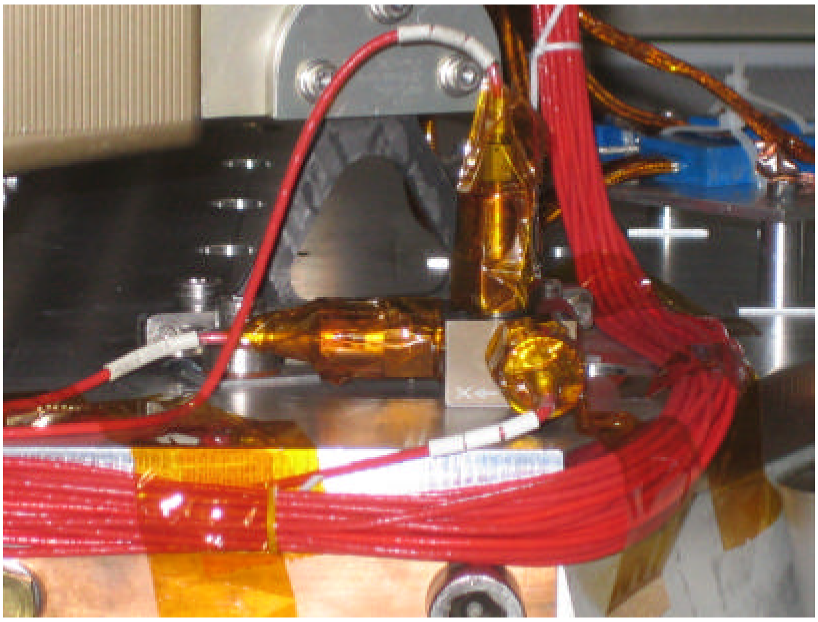
A-3: Triax on SOB outside (FPU)

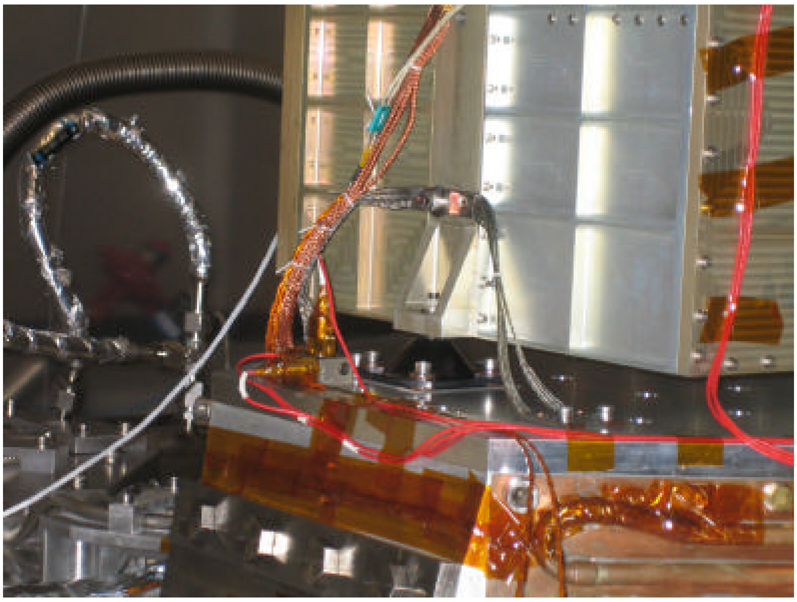


A-4: SMec

Additionally provided by the facility were accelerometers located at each interface point measuring out of plane at each interface point and in plane at two locations for each direction.



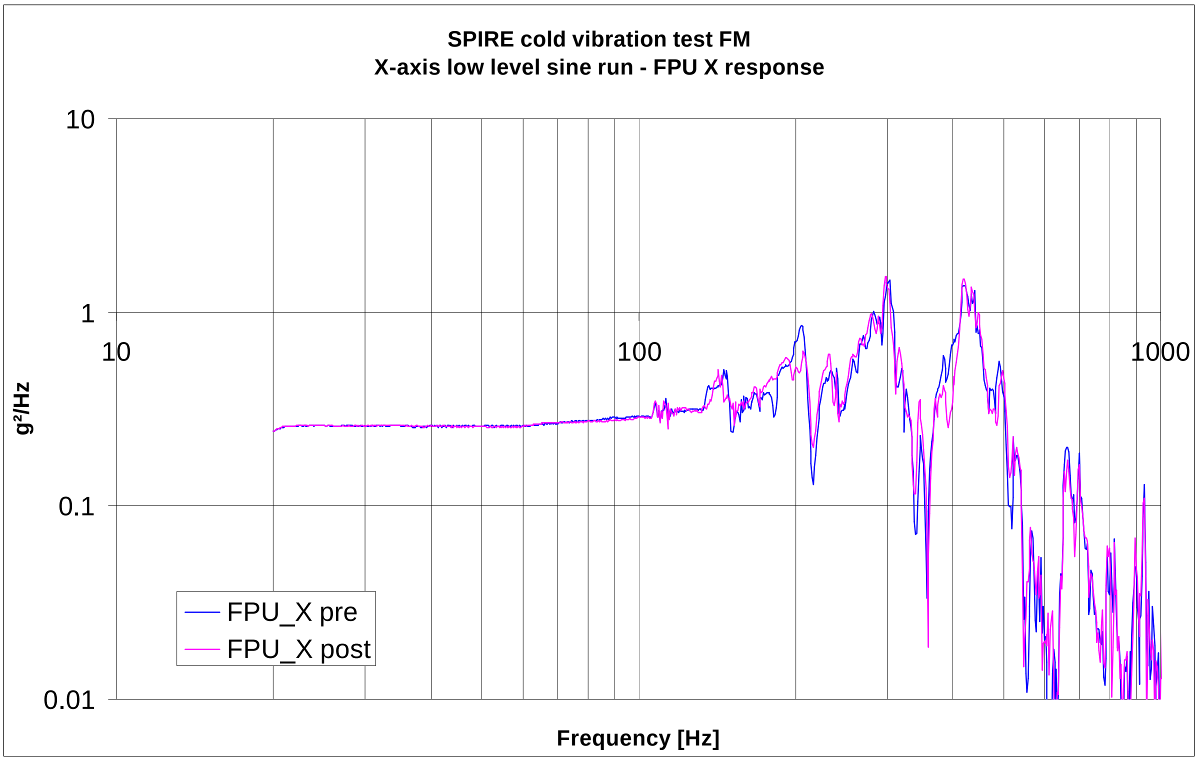


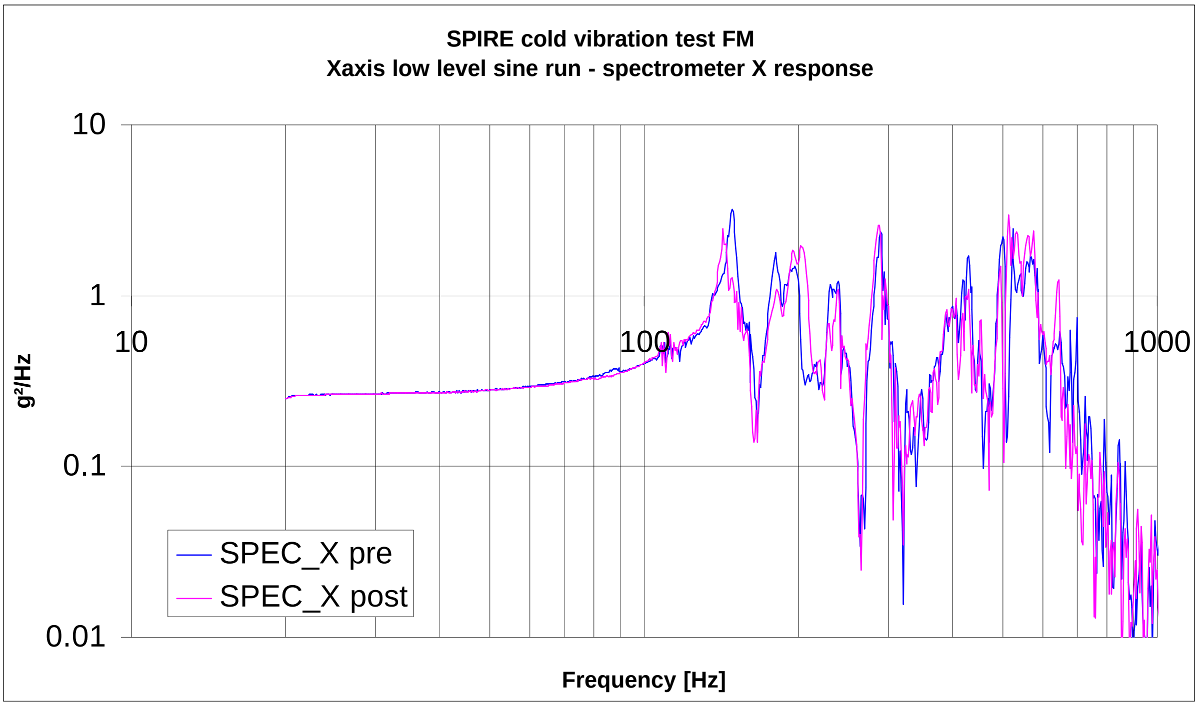


# Appendix B – Pre-Post sine and random comparison

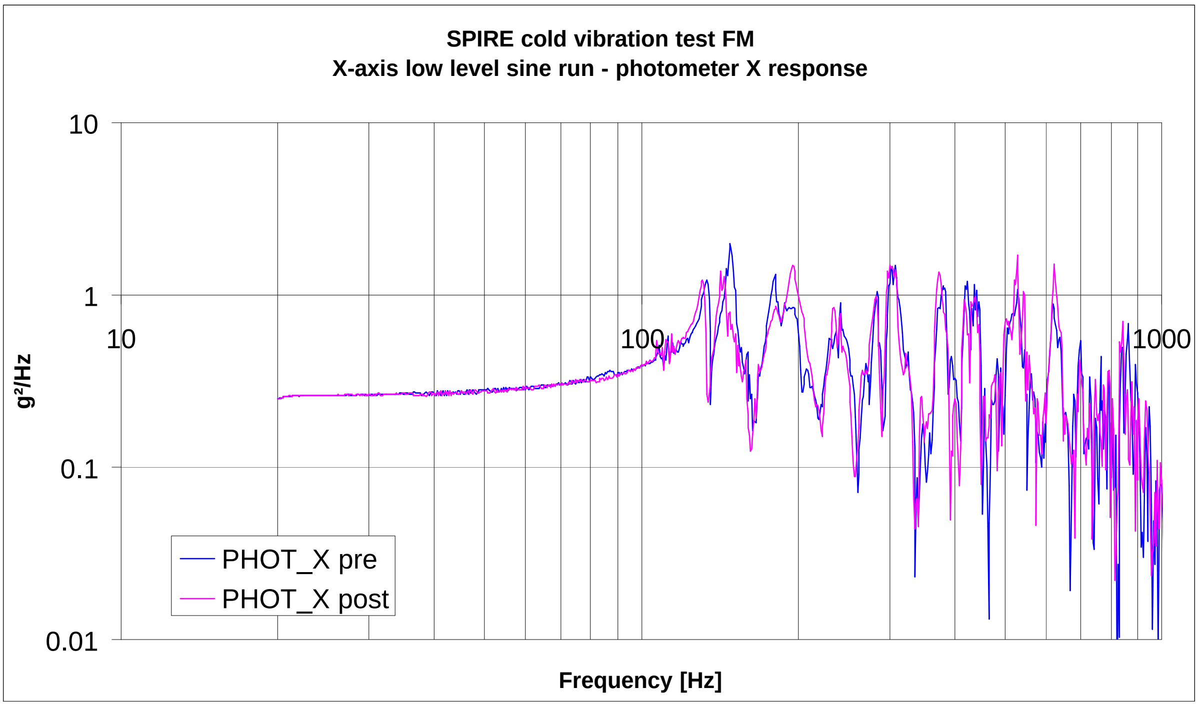
As for the CQM test programme all runs were controlled on the average of the accelerometers located nearest to the mounting points of the instrument. As a result of the cross-coupling of the shaker table itself with the cryostat the responses are biased. See the CQM cold vibration report.

Hereafter all pre-post test sequence sine responses are listed for the FPU, spectrometer detector box, photometer detectorbox and the SMEC in the excitation direction.

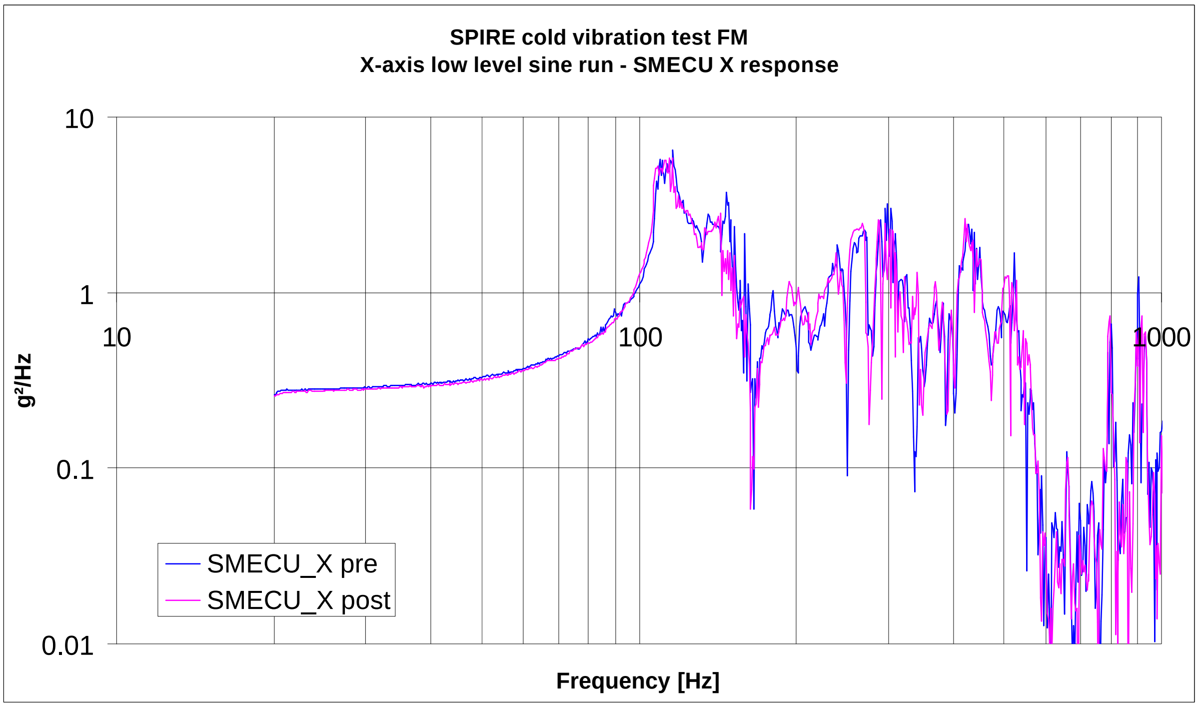




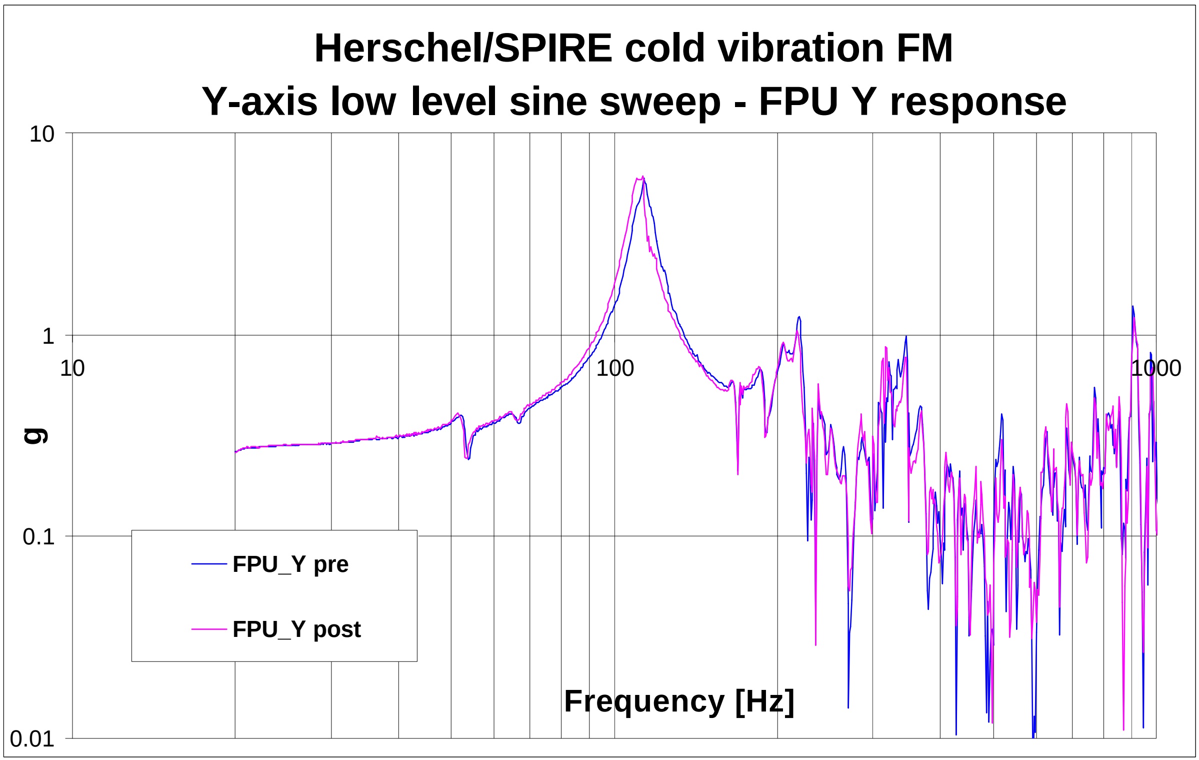
SPIRE cold vibration test FM
Xaxis low level sine run - spectrometer X response
10
1
0.1
0.01
10
100
1000
g²/Hz
Frequency [Hz]
SPEC_X pre
SPEC_X post

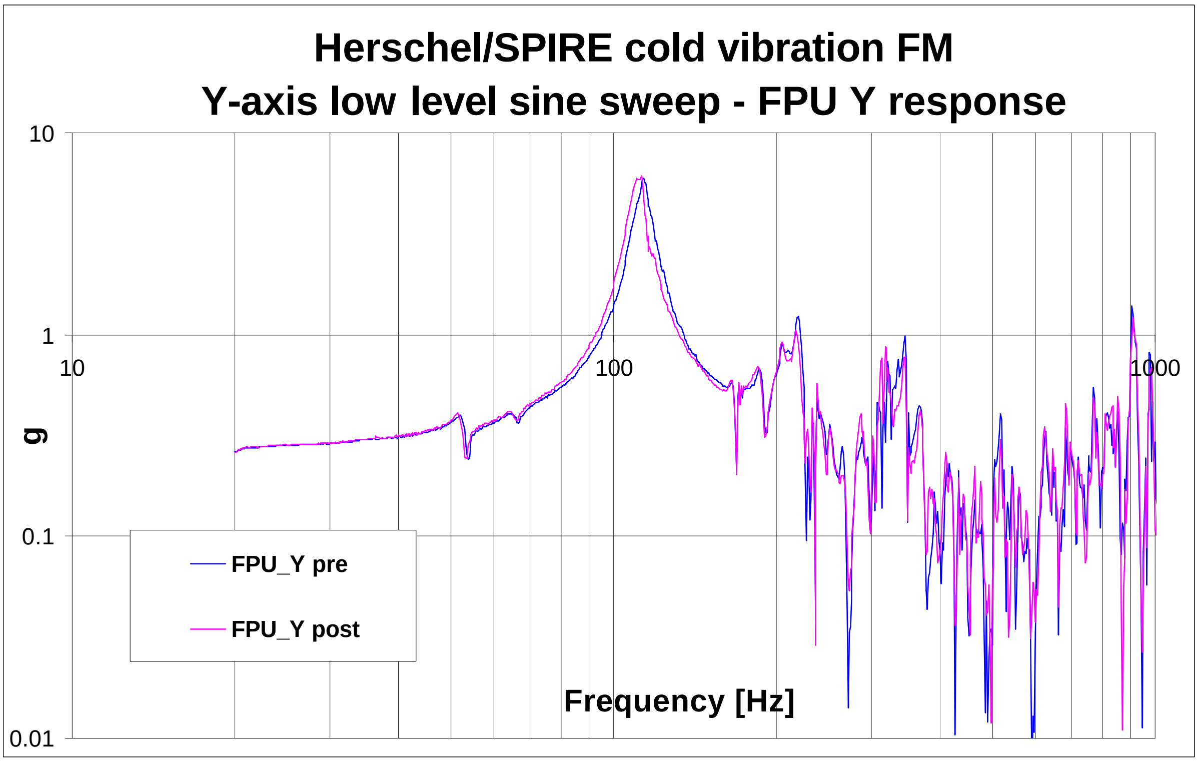
SPIRE cold vibration test FM
X-axis low level sine run - photometer X response
10
1
0.1
0.01
10
100
1000
g²/Hz
Frequency [Hz]
PHOT_X pre
PHOT_X post

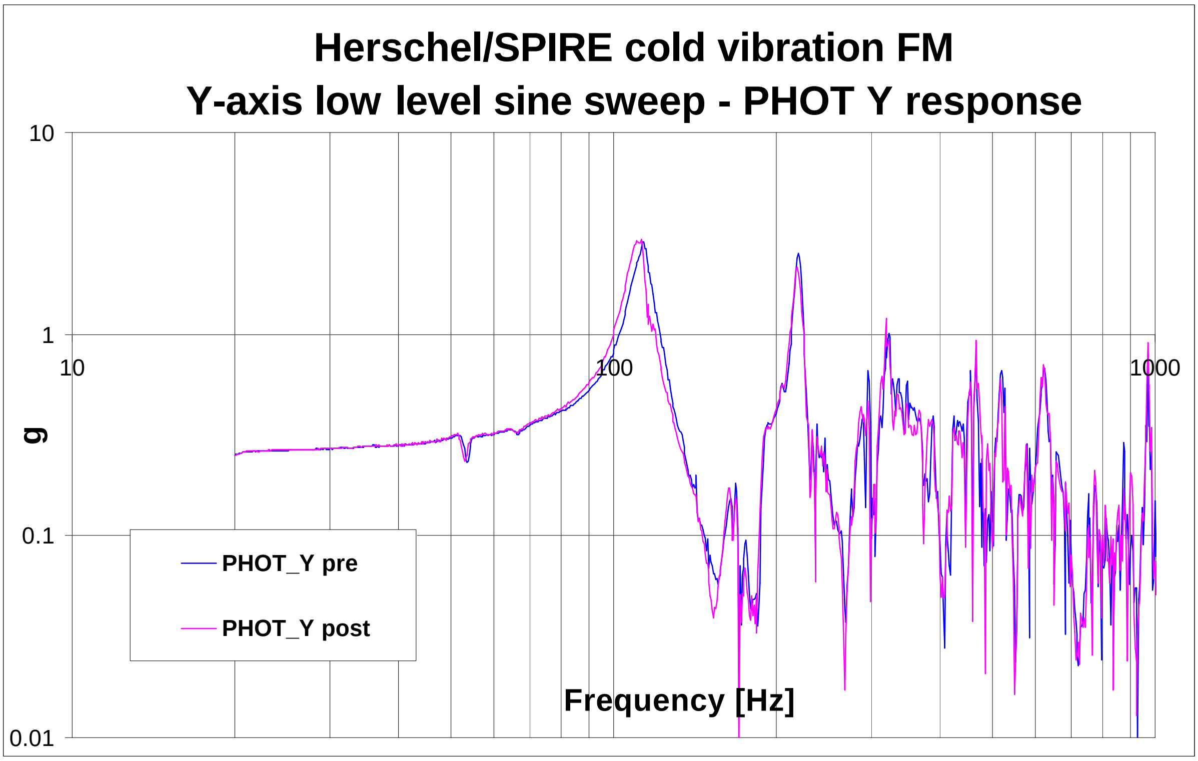


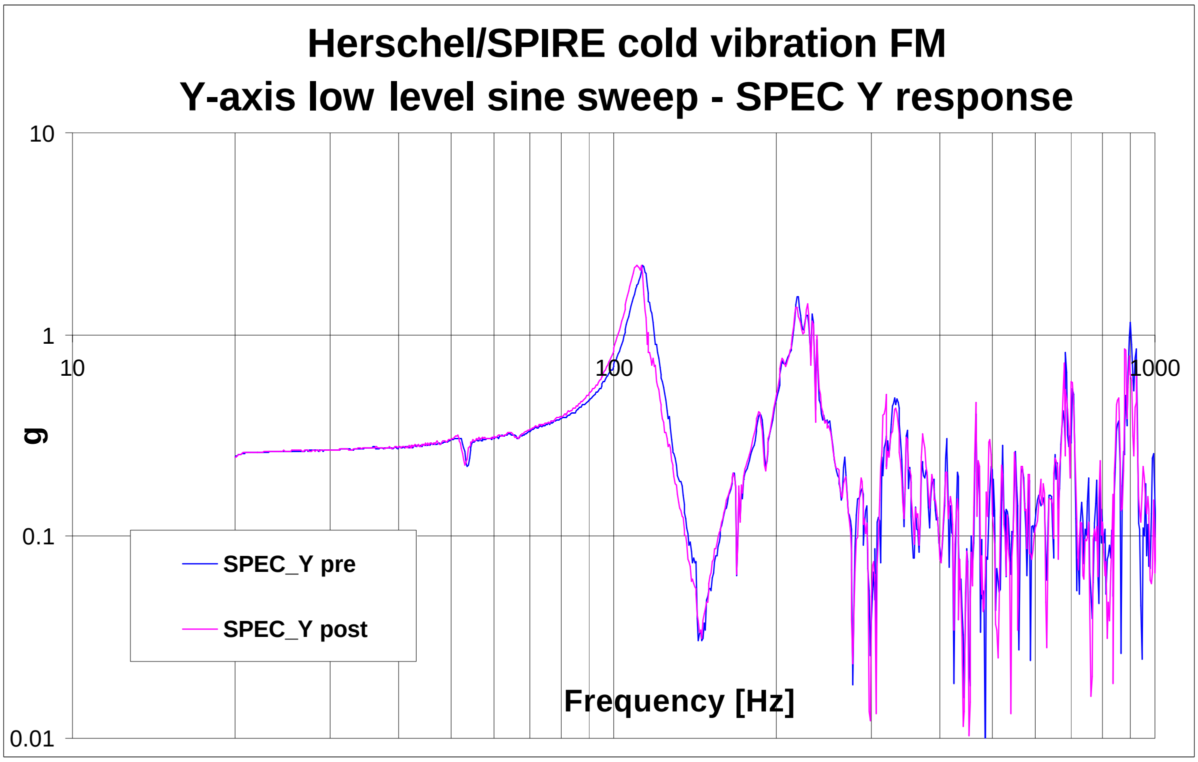
SPIRE cold vibration test FM
X-axis low level sine run - SMECU X response
g²/Hz
10
1
0.1
0.01
10
100
1000
SMECU_X pre
SMECU_X post
Frequency [Hz]

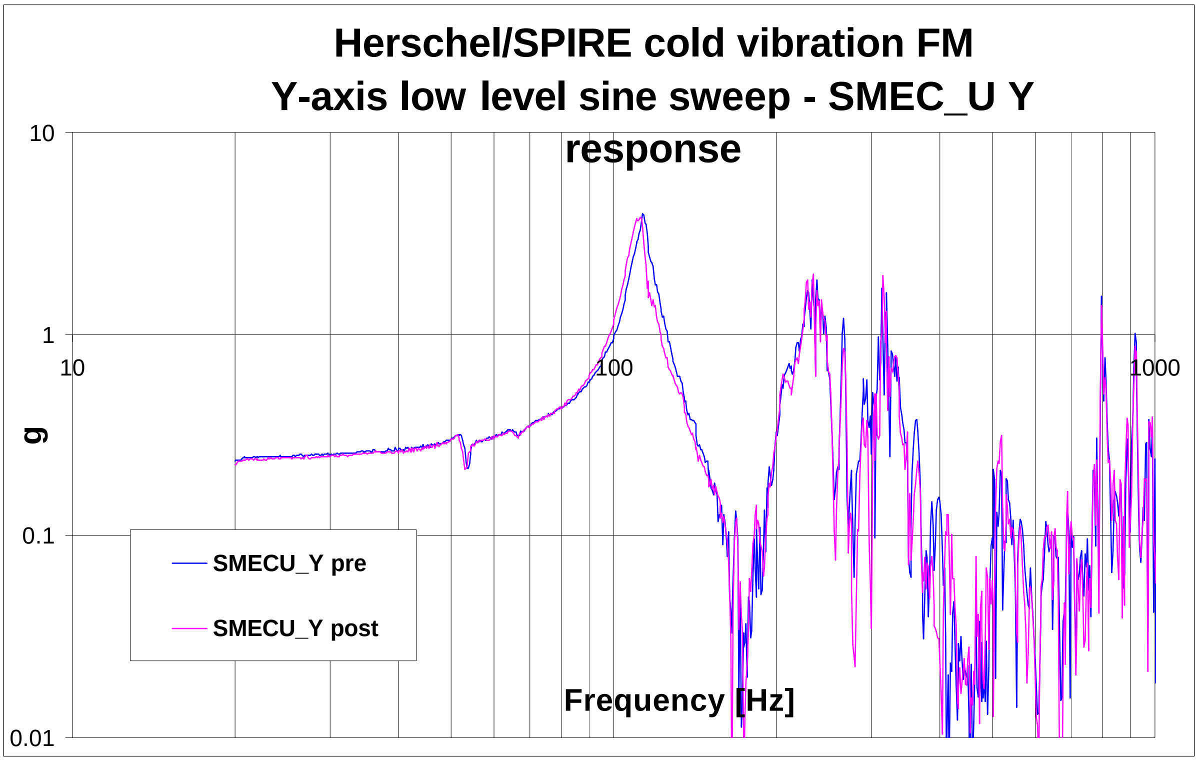



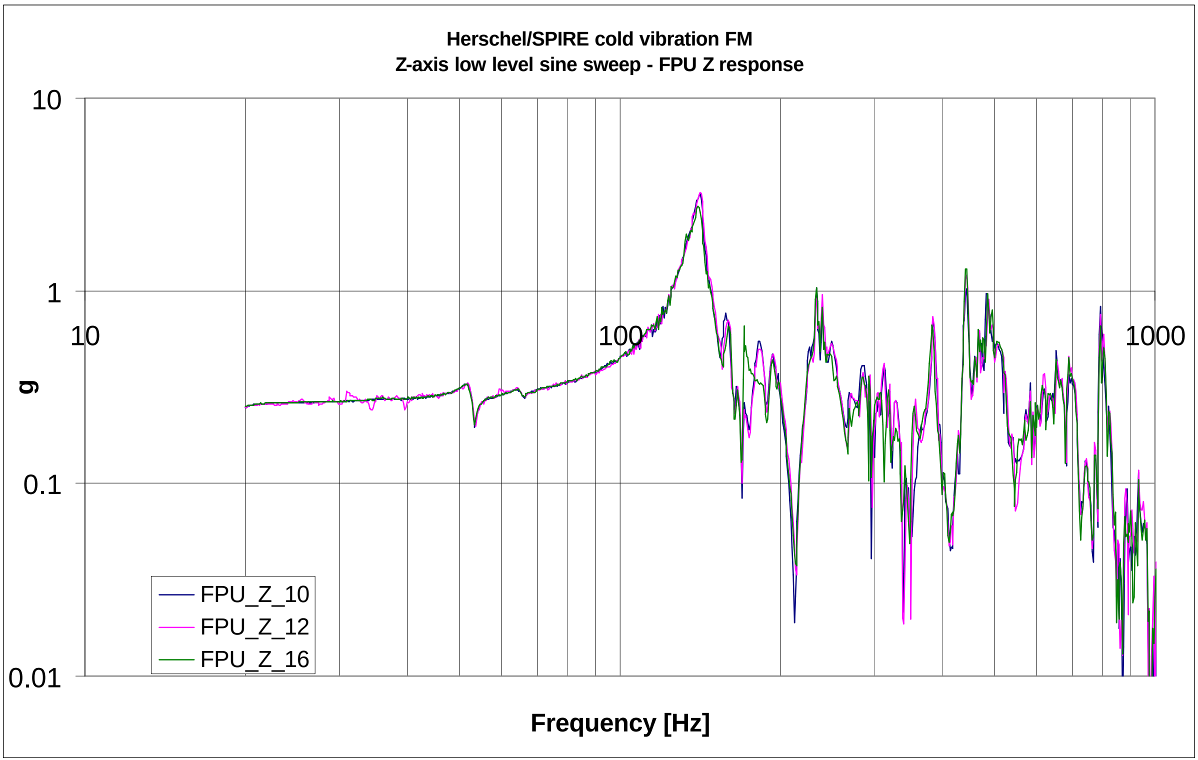
Herschel/SPIRE cold vibration FM
Y-axis low level sine sweep - FPU Y response
g
10
1
0.1
0.01
10
100
1000
FPU_Y pre
FPU_Y post
Frequency [Hz]


Herschel/SPIRE cold vibration FM
Y-axis low level sine sweep - FPU Y response
10
1
0.1
0.01
10
100
1000
g
FPU_Y pre
FPU_Y post
Frequency [Hz]

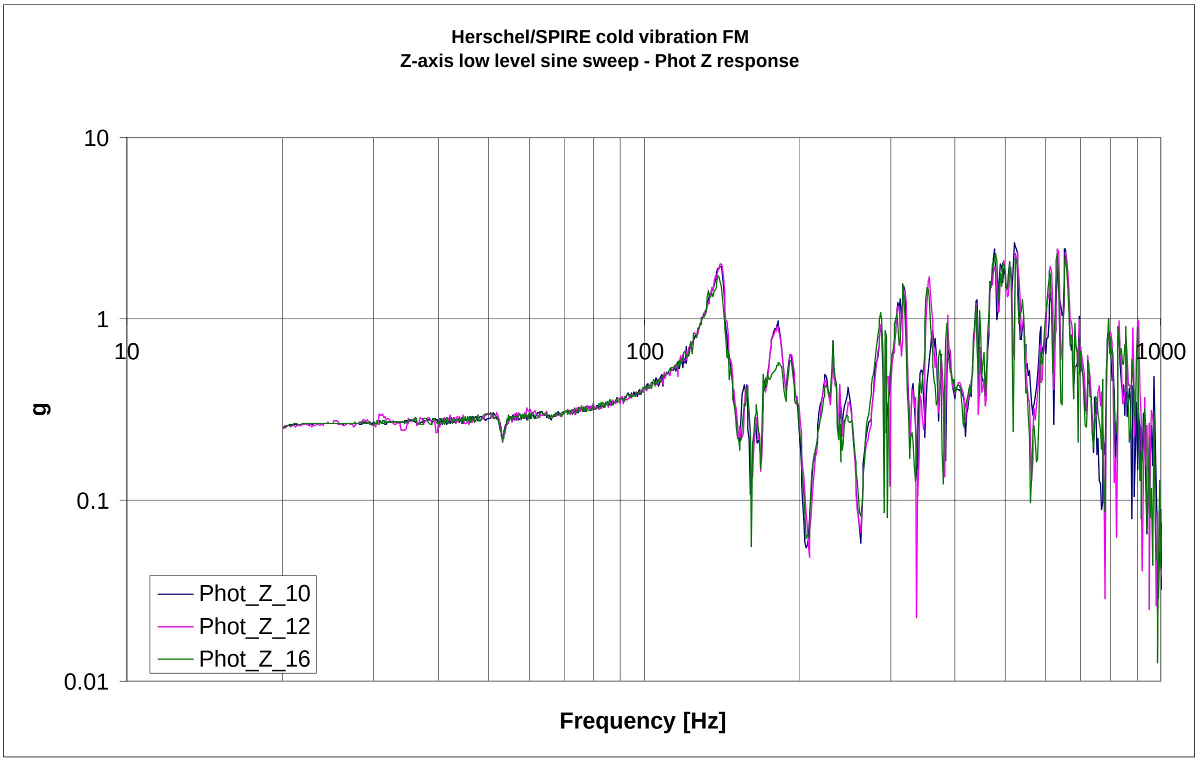

Herschel/SPIRE cold vibration FM
Y-axis low level sine sweep - PHOT Y response
10
1
0.1
0.01
10
100
1000
g
PHOT_Y pre
PHOT_Y post
Frequency [Hz]


Herschel/SPIRE cold vibration FM
Y-axis low level sine sweep - SPEC Y response
10
1
0.1
0.01
g
10
100
1000
SPEC_Y pre
SPEC_Y post
Frequency [Hz]

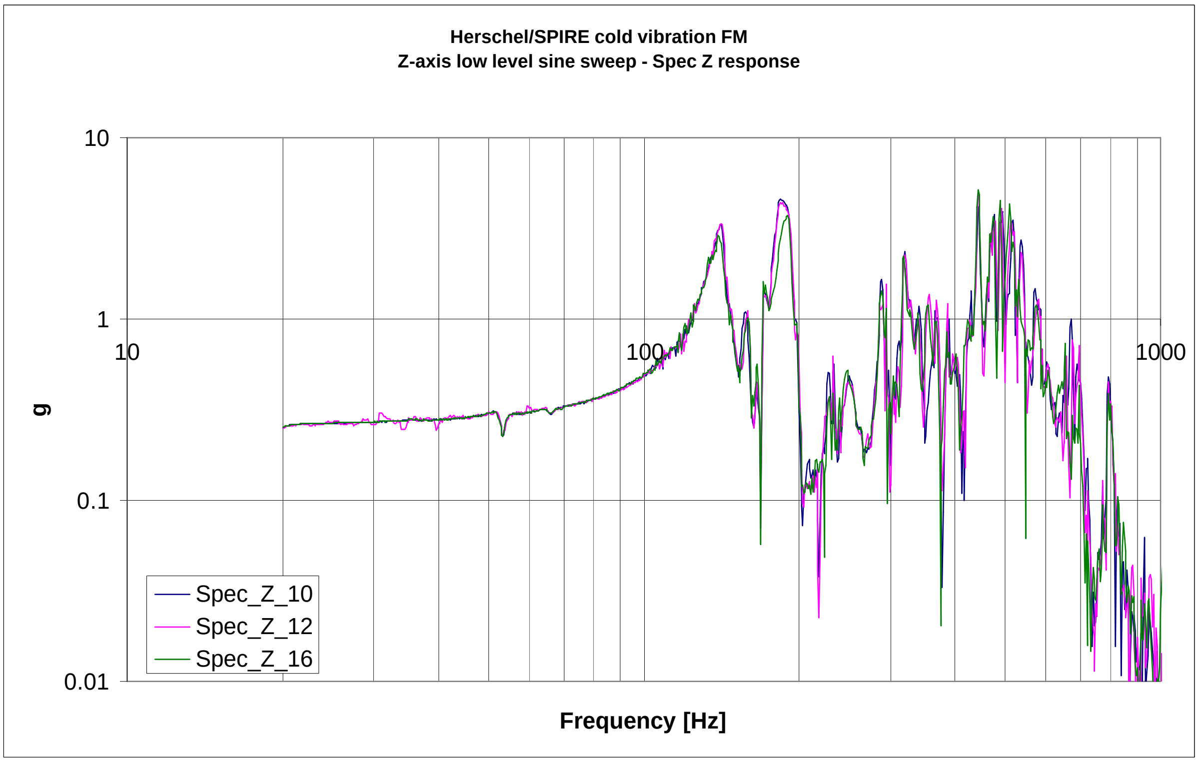

Herschel/SPIRE cold vibration FM
Y-axis low level sine sweep - SMEC_U Y response
10
1
0.1
0.01
g
10
100
1000
SMECU_Y pre
SMECU_Y post
Frequency [Hz]

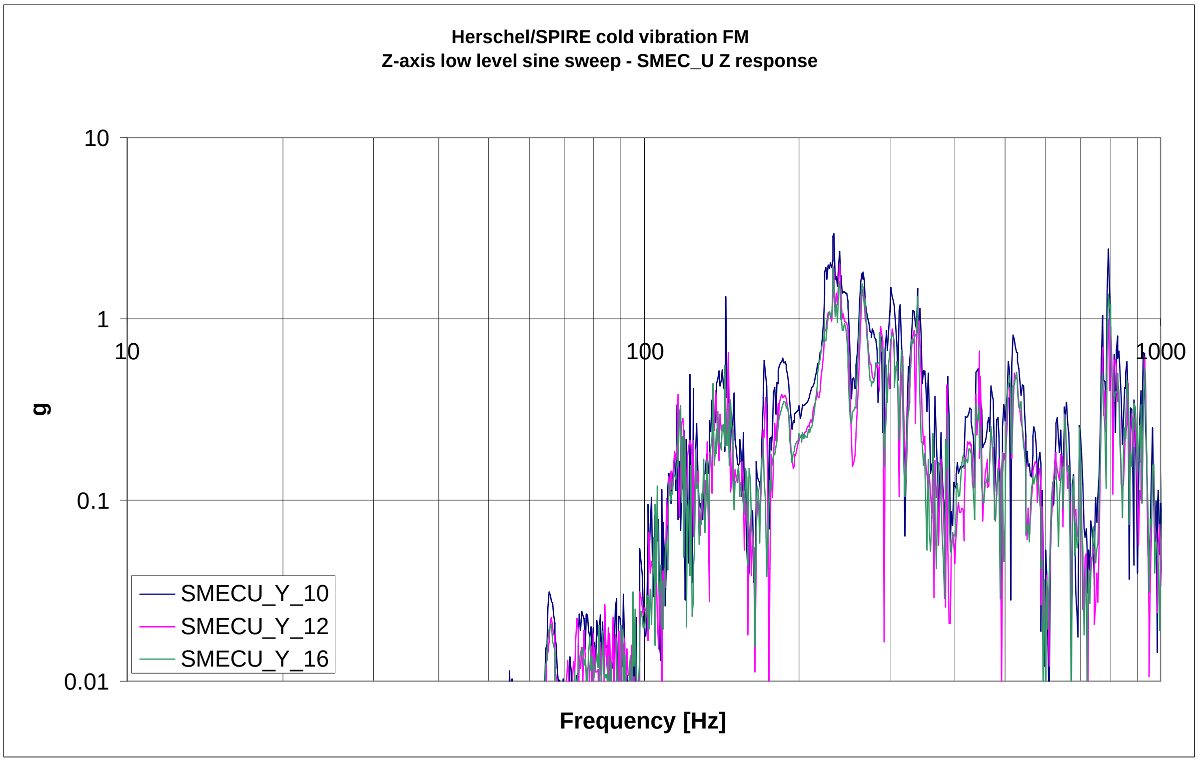


Herschel/SPIRE cold vibration FM
Z-axis low level sine sweep - FPU Z response
10
1
0.1
0.01
g
10
100
1000
Frequency [Hz]
FPU_Z_10
FPU_Z_12
FPU_Z_16

Herschel/SPIRE cold vibration FM
Z-axis low level sine sweep - Phot Z response
10
1
0.1
0.01
g
10
100
1000
Frequency [Hz]
Phot_Z_10
Phot_Z_12
Phot_Z_16




# Appendix C – Run list

See AD12 for a complete overview.

Below is a list of vibration runs and their identification code.

| Run | Date | Time | Axis | Description |
|---|---|---|---|---|
| BNS01Y.rsn | 22/11/05 | 17:35 | Y | Resonance search warm |
| BNS02Y.rsn | 22/11/05 | 18:05 | Y | Resonance search warm 1400 to 2000 |
| BNS03Y.rsn | 29/11/05 | 09:30 | Y | Cold sensor cal run 20 to 70 Hz, 0.25g |
| BNS04Y.rsn | 29/11/05 | 10:00 | Y | Cold resonance search, aborted |
| BNS05Y.rsn | 29/11/05 | 10:20 | Y | Cold resonance search, |
| BNS06Y.rsn | 29/11/05 | 11:25 | Y | Sine test intermediate level |
| BNS07Y.rsn | 29/11/05 | 11:35 | Y | Sine test repeat |
| BNS08Y.rsn | 29/11/05 | 11:40 | Y | Sine test full level |
| BNS09Y.rsn | 29/11/05 | 11:35 | Y | Resonance search |
| BNS10Y.rrn | 29/11/05 | 14:15 | Y | Random test low level |
| BNS11Y.rrn | 29/11/05 | 15:45 | Y | Random test intermediate level |
| BNS12Y.rrn | 29/11/05 | 17:15 | Y | Random test intermediate level |
| BNS13Y.rrn | 29/11/05 | 17:30 | Y | Random test full level |
| BNS14Y.rsn | 29/11/05 | 17:50 | Y | Resonance search |
| | | | | |

| Run | Date | Time | Axis | Description |
|---|---|---|---|---|
| BNS01Z.rsn | 30/11/05 | 14:00 | Z | Resonance search |
| BNS02Z.rsn | 30/11/05 | 15:10 | Z | Sine test intermediate level |
| BNS03Z.rsn | 30/11/05 | 15:15 | Z | Sine test full level |
| BNS04Z.rsn | 30/11/05 | 15:20 | Z | Resonance search |
| BNS05Z.rsn | 30/11/05 | 15:45 | Z | Low level sine 0.05g 1 oct/min |
| | | | | Warm up for inspection |
| BNS06Z.rsn | 5/12/05 | 17:15 | Z | Resonance search warm |
| BNS07Z.rsn | 15/12/05 | 17:15 | Z | Resonance search cold |
| BNS08Z.rsn | 15/12/05 | 18:00 | Z | Sine test intermediate level |
| BNS09Z.rsn | 15/12/05 | 18:10 | Z | Sine test full level |
| BNS10Z.rsn | 15/12/05 | 18:15 | Z | Resonance search |
| BNS11Z.rrn | 15/12/05 | 18:30 | Z | Low level random |
| BNS12Z.rsn | 16/12/05 | 07:20 | Z | Resonance search |
| BNS13Z.rrn | 16/12/05 | 07:30 | Z | Low level random |
| BNS14Z.rrn | 16/12/05 | 09:20 | Z | intermediate level random |
| BNS15Z.rrn | 16/12/05 | 10:40 | Z | full level random |
| BNS16Z.rsn | 16/12/05 | 10:50 | Z | Resonance search |
| | | | | |

| Run | Date | Time | Axis | Description |
|---|---|---|---|---|
| BNS01X.rsn | 16/01/06 | 17:50 | Z | Resonance search |
| BNS02X.rrn | 16/01/06 | 18:10 | Z | Low level random |
| BNS03X.rsn | 17/01/06 | 08:30 | Z | Sine test, intermediate level |
| BNS04X.rsn | 17/01/06 | 08:50 | Z | Resonance search |
| BNS05X.rsn | 17/01/06 | 09:00 | Z | Sine test, full level |
| BNS06X.rsn | 17/01/06 | 09:10 | Z | Resonance search |
| BNS07X.rrn | 17/01/06 | 10:50 | Z | Low level random |
| BNS08X.rrn | 17/01/06 | 11:10 | Z | intermediate level random |
| BNS09X.rrn | 17/01/06 | 11;20 | Z | Full level random aborted |

| | | | | |
|---|---|---|---|---|
| BNS10X.rrn | 17/01/06 | 11:30 | Z | Full level random |
| BNS11X.rsn | 17/01/06 | 11:45 | Z | Resonance search |
| | | | | |

# Appendix D - Summary of events

| Date | Activity |
|---|---|
| 21/11/05 | Delivery of SPIRE to CSL |
| 22/11/05 | Mount FPU on VTA in Y axis |
| | Warm low level run |
| 29/11/05 | SPIRE cold, Y axis test |
| 30/11/05 | Change axis to Z |
| 30/11/05 | Z axis vibration test<br>Change of signature |
| 1 to 5 Dec | Warm up |
| 5 Dec | Dismount SPIRE |
| 6 Dec | NRB |
| 7 Dec | Reintegrate SPIRE with one SS cone and two CFRP A frames |
| 8 Dec | Close cryostat |
| 11 Dec | Pump down |
| 12-14 Dec | Cool |
| 15 Dec | 80K calibration run for SMEC sensors |
| 16 Dec | Z axis repeat test |
| 16 to 19 | Warm up |
| 20 Dec to<br>5 Jan | Store in Nitrogen inside the cryostat |
| 5 Jan | Remove SPIRE |
| 11 Jan | Refit SPIRE |
| 12 Jan | Close cryostat |
| 13 -15 Jan | Cool down |
| 16/17 Jan | X axis test |
| 18-20 Jan | Warm up |
| 24 Jan | Remove SPIRE, Pack |
| 25 Jan | Ship to RAL |

# Appendix E - NCR HR-SP-RAL-NCR-136

| | | | | |
|---|---|---|---|---|
| **Spacecraft / Project** | **Herschel / SPIRE** | **Originator's Name** | Eric Sawyer | |
| **Experiment / Model** | SPIRE / PFM | **Signature** | | |
| **Sub-System** | FPU | **Date** | 5th December 2005 | |
| **Assembly** | | **Level** (Highlight if applicable) | **Major** | Minor |
| **Sub-Assembly** | | | | |
| **Item** | | **NRB Reference** | | |
| **Serial Number** | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **NCR Occurred During** (Highlight if applicable) | Manufacture | Inspection | **Test** | Integration | Other |

| | |
|---|---|
| **NCR Title** | **Cryo-vibration test Z axis** |

**NCR Description**

After the high level sine test in the Z axis, the post test resonance search indicated a 20% drop in the frequency of the first mode.

**Cause of NCR**

Detailed inspection of the FPU is required before the cause can be confirmed. It is likely to be damage to the CFRP mounting cone for the following reasons.

Y axis test results appear to be ok with not indication of damage.

Z axis excitation applied more load to the cone then testing in Y axis.

**Disposition / Corrective Action**

Inspection first then decide on course of action, options are:

1. Stop test and return SPIRE to RAL for further assessment/possible redesign of mounts.
2. Replace CFRP cone with stainless steel cone which has already been qualified, and continue test – repeat Z axis test then do X axis.

Option 2 Above was selected and all Corrective actions have now been completed Cold Vibration test's completed,

**NCR Closed**

| **Document or Drawing Affected** (Title, Number & Issue) | **Estimated COST OF NCR** (cost of : correction, Materials, Resource, and delay to Project etc.) |
|---|---|
| | |

| **NCR CLOSED** | **Name** | **Sign & Date** | |
|---|---|---|---|
| | | **Approved** | **Rejected** |
| **Project Manager** | **Eric Sawyer** | | |
| **Product Assurance:** | **Eric Clark** | | |
| **CCB-Chairman:** | | | |
| **Principle Investigator** | | | |
| **Product Assurance:** | | | |
| **Co-Investigator** | | | |
| **Prime Contractor** | | | |
| **ESA Project Office** | | | |