	FE Analysis ATLAS: End Cap Support Structure **PSD Spectrum Analysis**	Doc.No. : FEA/EndCap/cjn/rep9 Prepared by: C.J.Nelson Issue: 2 Date: 16/07/2001 Project: TDL 004

1. SCOPE
This report investigates the effect of a PSD (Power Spectral Density) random input load on an early FE model of the ATLAS EndCap Support Structure. Statistical predictions of the maximum displacement are presented.

2. INTRODUCTION
A random psd input load has been applied to the support structure model at its mounting points. This is to simulate the vibration transmitted into the structure from the environment. It is difficult to estimate the level of this vibration, therefore a sensitivity study has been done around possible values, and comparison is made with measurements in similar surroundings.

3. MODEL
The cylinder is modelled as 10 mm (0.2-9.6-0.2) Honeycomb composite and the fins as 30mm HC (1-28-1). The total mass of the model is 100.26 Kg.

4. LOAD
The model is in mm, and therefore g is entered as 9807 mm/s^2.
15 modes (up to a frequency of 95 Hz) have been used for the baseline analysis, and the psd input used is a flat spectrum from 1 Hz to 100 Hz. An input psd value from 1×10^{-8} to 1×10^{-10} g2/Hz has been studied. Material damping is likely to be between 1% and 5% for a composite structure, but in reality there will be extra damping due to all the attached cabling etc.

5. CONSTRAINTS
Fig 1 shows the modelled constraints at the end of each fin of the model (only the +Z Fins are constrained in the Z-direction). The mounting concept is to allow thermal expansion in the X and Z directions.

6. REQUIREMENT
The following are taken from the TDR Vol 2 page 512. It has also been checked that these are still applicable values for vibration displacement.

Direction	Maximum displacement (μm)
r-phi	12
r	50
Z	200

7. RESULTS

The first mode for the baseline design is at approximately 7 Hz, and the 2nd is above 30 Hz. The first mode for the structure has always been Z-direction movement of the cylinder, bending the constrained fins. All the deflection plots are in mm. The 1σ plots for the baseline analysis with an input level of 1 x 10^{-8} g^2/Hz and 1% damping are listed below and attached. There is a systematic displacement of the supports due to the input psd, but it is the displacement of the model relative to the supports that is required, since it is the relative displacement of the detectors with respect to the rest of the tracker that is required, and therefore relative displacements are presented.

Figure no.	Page No.	Excitation direction	Displacement in excitation direction (μm)	Vector displacement (μm)
2	7	X	0.263	
3	8	X		0.849
4	9	Y	0.711	(0.726) not shown
5	10	Z	12.239	

Plots of predicted 1σ relative displacement

Sensitivity study

The 3σ predictions of maximum relative displacement for three orders of input psd level and damping ratios of 1 and 5% are shown below. (3σ values = 3 x 1σ values in this case). It is a statistical prediction and the 3σ values give a probability of 99.7 % that the displacement is less than that shown.

	Psd level (g^2/Hz)					
	1x10^{-8}		1x10^{-9}		1x10^{-10}	
	1%	5%	1%	5%	1%	5%
X-direction	0.79	0.32	0.25	0.10	0.08	0.03
Vector	2.55	0.93	0.80	0.29	0.25	0.09

Maximum 3σ displacement (μm) due to input in X-direction

	Psd level (g^2/Hz)					
	1x10^{-8}		1x10^{-9}		1x10^{-10}	
	1%	5%	1%	5%	1%	5%
Y-direction	2.13	0.92	0.68	0.29	0.21	0.09
Vector	2.18	0.98	0.69	0.31	0.22	0.10

Maximum 3σ displacement (μm) due to input in Y-direction

	Psd level (g^2/Hz)					
	1x10^{-8}		1x10^{-9}		1x10^{-10}	
	1%	5%	1%	5%	1%	5%
Z-direction	36.72	16.36	11.61	5.18	3.67	1.64

Maximum 3σ displacement (μm) due to input in Z-direction

The displacement is greatest in the Z-direction when excited in that direction as expected because of the main fundamental mode in that direction. However, the requirement is much more stringent in the other directions.

8. VALIDATION

It is possible to compare the 1st mode with its simple Z-direction motion to a 1dof spring/mass system. This has been done very thoroughly in several ways across a range of input values, damping and frequencies as shown in the table:

1) An ANSYS model has been made of a 1dof system
2) A formula (CERN EST) derived from the theory for a 1 dof system;

$$sx \approx \sqrt{\frac{G}{8x(2pf)^3}}$$

has been applied

3) The transmissibility function has been modelled on a spreadsheet and σ calculated.

Damping	Psd Level (g2/Hz)	F_0	Main Model (F_0 =7.2 Hz) ABS	REL	1)ANSYS sdof model ABS	REL	2) Formula	3) Spreadsheet ABS	REL
0.001	$1x10^{-10}$	2			24.7	24.6	24.6	24.7	24.62
	$1x10^{-10}$	3			13.5	13.4	13.4	13.52	13.4
	$1x10^{-10}$	6			4.99	4.74	4.74	4.96	4.74
	$1x10^{-10}$	10			2.65	2.2	2.2	2.6	2.2
0.01	$1x10^{-10}$	3			4.6	4.23	4.6	4.58	4.25
	$1x10^{-7}$	7	61.7	38.7	61	37.5	37.6	58.65	37.85
	$1x10^{-8}$	7	19.5	12.2	19.3	11.9	11.89	18.56	11.97
	$1x10^{-9}$	7	6.17	3.87	6.09	3.75	3.76	5.87	3.78

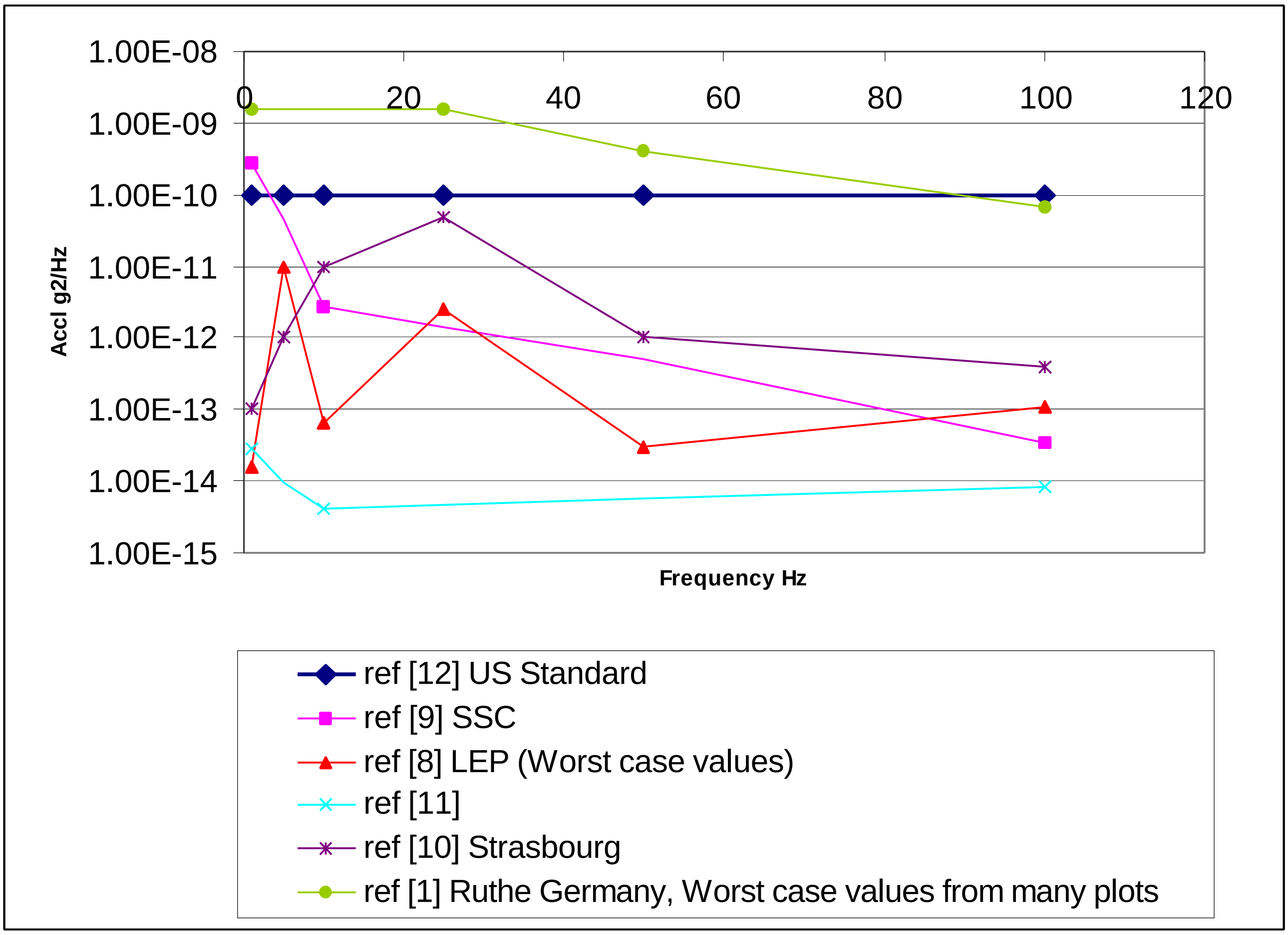
1σ displacements (μm) obtained by the three methods (REL = Relative, ABS = Absolute)

At 0.1 % damping and low psd levels there is little difference between the absolute and relative displacement, and a wider range of values were calculated to confirm the validation. The formula 2) method is clearly showing relative values. There is good agreement between all three methods, and with the main model, confirming the validity of the predictions of the main model.

The effect of natural frequency on the predicted displacement for a 1DOF system with 1% damping and an input level of 1 x 10^{-8} g2/Hz can be seen from the following table;

Natural frequency (Hz)	3σ displacement μm
2	233
7	35.7
10	20.9

9. COMPARISON OF VIBRATION LEVEL



The chart shows vibration level data from a number of different locations and measurements. Reference [12] refers to a US standard flat background spectrum of $1\text{x}10^{-10}$ g2/Hz which was developed from data available at several US national laboratories. Data has also been studied from two US sources, and the highest is plotted as ref [9]. This shows data from the SSC collider. The data has been converted and shows a maximum value of $2.68 \text{ x } 10^{-10}$ g2/Hz, but only at very low frequencies.
Ref [8] shows the worst case measurements from the LEP tunnel with a maximum value of $1 \text{ x } 10^{-11}$ g2/Hz at 5 Hz.
Ref [10] measurements are from the Institut de Physique du Globe in Strasbourg.
Ref [1] shows measurements from the GEO experiment at Ruthe. The worst case values from many plots are shown. There is a maximum value of $1.6 \text{ x } 10^{-9}$ g2/Hz, but the data is a little unclear and has had to be converted.

Fig 7 shows a spectrum taken at Daresbury Laboratory near the SRS, and Fig 6 shows a spectrum taken at Rutherford near the beam lines. The RAL spectrum shows maximum levels of up to $1\text{x}10^{-8}$ g2/Hz between about 100 and 400 Hz. The DL spectrum shows an isolated peak of $1\text{x}10^{-8}$ g2/Hz at about 120 Hz. These are however very noisy environments with choppers running on the beamlines which are not present on the LHC.

10. CONCLUSIONS

It is likely that the background vibration level will be below 1×10^{-10} g2/Hz, especially since the actual data from LEP is well below that level with a maximum of 1×10^{-11} g2/Hz. Even with only 1% damping this will produce displacements of a fraction of a micron in the X and Y directions, and of <4 microns in Z. In the unlikely case that the vibration levels are as high as those measured at Rutherford/Daresbury (1×10^{-8} g2/Hz), even at low frequencies, the flat spectrum analysis only produces displacements of up to 2.5 µm in the X, Y or vector directions, which as a worst case could equate to r-phi displacements.

Like wise, in the Z-direction this unlikely worst case would produce a Z displacement of 36µm. Therefore even these very worst case displacements would still be well within the specification.

Direction	Requirement (µm)	Likely maximum Input psd 1×10^{-10} g2/Hz	Worst case Input psd 1×10^{-8} g2/Hz
r-phi	12	0.25*	2.5*
Z	200	3.7	36.7

*in any direction; X, Y or vector

Predicted 3σ displacements (µm) with 1% damping

Note The analysis has been rerun for 50 modes and with a flat input spectrum up to 200 Hz. The worst case 3σ r-phi displacement in the above table changes from 2.5 to 2.75 µm. The total effective mass is then 98% (x), 99.6% (y), 99.7% (z).

11. REFERENCES

Where applicable reference numbers are kept the same as used in the CMS note (ref 2) to avoid confusion.

[1] GEO 600 Ruthe Germany

http://www.geo600.uni_hannover.de/geo600/project/seismik/seismik.html

[2] Vibration study for the CMS – MGSC Forward Tracker, W. Van Doninck - Vrije Universiteit Brussel, J.M.Brom, CRN Strasbourg; CMS IN 1997/012

[3] Response Spectrum results for the standard mono, G.Houghton; B Fell

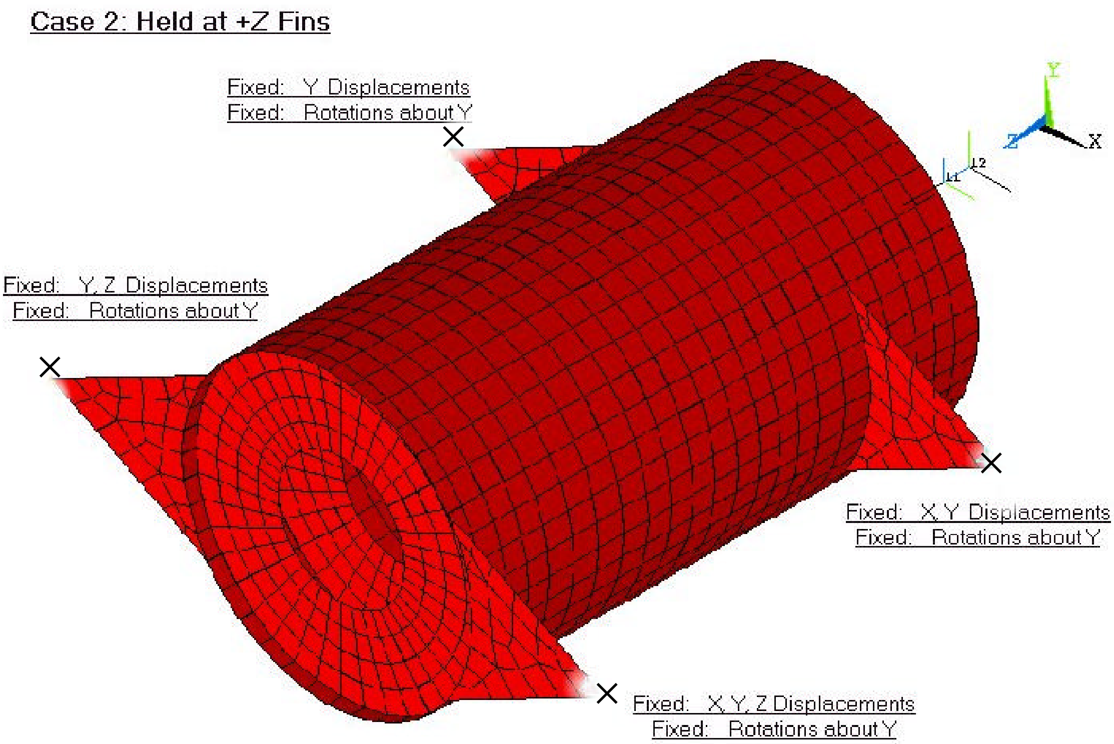
[8] Investigation [sic.] of seismic vibration in the CERN LEP tunnel, Juralev et al Russia; W Coosemans et al CERN, CERN-SL/93-53 and CLIC note 217

[9] CMS Tracker Support Structure, Tim Thompson et al - Los Alamos, Tom Meyer – CERN, CMS TN/95-155

[10] L. Rivera, Institut de Physique du Globe, Strasbourg

[11] Quantitative seismology, Aki K. Richards P., Freeman 1982

[12] Summary of work, CMS Central Tracker Global Support Structures, Marcus Libkind, Nov 1996


Case 2: Held at +Z Fins
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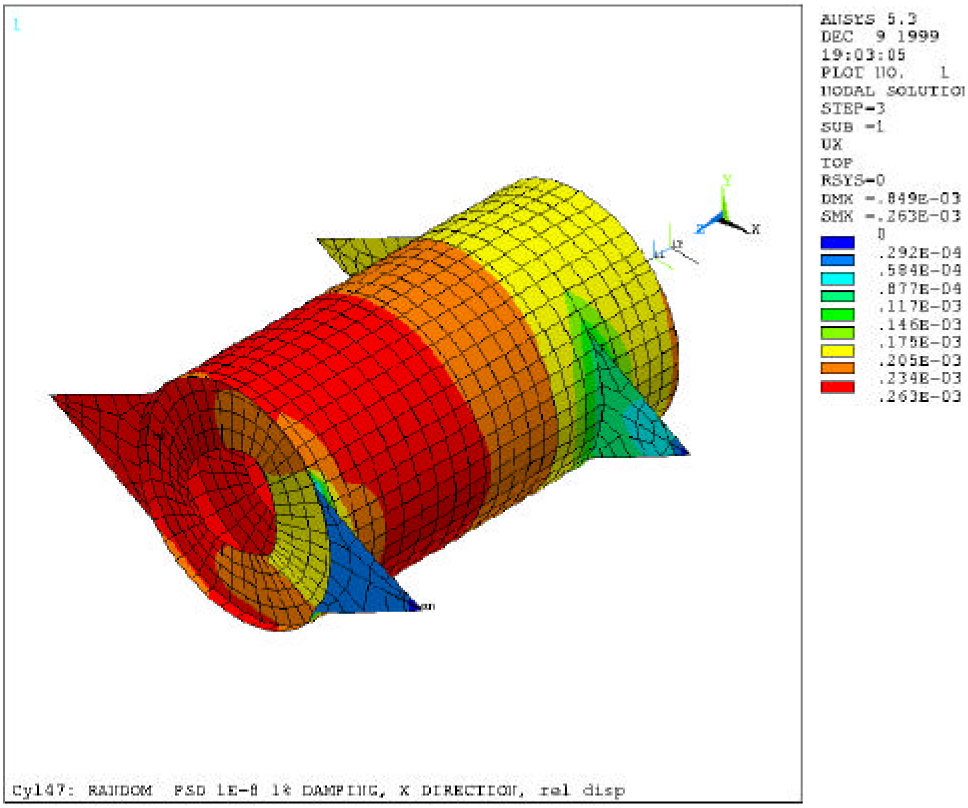
Fixed: Rotations about Y
Fixed: Y, Z Displacements
Fixed: Rotations about Y
Fixed: X, Y Displacements
Fixed: Rotations about Y
Fixed: X, Y, Z Displacements
Fixed: Rotations about Y
Y
Z
X

Fig. 1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.175E-03
.205E-03
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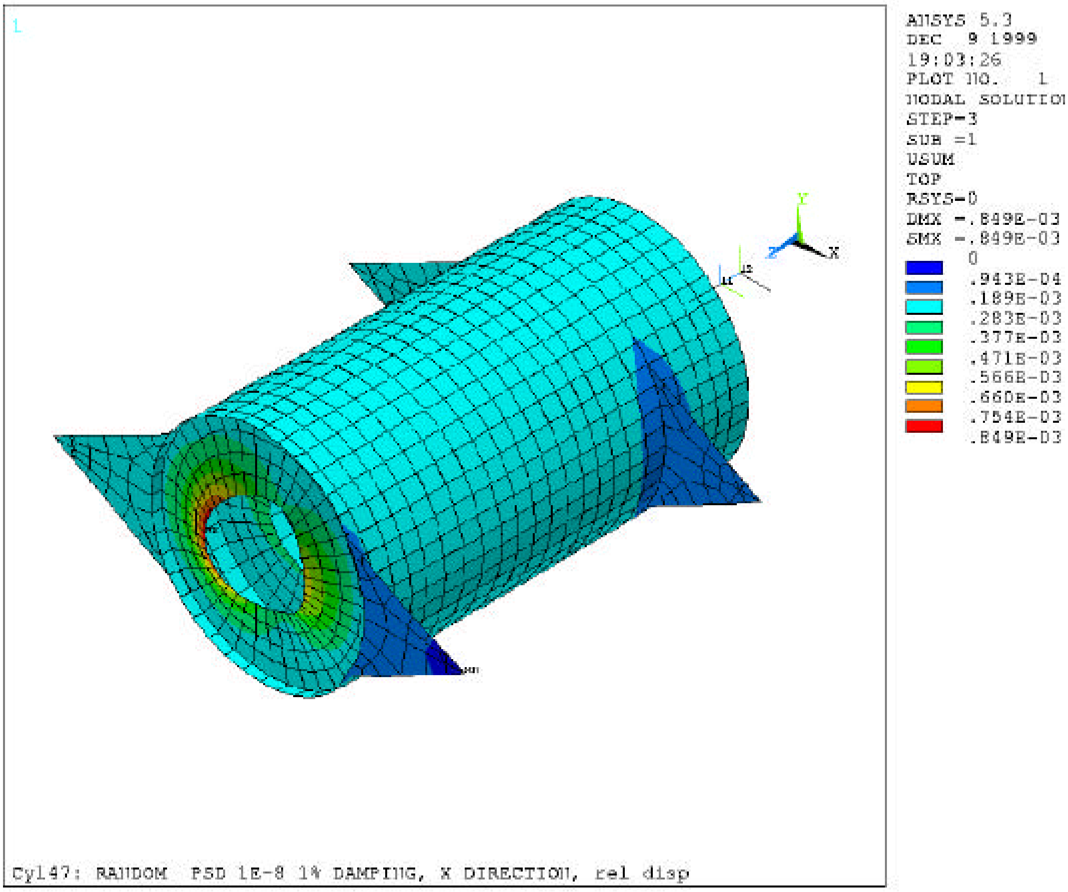
Y
Z
X
Cyl47: RANDOM PSD 1E-8 1% DAMPING, X DIRECTION, rel disp

<u>Fig.2</u>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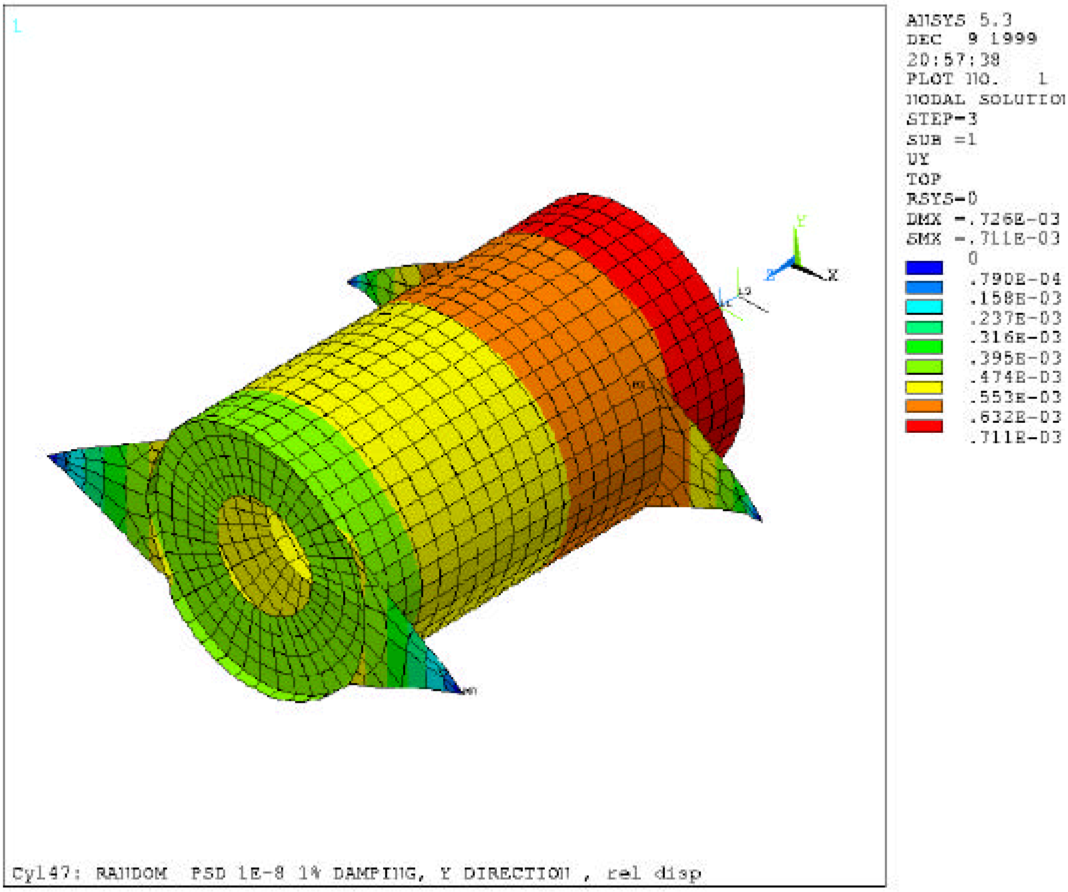
Cyl47: RANDOM PSD 1E-8 1% DAMPING, X DIRECTION, rel disp

Fig. 3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Cyl47: RANDOM PSD 1E-8 1% DAMPING, Y DIRECTION , rel disp

Fig. 4

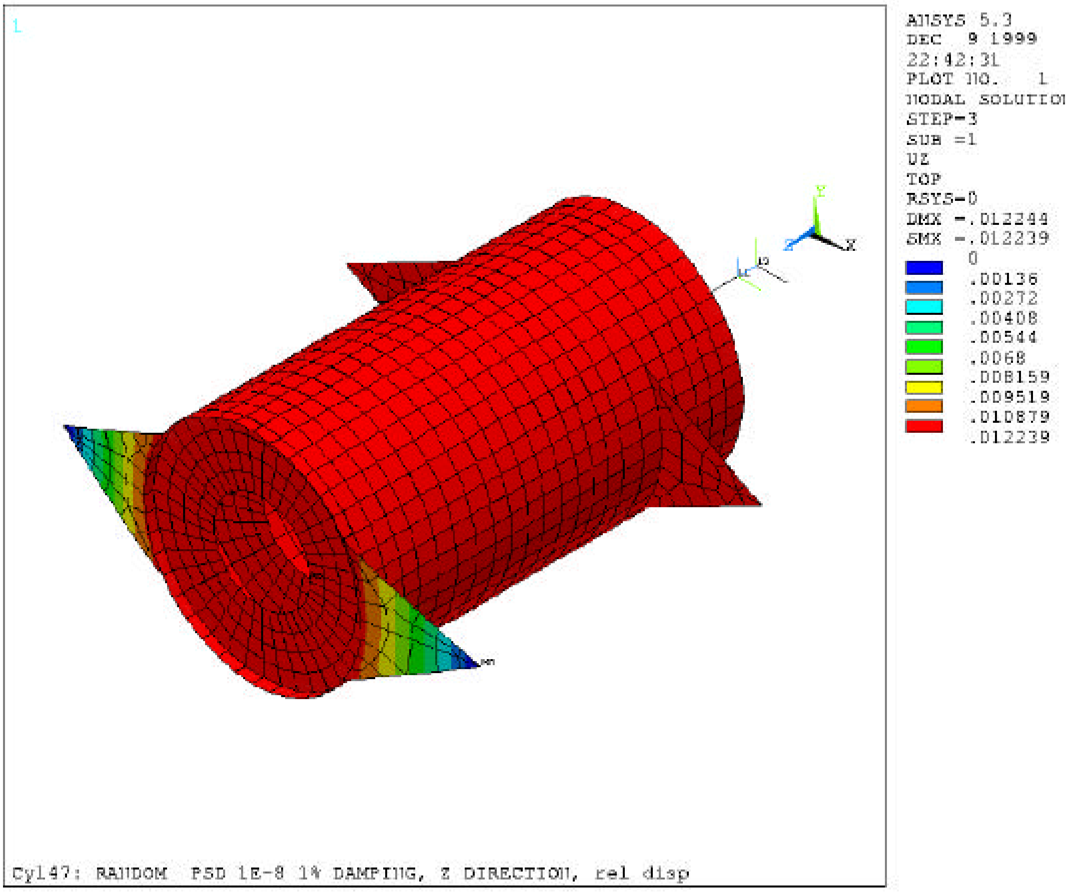

Fig. 5

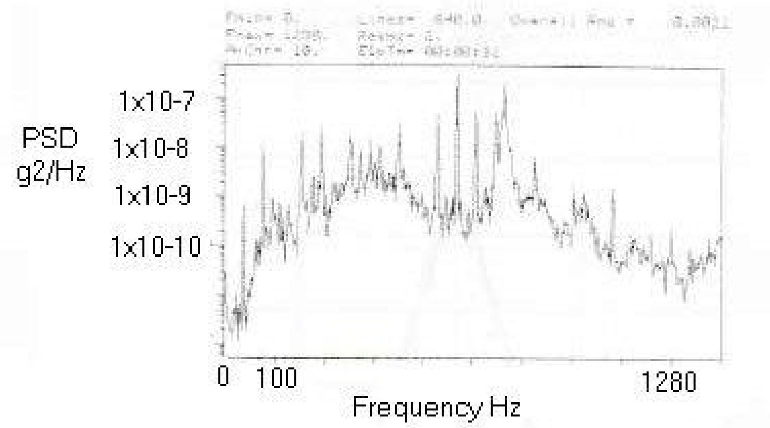

Fig. 6: PSD spectrum from ISIS

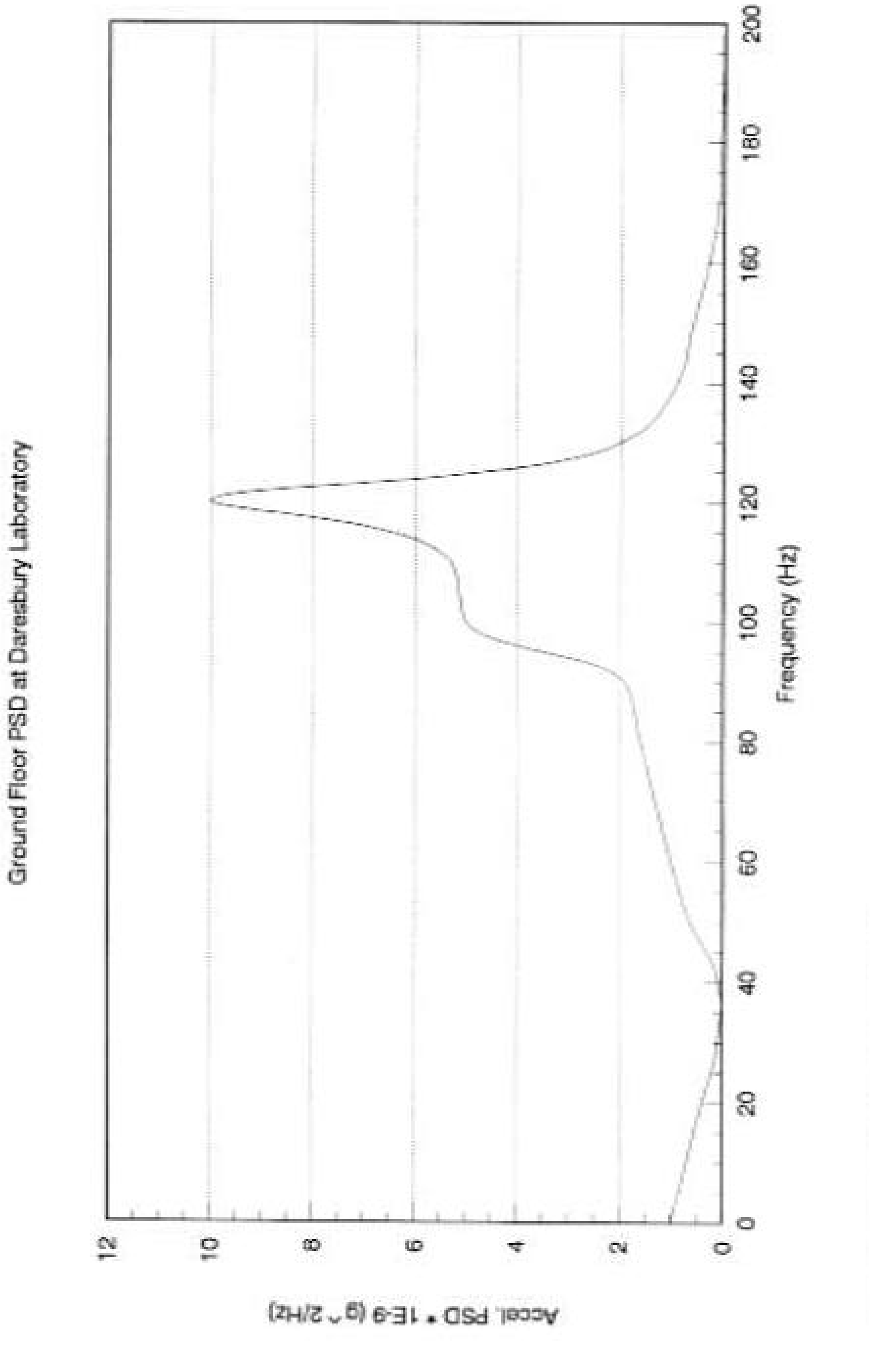

Fig. 7 PSD Spectrum from Daresbury Ref [3]