SUBJECT: Instrument Vibration Test Report
STM Qualification

PREPARED BY: B. Winter

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CHANGE RECORD

ISSUE	SECTIONS	REASON FOR CHANGE
1.0	all	New issue

Table of Contents

1. SCOPE

This document lists the main results of the qualification vibration test of the Herschel SPIRE instrument structural thermal model (STM). This model is structural representative with a few exceptions as listed in section 5. The STM model was tested in April 2003 with the stainless steel supports for the instrument itself and the dectorboxes.

The notching philosophy applied is outlined in Technote AD (2).

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)	Drawing of interface fixture for head expander	A1-5264-404-30
AD (4)	Drawing of interface ficutre for slip table	A1-5264-404-31
AD (5)	As built status	
AD (6)	Instrument Vibration Test Specification – STM Qualification	MSSL/SPIRE/SP007.1, issue 2.0
AD (7)	HERSCHEL : SPIRE STM QUALIFICATION	AIV-2003-027-VIB

REPORT REF:

3. DEFINITIONS

3.1. ABBREVIATIONS

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

4. TEST PHILOSOPHY

The design of the STM of the SPIRE instrument is identical to the flight model except as stated in section 5. This model will be used to qualify the structural design of the SPIRE instrument.

5. BUILD STANDARD

The STM of the SPIRE instrument is identical to the PFM with the following exceptions:-

- Mass thermal dummies of the following subsystem are fitted in place of the Flight units:-
- Beam Steering Mirror (and support)
  Spectrometer calibration source
- Spectrometer Mechanism (full structure but no electronics and dummy flex-pivots)
- Detectors (mass representative and internally suspended mass representative of the flight hardware with thermal interface for thermal busbar)
- Helium-3 cooler (mass dummy for the heater/evaporator, rest structure representative including suspention)
- Filters are optical dummies
- The instrument and dector boxes are supported by stainless steel parts, currently being re-designed.

The interface to the spacecraft is identical to the flight unit. The mass of the STM model of the SPIRE instrument is 38.5 kg.

6. TEST OBJECTIVES

- To Qualify the structural design of the SPIRE instrument and to recover response spectra at critical internal interfaces between system structure and subsystem structures.
- To measure the input levels of the subsystems.
- The test sequence is such that a proper response signature of the instrument is identified both in sine and in random vibration. This will lead to extra reconfigurations of the test set-up and extra runs. In effect all the responses are measured for all excitation directions at levels lower than flight levels before the structure is subjected to qualification levels.

The test objectives have been met. The test sequence was altered during the test after the initial Y-axis run. See appendix B.

7. FIXTURE

For the X axis vibration (on the nose of the shaker) fixture to drawing AD (3)-A shall was used.
For the Y and Z axis vibration (on the slip table) fixture to drawing AD (4) shall was used.

8. TEST REQUIREMENTS

8.1. SUMMARY

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

8.2. Fixture qualification runs

Runs on just the bare fixture werecarried out to prove that the fixture 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. Between major runs the bolt torques were checked and no loss of torque was observed.

Hereafter some examples of traces before and after the major runs are shown.

8.4. Sine vibration test

As stated in IID-A, AD (1) the qualification levels are:

X axis

Frequency Range Hz	Qualification level
5 - 20.1	+/- 11mm
20.1 - 100	18 g

Test sweep rate 2 Oct/min, the input was limited to the equivalent quasi static interface force.

Y and Z axis

Frequency Range Hz	Qualification level
5 - 13.5	+/- 11mm
13.5 - 100	8 g

Test sweep rate 2 Oct/min, the input was limited to the equivalent quasi static interface force.

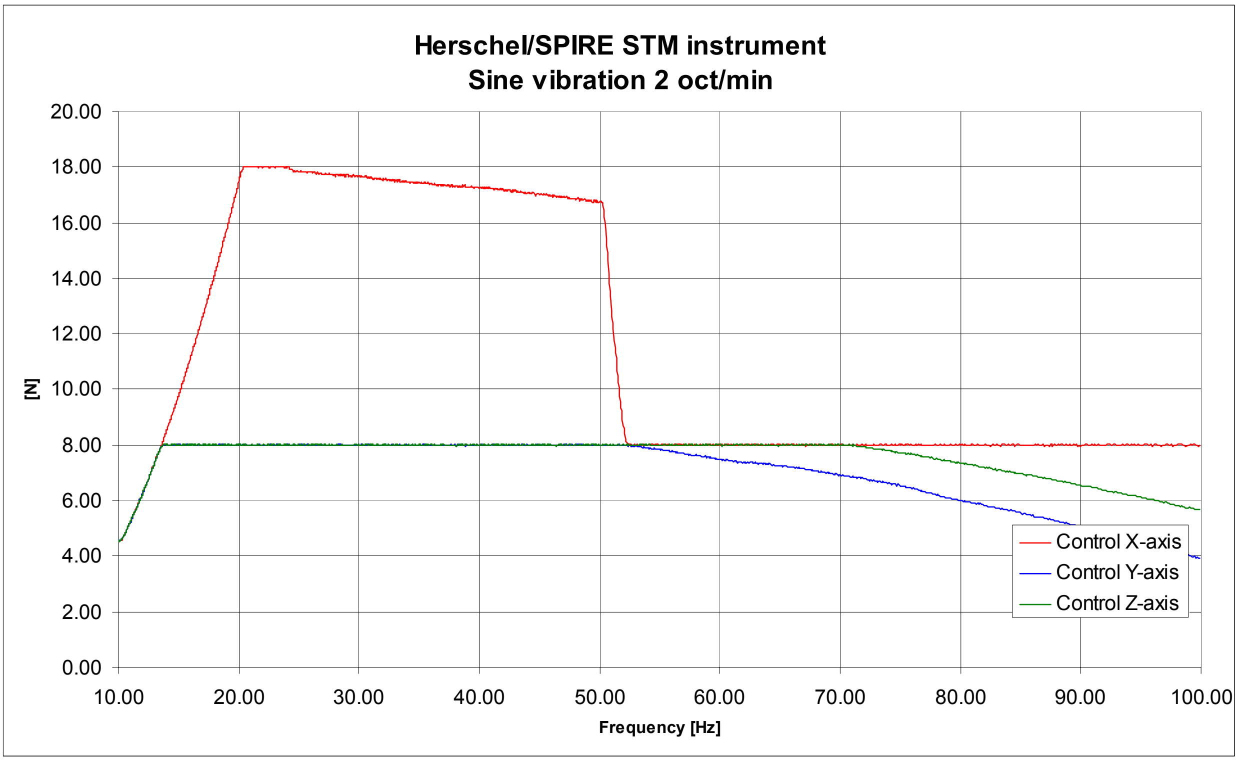


Figure 8.4-1 Achieved inputs for the 3 directions

As can be seen from figure 8.4-1 the force notch kicked in for the X direction at 24 Hz, for the Y direction at 52.5 Hz and for the Z direction at 71 Hz. For the X direction the input above 50 Hz was limited to 8 g. This to prevent fatigue damage to the main cone of the instrument. See log in appendix B. The cone at maximum load is stressed up to 85% of its allowable stress. Therefore it was decided to limit the amount of maximum load cycles to 1000. Hence the reduction after 50 Hz.

8.5. Random vibration test

As stated in IID-A, AD (1) the qualification levels were:

Y and Z axis

Frequency Range Hz	Qualification level
20-100	+3dB/Oct
100-150	0.02 g^2/Hz
150-300	0.0125g^2/Hz
300-2000	-7 dB/Oct
Global	…. gRMS

Test duration 2 minutes in each axis

X axis

Frequency Range Hz	Qualification level
20-100	+3dB/Oct
100-150	0.05 g^2/Hz
150-300	0.02g^2/Hz
300-2000	-7 dB/Oct
Global	…. gRMS

Test duration 2 minutes

For all tests force notching was applied.

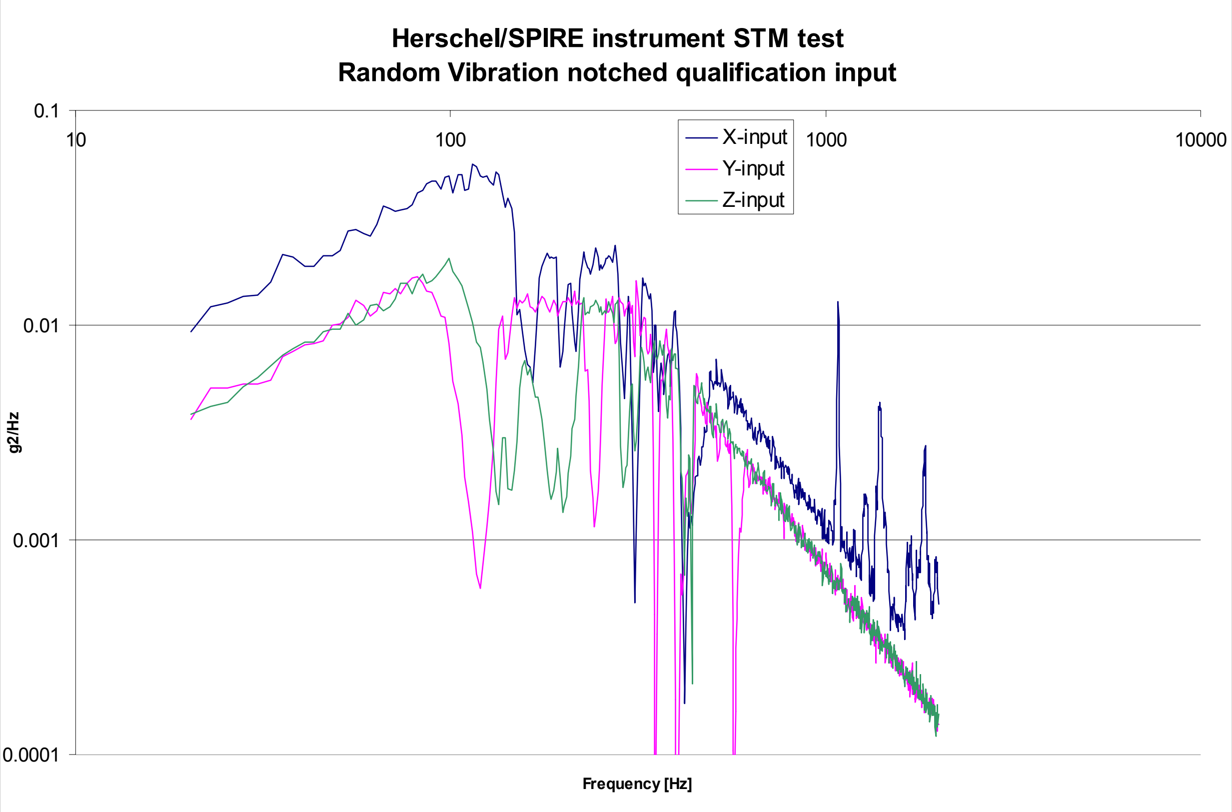


Figure 8.5-1 Achieved random inputs

As can be seen from figure 8.5-1 the force notch kicked in all over the frequency range between 100 and 600 Hz.

8.6. Measurement of subsystem levels

The instrumentation of the instrument should be sufficient to characterise the responses at critical locations and allow for the characterisation of the responses at the various subsystem interfaces. If needed runs will be repeated to cover all locations if the data acquisition doesn't allow for simultaneous measurement of all accelerometers at these locations.

Input levels at the following subsystems are required:-

Detectors (detector boxes)
Spectrometer mechanism
Helium cooler
Beam steering mirror (at base of the support structure)

The following graphs show the updated specification after the instrument test for these subsystems. These are based upon averaged and maximum measured levels during instrument testing. Enveloping them where appropriate. High frequency spikes have been ignored since they are a shake artefact.

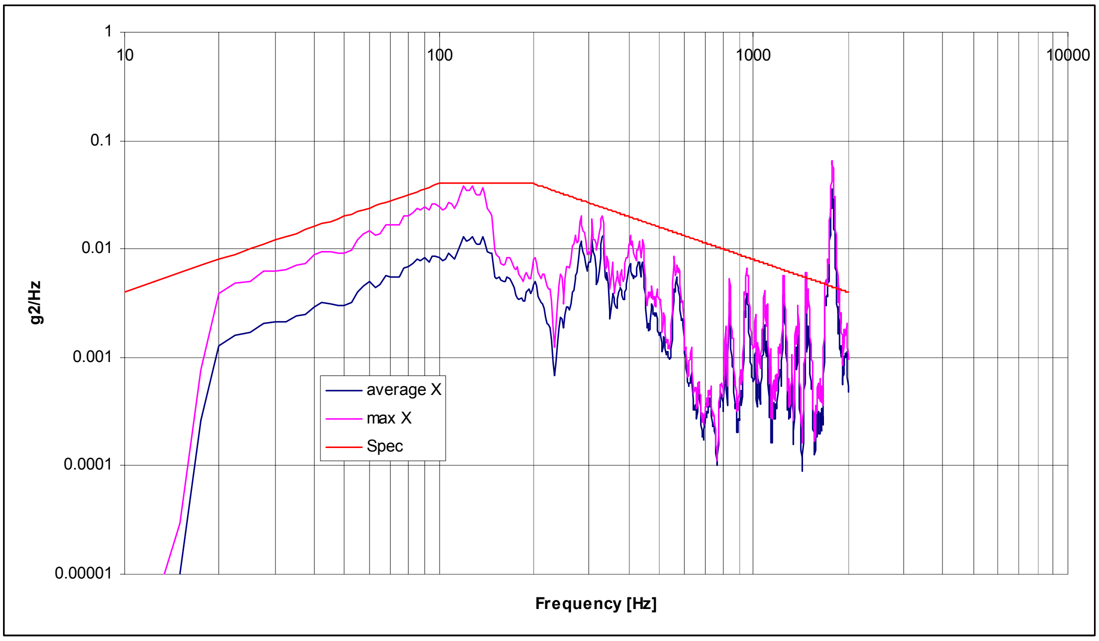


Figure 8.6-1: Updated specification of units mounted on the SOB (X-axis)

For the X-axis vibration (instrument coordinates co-aligned to S/C coordinates)

+3 dB/oct between 20 and 100 Hz
0.04 g^2/Hz between 100 and 200 Hz
-3 dB/Oct between 200 and 2000 Hz

This is about 5 g-rms

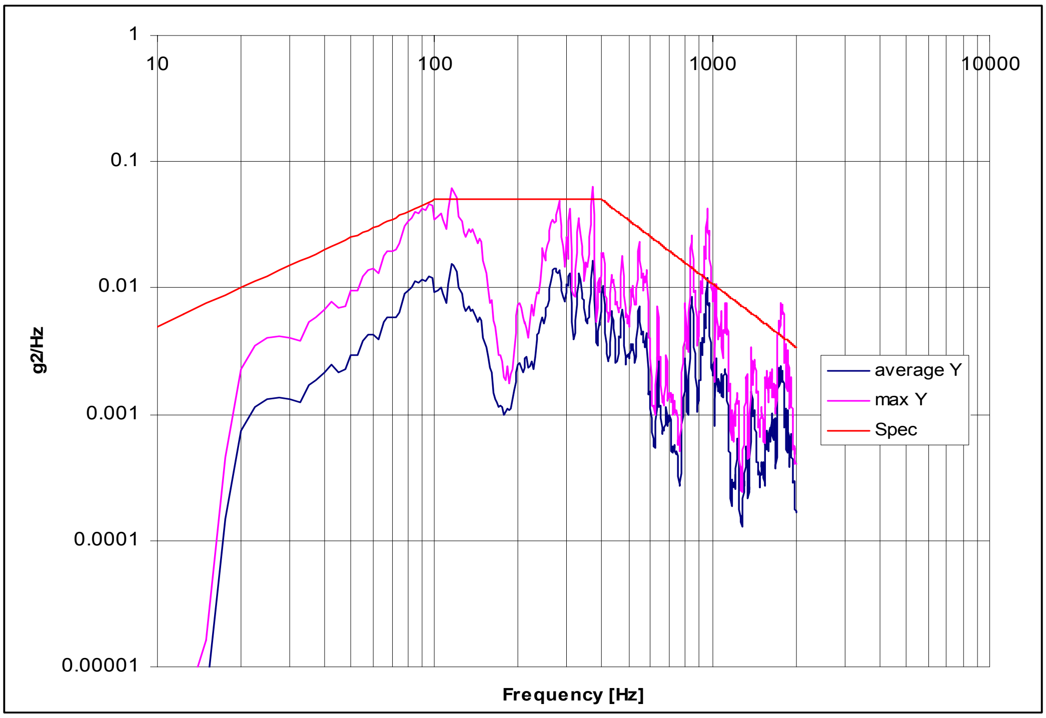


Figure 8.6-2: Updated specification of units mounted on the SOB (Y-axis)

For the Y-axis vibration (instrument coordinates co-aligned to S/C coordinates)

+3 dB/oct between 20 and 100 Hz
0.05 g^2/Hz between 100 and 400 Hz
-5 dB/Oct between 200 and 2000 Hz

This is about 6 g-rms.

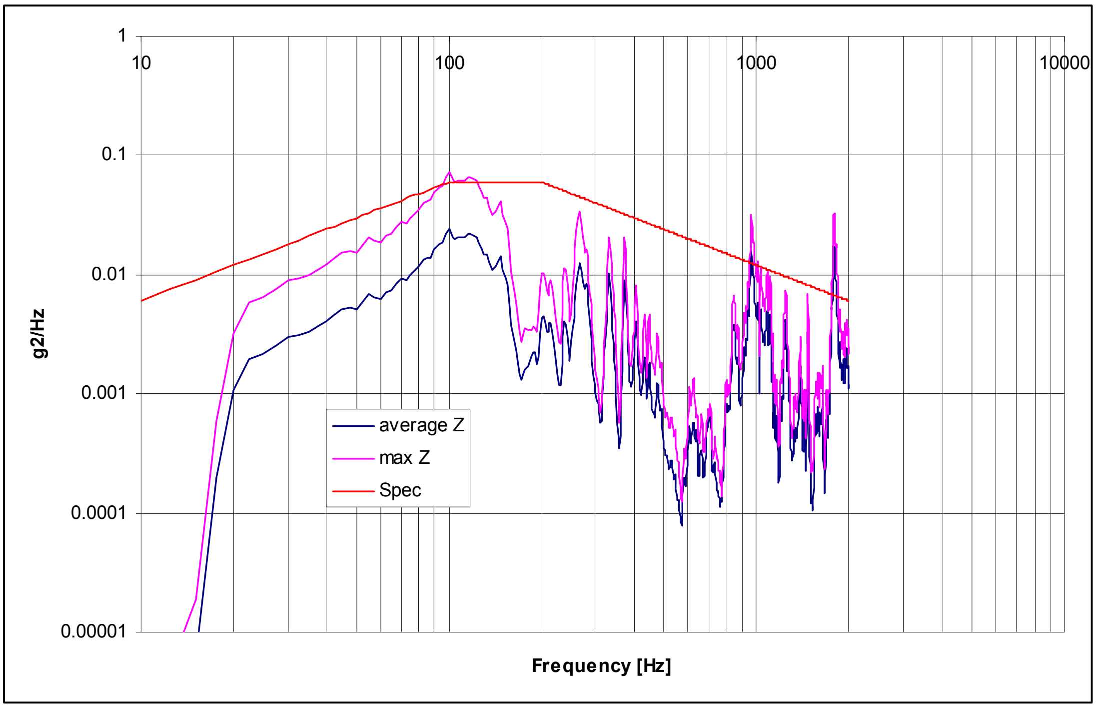


Figure 8.6-2: Updated specification of units mounted on the SOB (Y-axis)

For the Z-axis vibration (instrument coordinates co-aligned to S/C coordinates)

+3 dB/oct between 20 and 100 Hz
0.06 g^2/Hz between 100 and 200 Hz
-3 dB/Oct between 200 and 2000 Hz

This is about 6 g-rms.

8.7. Main resonance frequencies found

Main frequencies based on pre-post interface force measurements [Hz]		
X axis	Y axis	Z axis
	122	
	141	137
		147
176		
	197	
206		205
219		
	249	
314		

8.7-1: Main frequequencies (test mass 38.5 kg)

The requirement to have the first eigenfrequency above 100 Hz is met. Also the goal to have the first resonance above 120 Hz is met.

9. REJECTION AND RETEST

No test run was rejected or a re-test performed. One test was added (see log in appendix B) to verify the behaviour of the accelerometer mounted inside one of the detectors. Using an occiloscope signal clipping was observed at medium levels, not at low level.

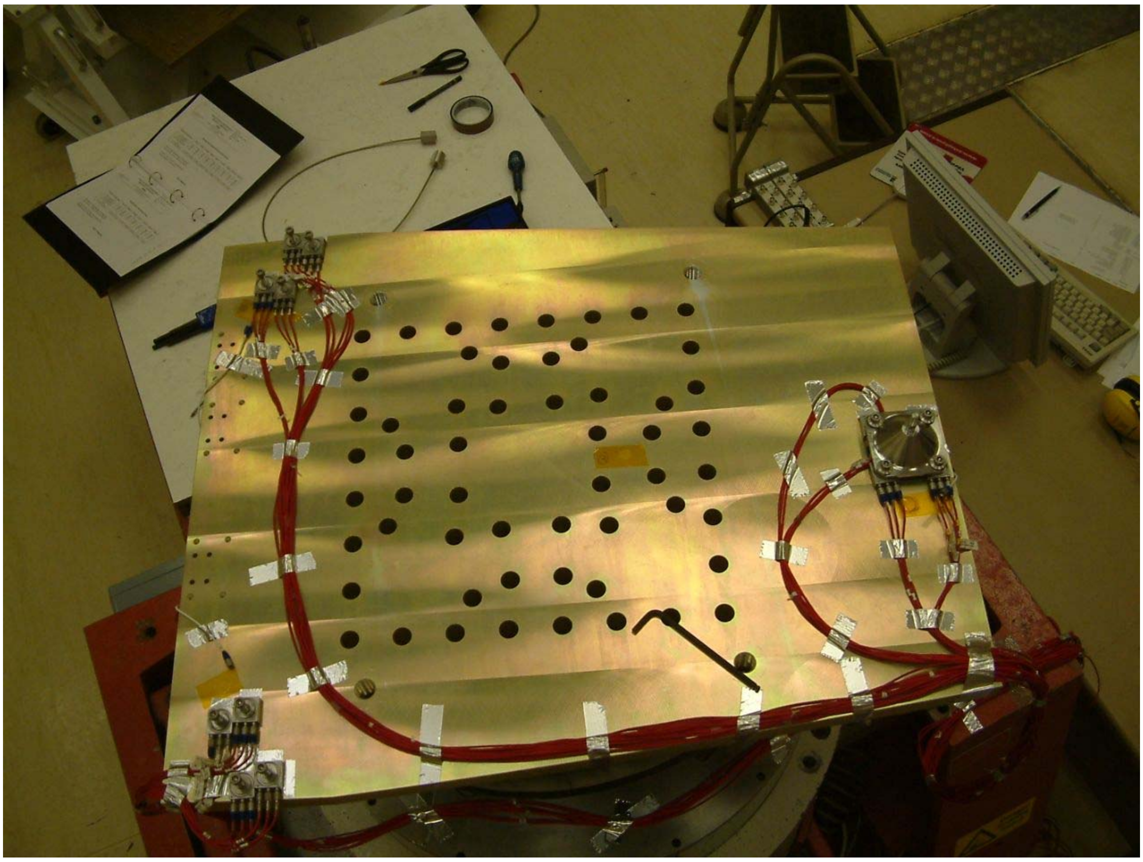
Appenix A - INSTRUMENTATION SPECIFICATION

The instrumentation consists of:

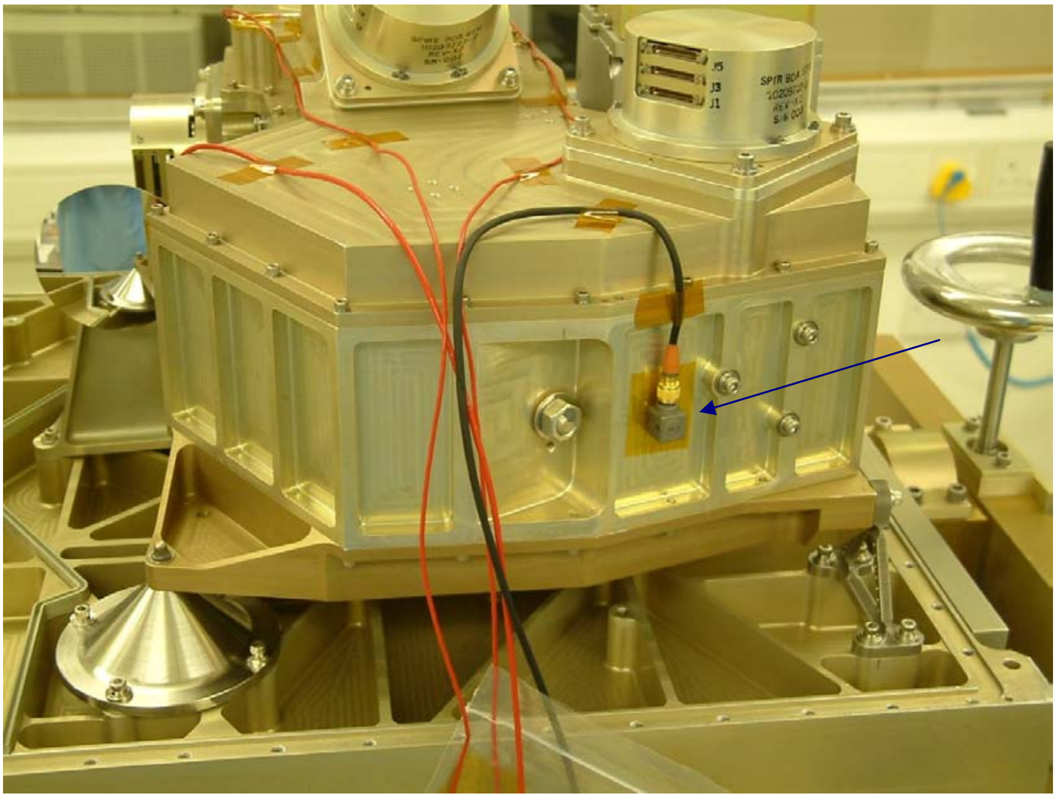
- At the monuting point of the instrument (interface with vibration fixture) tri axial for one, excitation direction for all (4 channels)
- Top of the optical bench in instrument coordinates: +X,+Z tri-axial or near that location. (3 channels)
- +X,-Z,-Y corner of the instrument, tri-axial (3 channels)
- Spectrometer detector box tri-axial (any suitable location) (3 channels)
- Photometer detectorbox 2 on extreme oposite ends measuring in Z direction (2 channels)
- Photometer detectorbox 2 on extreme oposite ends measuring in Y direction (2 channels)
- Photometer detectorbox 1 on any suitable location measuring in X direction (1 channel)
- At the foot of He3 cooler in Y direction (1 channel)
- At the foot of the SMec in Y direction (1 channel)
- At the foot of the BSM in Y direction (1 channel)
- Force in three axes (interface force) (3 channels)

The implemented instrumentation:

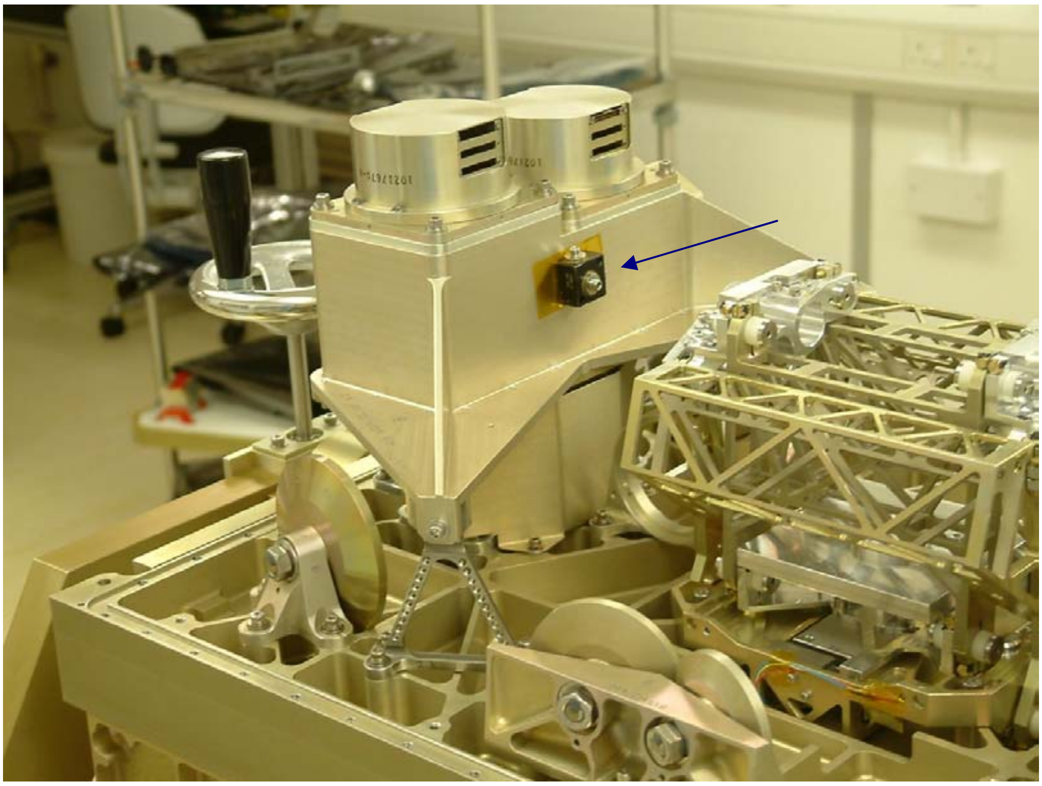
A-1:Control accelerometers



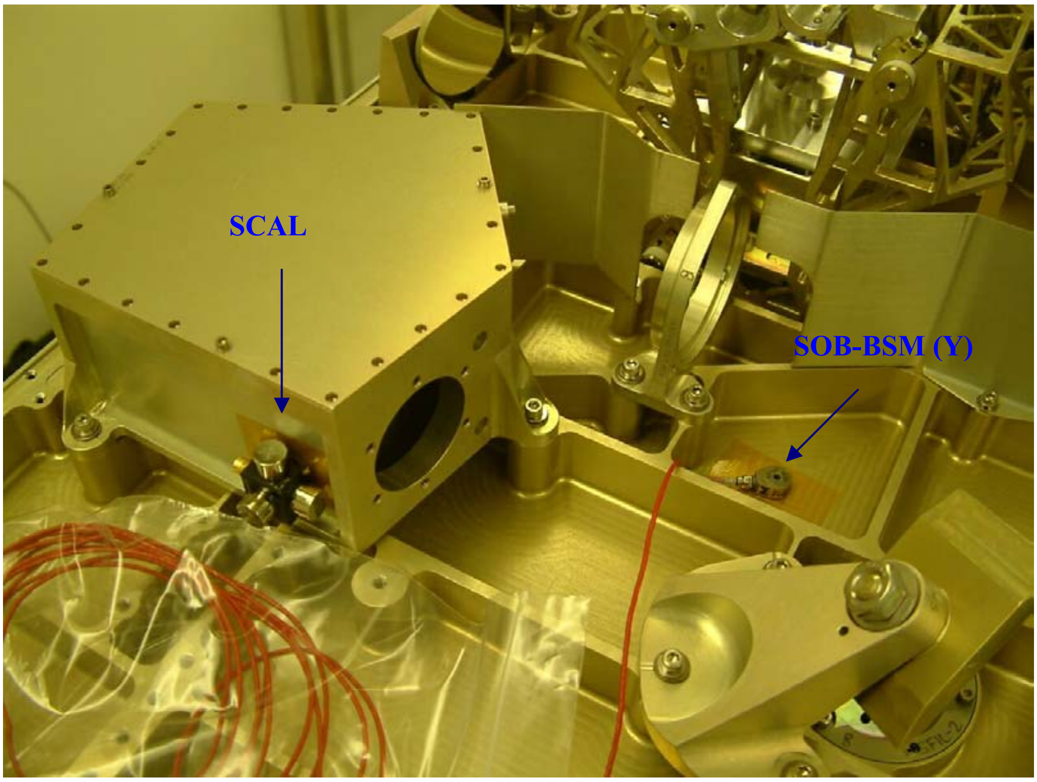
A-2:Force transducers at all interface bolts



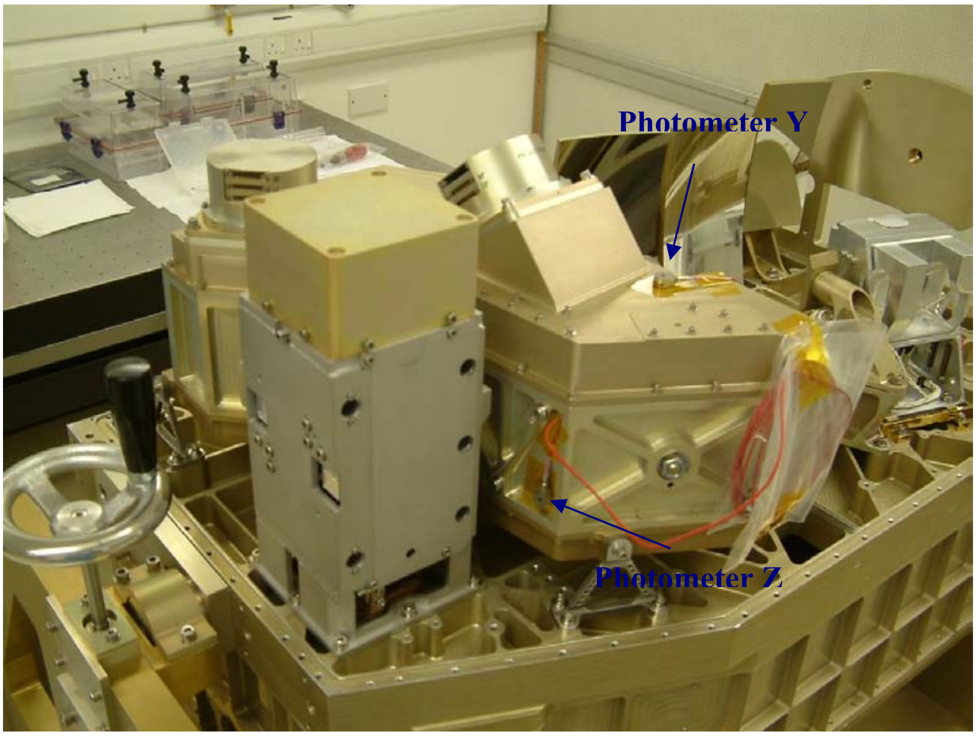
A-3: The triax on the photometer detector box



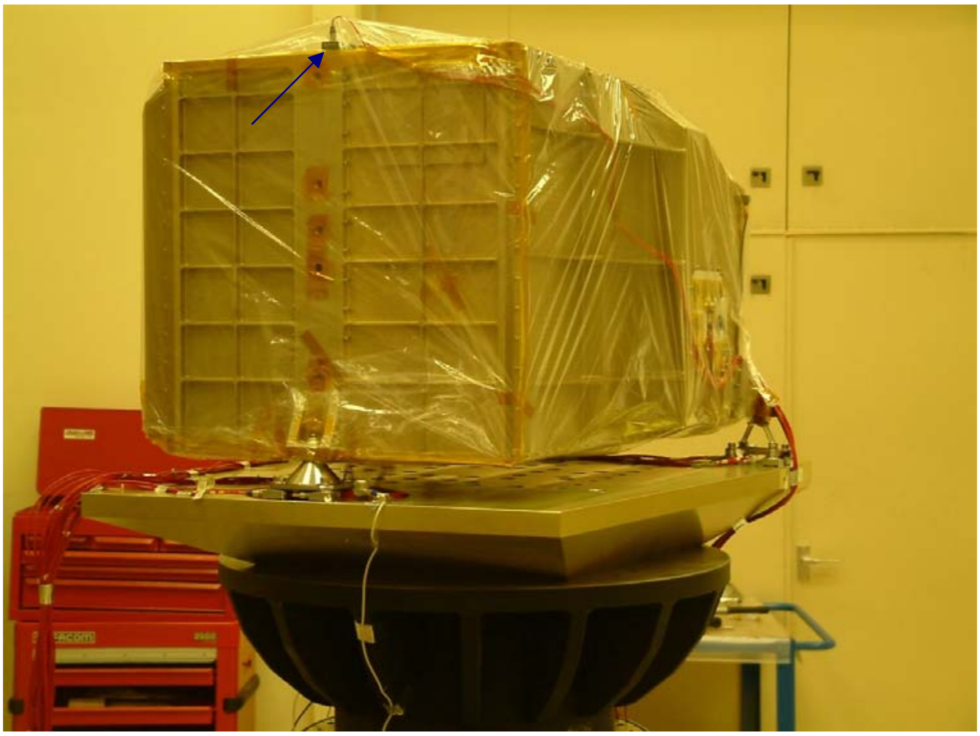
A-4: The trixax on the spectrometer detector box



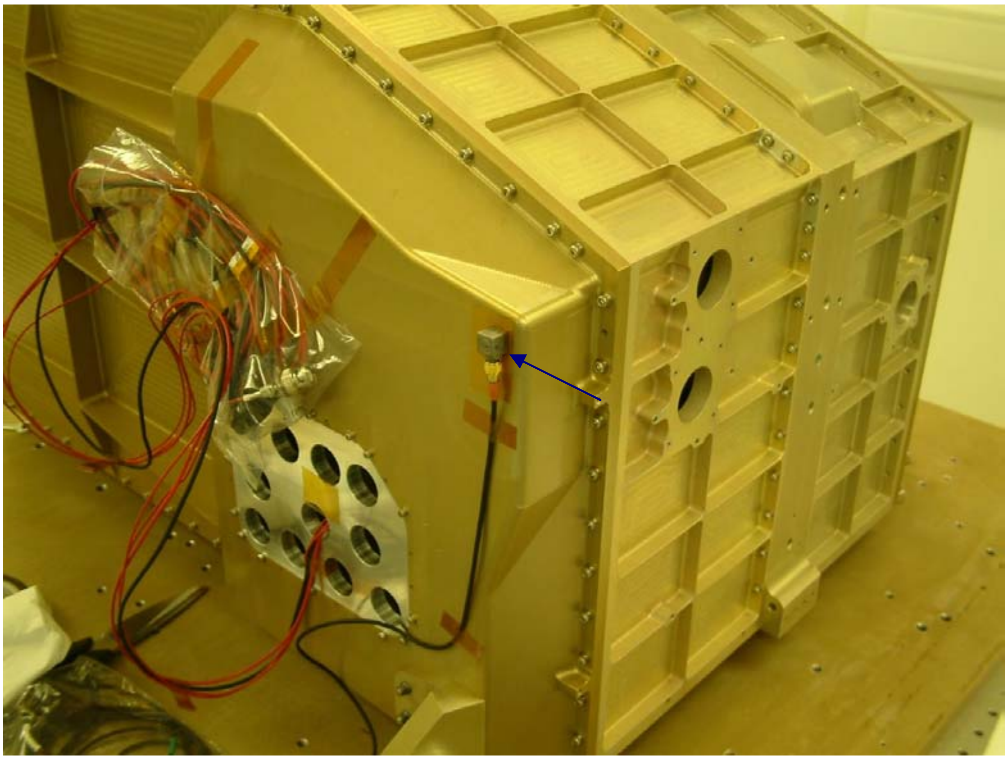
A-5: SCAL trixax and SOB-BSM location



A-6: Photometer detectorbox (extra at extreme ends)



A-7: Tri-ax on SOB outside



A-8: Triax on photometer cover

A-9: Cover plate (Y)

Appenix B – VIBRATION LOG

(These are notes taken by B. Winter during the vibration test)

Vibration log

24/04/03

Started with configuring for X axis vibration

Dave Rippington reported that the photometer tri-ax Z seems to be dead.
Measured the weight of the instrument about 250 g accurate: 38.5 kg

Low level sine sweep was repeated a few times to sort out signal clipping on the force transducers. Sorted

Source for accelerometer glue: RS 159-3935 (gel) and 159-3941 (activator)

Visual inspections before and after the test runs showed no damage, signature runs before and after the intermediate random confirmed no damage to the structure.

Photometer corner showing many peaks all the way up to 600 Hz.

Amplification factors between 5 and 10 for the main structure.

Main resonances at 180 Hz and around 300 Hz (looking at force profile)

A lot of cross coupling for the photometer box.

All in all all response traces show a vast amount of peaks at many different frequencies, spread out between 180 and 600 Hz.

The force trace suggests a cross couple mode at 122 Hz and at 140, 170 Hz. The 122 Hz is likely the first Y-mode.

25/04/03

Reconfigured for Y axis.

First sine sweep showed clipping on the force transducer signal. First resonance showed a steep ascent and decent (before and after clipping). Decided to reduce sweep input from 0.25 g to 0.15 g. And the sweep rate up from 2 oct/min to 4 oct/min.

Repeated the run. Clearly some non-linear behaviour is observed between 115 and about 125 Hz. This is likely due to minimal play in the A-frame spigot. We checked all bolt torques on the interfaces and they are close to 10 Nm. This should give us more than enough margin against slipping on the interface. The nonlinear behaviour is expected to originate inside the structure.

Based upon the minor amplifications of the structure, it was decided to complete this axis. That is go up to full level for both the sine and the random.

Tests were performed without any anomalies, but some minor issues on signal clipping on the sine sweep. Nothing serious. Pre and post full level run visual inspections showed no apparent damage to the A-frames or the cone. The sine signature run overlay (pre-post) showed no significant shifts in peak. Just the usual slight settling of the hardware, indicated by shifts in amplification. The non-linear response at 115 Hz was consistent throughout the whole axis.

Reconfigured to Z-axis.

26/04/03

Continued the test with the first low-level sine signature run in Z. Intention is to complete this axis in full as we did yesterday for the Y-axis. Remove instrument and make the shaker available for reconfiguration on Monday morning.

Low level sine sweep and low level random show no issues, nice clean modal behaviour. Again, damping in our favour. Resonance at about 130 Hz, main resonance at about 146 Hz.

Going into intermediate level random with force notch both on Z and X. Since the X force is strongly coupled to the Z and following it closely.

After full level random the sine signature looks fine. The only odd on out is the cooler-Y location (on the optical bench) which shows a shift (downwards) of 5 Hz (137 down to 132 Hz) but looks ok at higher frequencies. Same for photometer box Y. This may be an issue of bad synchronisation of this particular data acquisition computer (hired one) the control computer with accelerometers at similar locations shows no shifts at all. Both for the photometer detector box as well as for the main structure. Whatever the effect is (if real) must be very local.

Sine sweep was successful, not problems. Sine signature run afterwards is same as between full random and full sine. So no more shifts observed.

Visual inspection didn't bring up any anomalies. Ready to change axis.

Removed instrument from slip table fixture and put it aside on the HOB-simulator. Monday morning the shaker will be reconfigured back to X-axis excitation.

28/04/03

Mounted the instrument back on the head expander. Visual inspection of the A-frames showed that no gremlins had visited the facility over the weekend. Ready to roll.

Decided to deviate from test spec, first full run will be random, since its less severe than the 18 g quasi-static. The other deviation is to step down the input of 18 g above 40 Hz, down to 8 g. The structure will in that case see the 18 g full level for 30 seconds.

After discussions with Thijs van der Laan and Eric Sawyer decided to lower the sine input above 50 Hz down to 8 g. This based on the stressing of the main cone during this run. There is little margin left and we need to minimise the fatigue damage. The cone is stressed up to 85% of its allowable stress. The number of full load cycles was reduced to 1000.

We introduced an extra random run at -3 dB full level for 10 sec to verify the accelerometer mounted on the PLW detector. It showed consistent signal clipping at higher input levels. Using an oscilloscope we looked at the time domain data and noticed serious spikes in an otherwise clean signal at higher input levels (at low level the signal seemed clean). So there is indeed a threshold to be exceeded before we see that behaviour. Visual inspection after the test inside the instrument may shed some more light on this. For now I would recommend to ignore the readings of this accelerometer for higher levels.

We did the high level sine, 18 g between 20 and 50 Hz was as impressive as one can expect. Better not repeat that one. Pre and post sine signature matched up rather nicely.

After consulting Eric Clark we dismantled the test set-up.

Appenix C – Structural integrity

X-axis

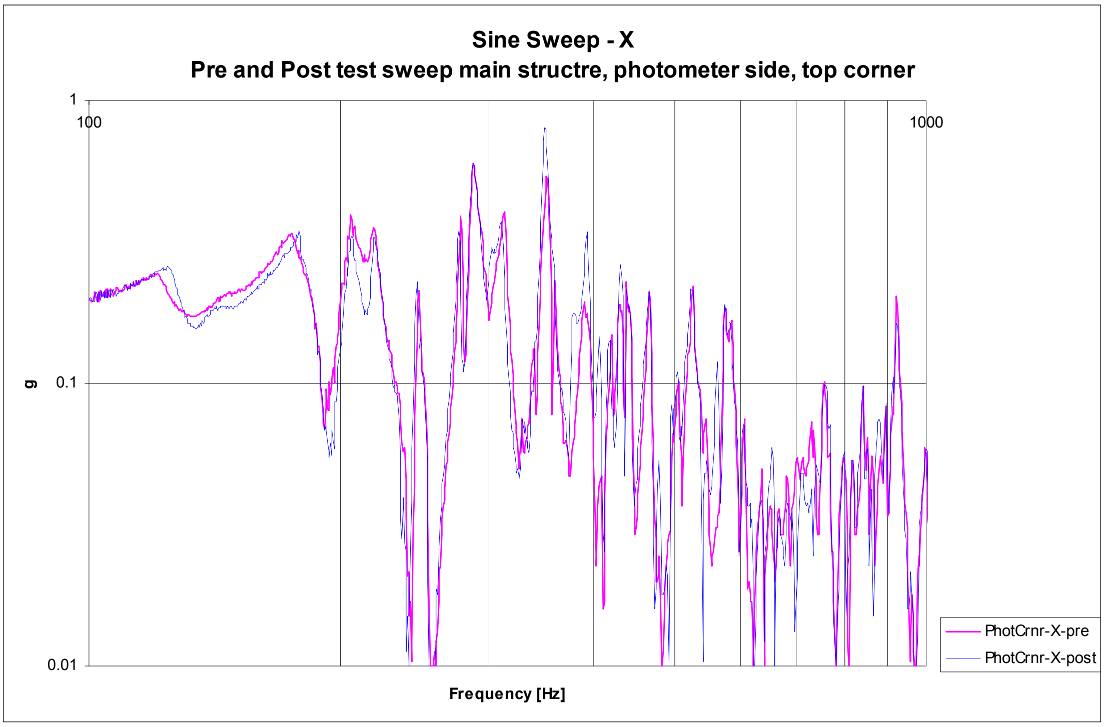


Figure B-1: Main structure in excitation direction (position shown in figure A8, appendix A)

Figure B-1 shows that the main structure changed its amplification slightly for several modes. No major frequency shifts. Not that this is a comparision between the first sweep at the beginning of the test campaign and the last test of the test campaign. It also envelopes the Y and Z axis vibration tests.

Figure B-2: Photometer det. box in excitation direction (position shown in figure A3, appendix A)

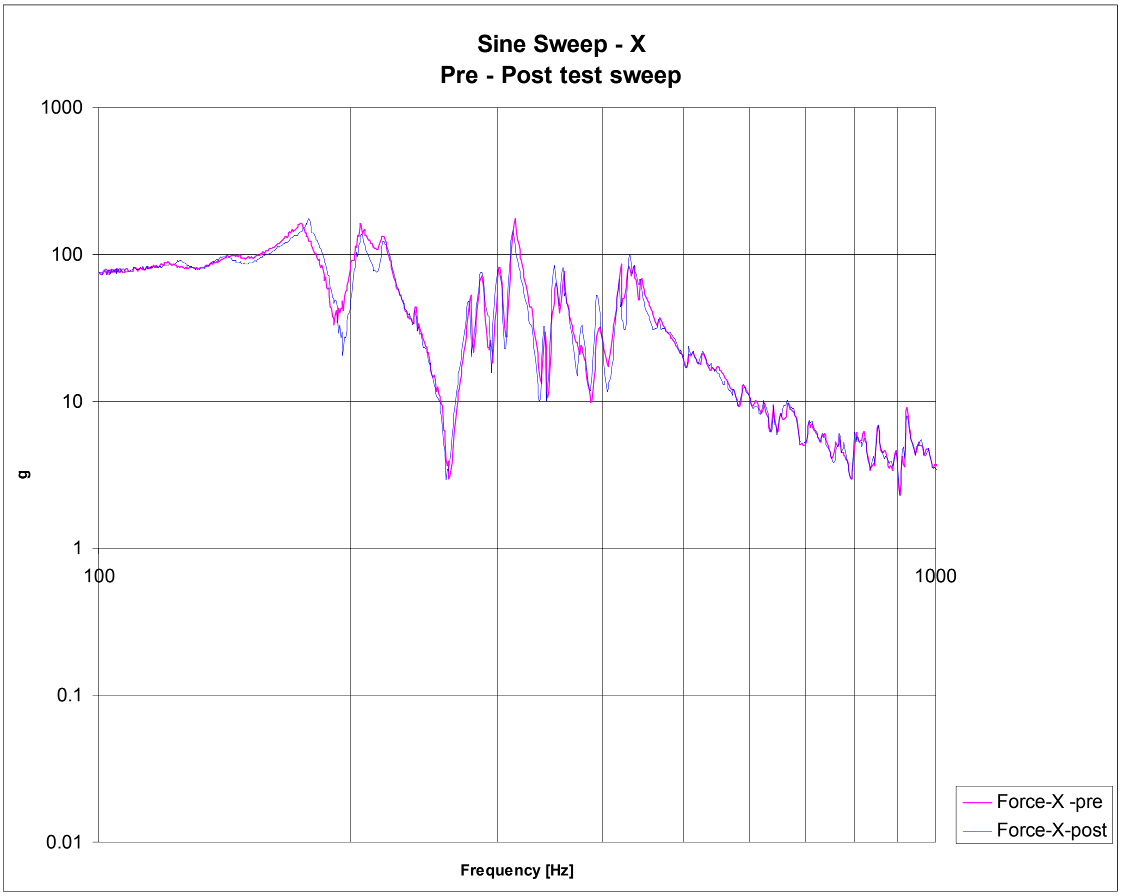


Figure B-3: Interface force in excitation direction

Y-axis

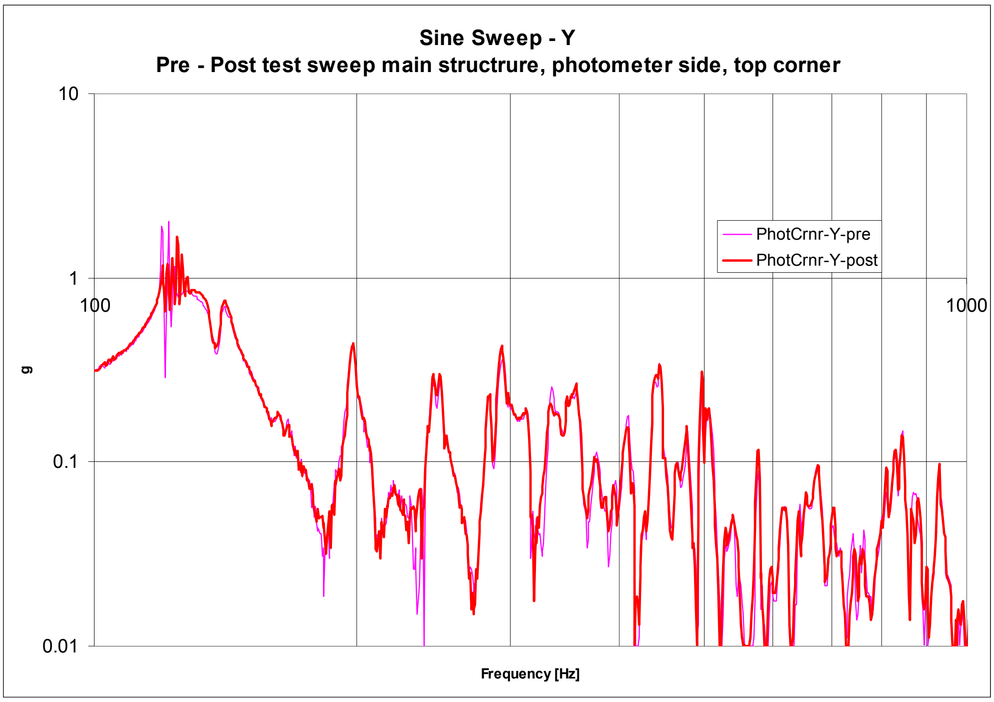


Figure B-4: Main structure in excitation direction (position shown in figure A8, appendix A)

Figure B-4 shows that the main structure has a resonance between 120 and 130 Hz. This resonance is the one predicted for 135 Hz (main mode in Y). However due to the slight play at the A-frames the mode hardly shows and is shifted downwards in frequency. No frequency shifts observed in pre-post test run.

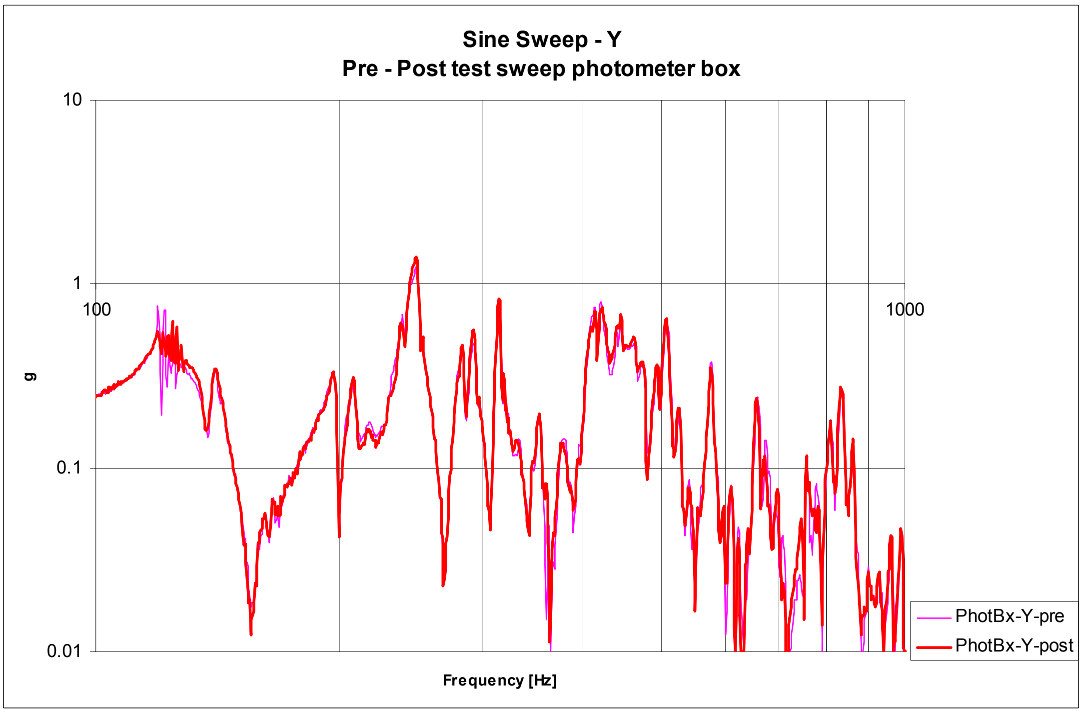


Figure B-5: Photometer det. box in excitation direction (position shown in figure A3, appendix A)

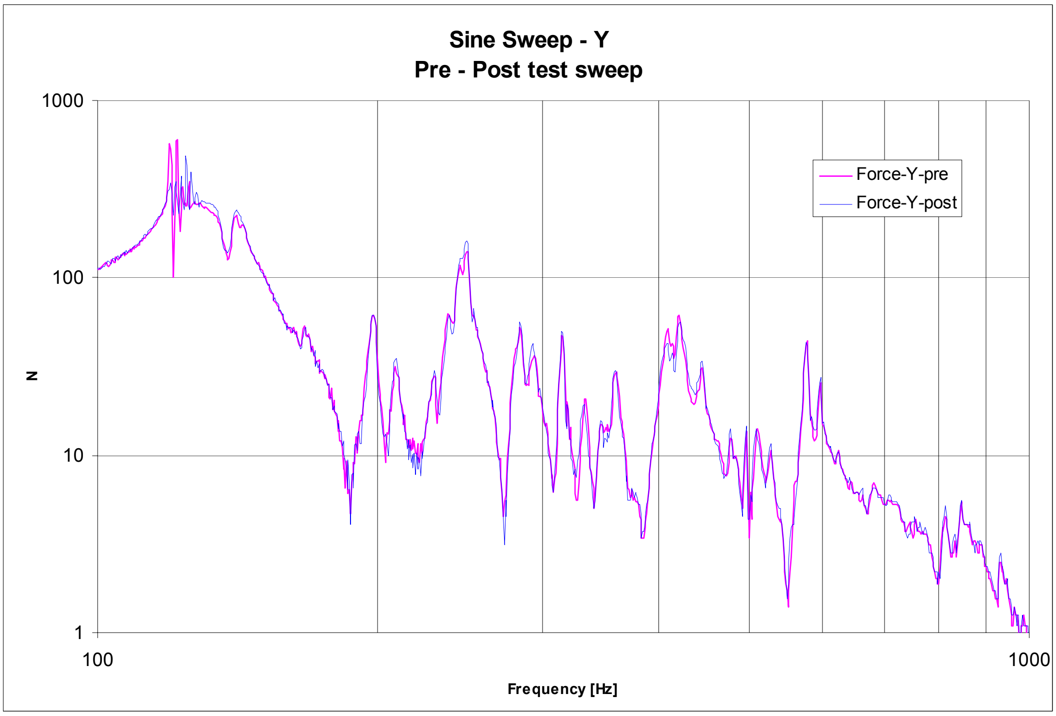


Figure B-6: Interface force in excitation direction

Z-axis

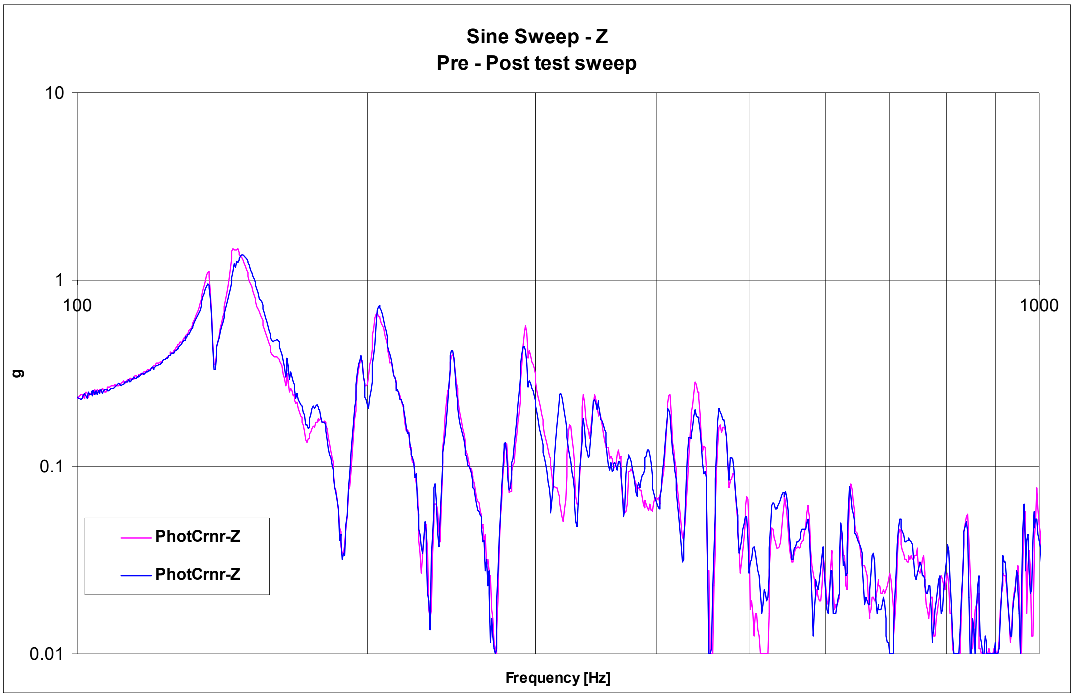


Figure B-7: Main structure in excitation direction (position shown in figure A8, appendix A)

Figure B-7 shows that the main structure has resonances 137 and 146 Hz. No frequency shifts observed in pre-post test run.

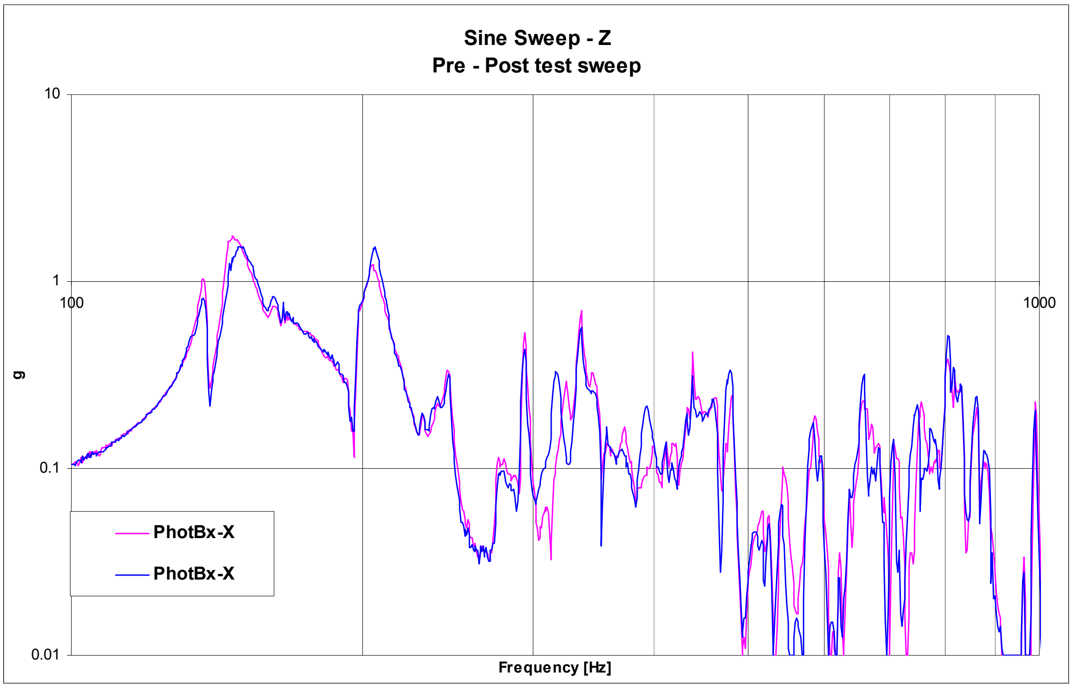


Figure B-8: Photometer det. box in excitation direction (position shown in figure A3, appendix A)

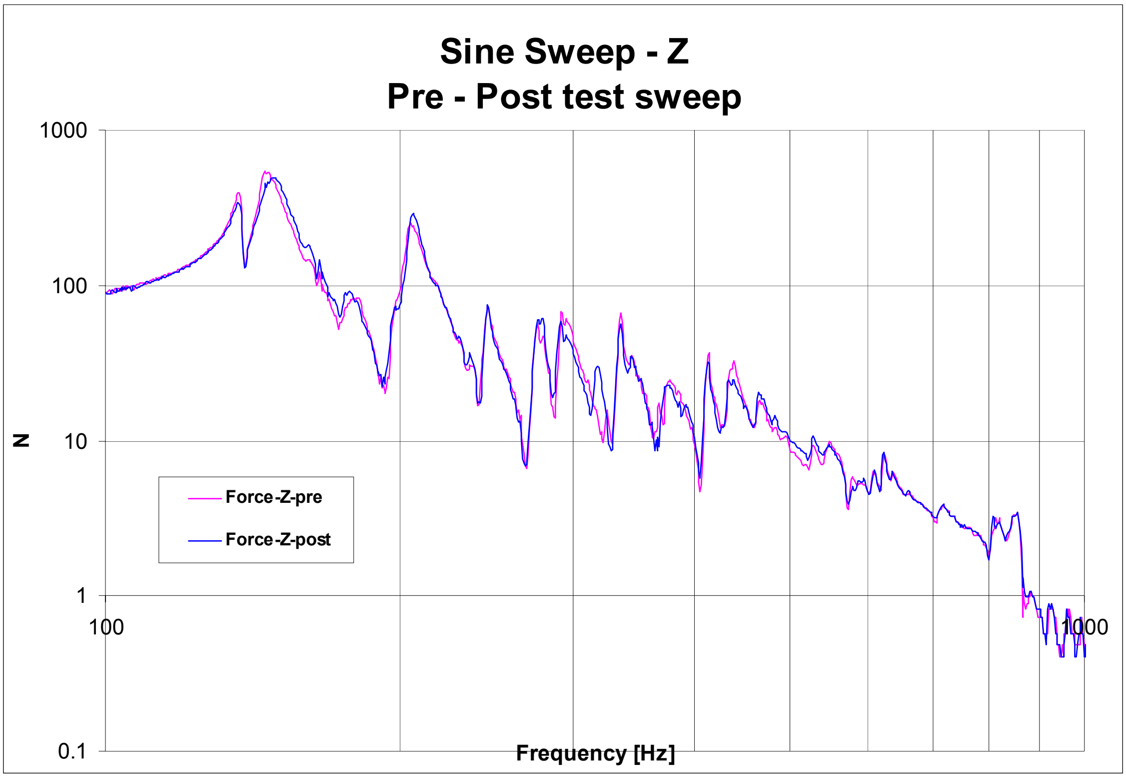
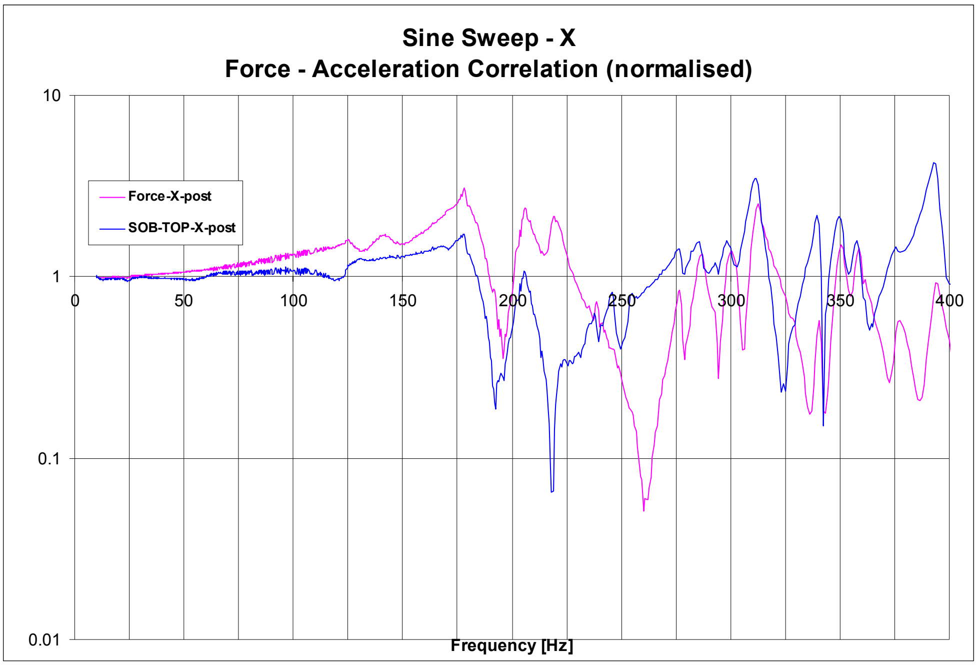


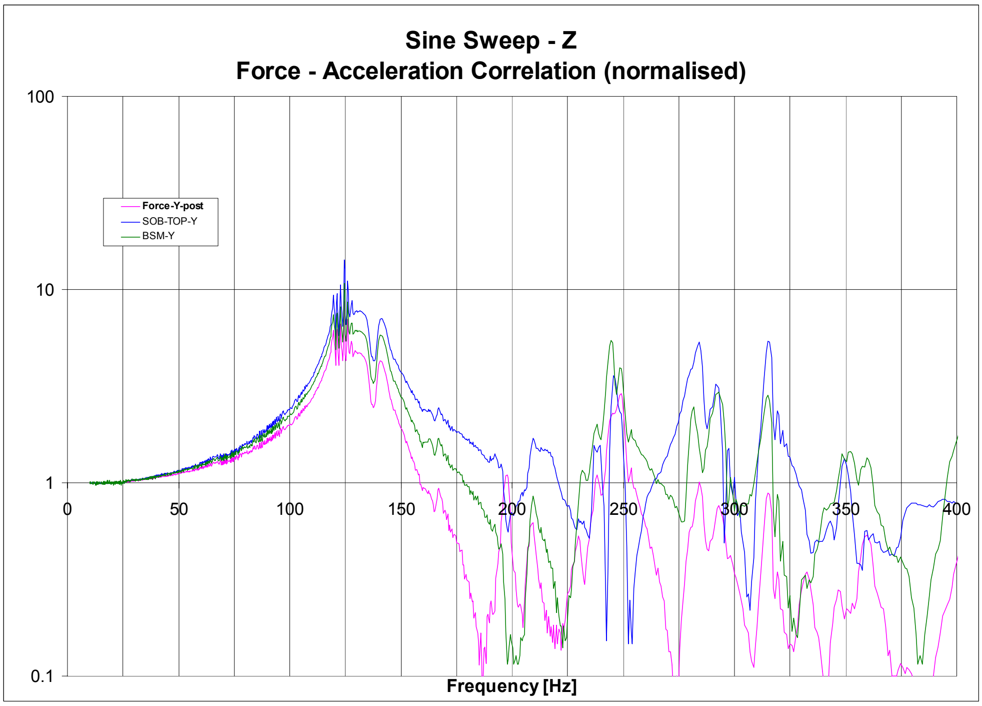
Figure B-9: Interface force in excitation direction

Appenix D – Interface force – acceleration correlation

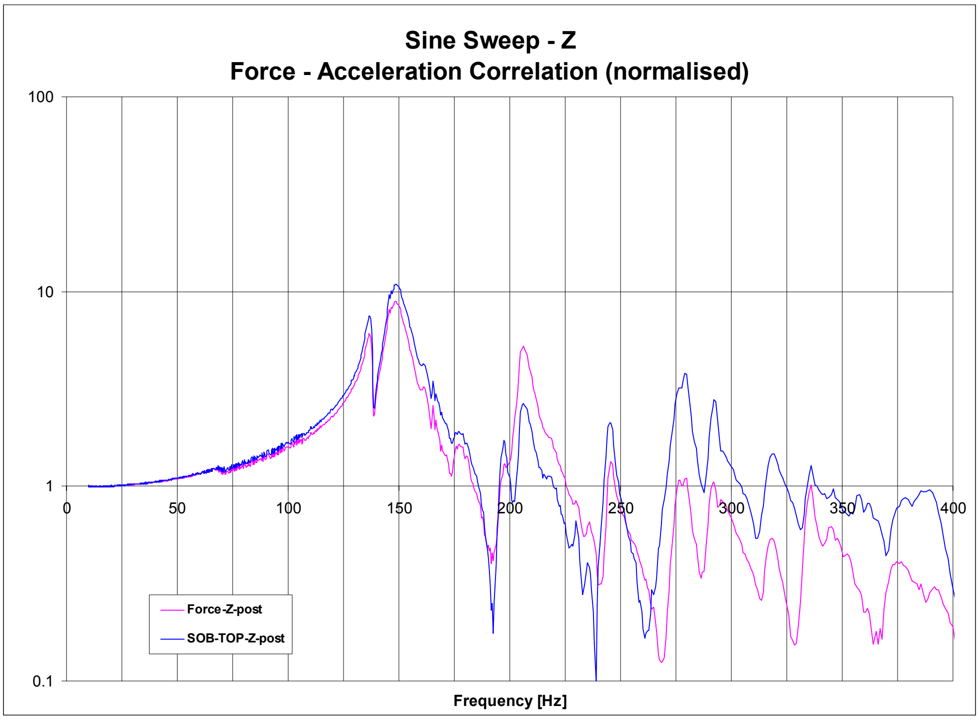
In this appendix the measured interface force is compared with the acceleration measured on top of the Spire optical bench (SOB). The correlation is limited to below 400 Hz. Both the force as well as the acceleration have been normalised to 1 at 10 Hz.



D-1: Interface force and SOB acceleration in X



D-2: Interface force and SOB acceleration in Y



D-3: Interface force and SOB acceleration in Z