EPAC Building Vibration Survey and Stability Analysis of EPAC Support Structures

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Abstract

This report presented the vibration survey for the new EPAC building and structure stability analysis for support structures and breadboards in the EPAC system. The vibration survey was carried out after the construction of the EPAC building was finished and before the installation of the laser system. This allowed the vibration of the building to be investigated and provided important data for future analysis in the EPAC system design. In addition, stability analysis was performed for critical structures including the high level upper chamber and a breadboard for the target chamber. The results enabled the engineers to understand the dynamic behaviour of the key structures and evaluate the impact of vibration on the laser system.

Introduction

The EPAC building is a new purpose-designed structure at Harwell Campus to house STFC's new flagship laser system. The laser facility consists of high precision optical system that is sensitive to vibration. Understanding of the ground and environment vibration in critical laser areas within the EPAC building is essential to ensure correct configuration of the laser system. Vibrations in a building can come from various sources. BS7385:1990 [3] describes the structural response stemmed from different sources, including acoustic, traffic and human activities, to be in the range of 0.1 to 250 Hz. It is also mentioned that the typical range of fundamental shear frequency of 3-12m tall buildings is 4 to 15 Hz. This indicates that such vibration sources may excite a building at their fundamental frequencies and cause significant displacements at different locations in the building. Therefore, measurements should be made at the construction site to investigate background vibrations and evaluate their impacts.

The data obtained in vibration survey can be used to support the design, installation and calibration of laser system for current and future projects. In the design stage, the data can be used for stability analysis, which is a powerful method to study the dynamic performance of critical structures and evaluate the impact of vibration response on the laser system.

EPAC Building Vibration Survey

KP Acoustics Ltd was commissioned by PES (UK) Limited to undertake a prevailing vibration impact assessment for the proposed EPAC facility at Harwell Campus. The main purpose was to investigate the vibration levels currently present within the building with the nearby ISIS laser facility both operating and not operating. The vibration survey was undertaken between 26th-28th July 2022 (ISIS On), and 08th-10th August 2022 (ISIS Off).

The survey included positions in key areas across the facility, including both ground floor and second floor, as listed in Table 1. It was taken after the building construction had been completed and before any laser equipment/instruments were installed. This allowed the measurement to be focus on background vibration without interference of noise from facilities in the building.

Ground Floor:

Zone No.	Area (m^2)	Survey Points*	Remark
002 and 001	176+197	4+2	Experimental Area 1
003	173	2+2	Experimental Area 2

Second Floor:

Zone No.	Area (m^2)	Survey Points*	Remark
204	88	2	Front End
226	26	1	Beam Prop for Experimental Area 2
201	166	3	D100 Laser
202	216	2+3	10Hz Tis Sapphire
203	388	3	Hi Laser & Gemini Laser

Table 1 Survey Points

Measurements of spectral acceleration with a frequency resolution of $\leqslant$0.15Hz have been taken in 3 orthogonal axes, in order to determine the power spectral density, and acceleration cross spectrum within the spaces. The overall methodology which was followed for this assessment exercise adhered to the following British Standards [1-3]:

- BS 5228: Part 1: 1997: "Code of practice for noise and vibration control on construction and open sites – Noise"
- BS 5228: Part 2: 2009: "Code of practice for noise and vibration control on construction and open sites – Vibration"
- BS 7385: 1990 (ISO 4866:1990): "Evaluation and Measurement for Vibration in Buildings. Guide for Measurement of Vibrations and Evaluation of Their Effects on Buildings"

Experimental Area 1 Survey Results

Measurement positions within the Experimental Area 1 are illustrated in Figure 1. A total of 4 points were surveyed, of which one is a reference point. The acceleration of the captured data on 26 July 2022 (ISIS on) is presented in Figure 2. It shows that overall acceleration amplitudes across the Experimental Area 1 space are low – within the region of 0.6mm/s^2 in all axes. Another survey on the next day showed similar baseline vibration levels. This suggests that prevailing background vibration is very low in the building. However, it is worth highlighting that some off-scale individual events were recorded. Due to the sporadic nature of these events, and an appreciation of the scale of acceleration measured in these instances being representative of a clearly tactile occurrence, it is expected that these events are the direct result of extraneous influence on vibration levels in the space, such as undamped doors slamming as building occupants move around the building. The prevailing vibration levels are consistent with those captured the day prior. This does however highlight a potential issue for future device implementation, in that the

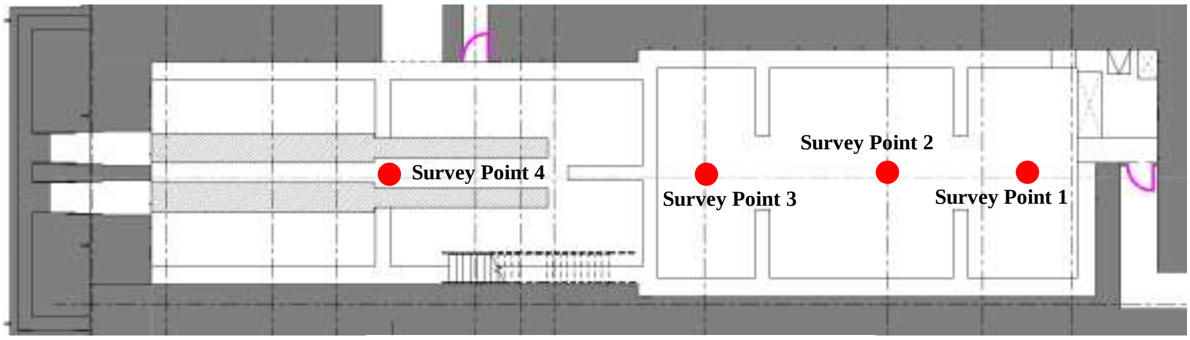


Figure 1 Experimental Area 1 Survey Points

nature of the solid structure of the building allows transfer to occur easily through the space when impulsive events, such as undamped doors slamming, or heavy footfall etc. occur.

Figure 3 (a) shows the measured power spectral density (PSD) as captured in the first survey with ISIS operational. This is used to identify frequency dependent characteristics of the prevailing vibration profile in the spaces. The PSD plots show the relationship between different frequencies in ratios to one another. This allows the most significant frequency components of the vibration incident on the accelerometers to be defined. The most prominent frequency bands (besides internal noise induced within the equipment at frequencies close to DC), are shown in the 25Hz and 50Hz regions when ISIS was operational. Additional artefacts were present at 600-800Hz, however these would fall within the audible spectrum, and would not be expected to be problematic to the operation of any equipment. For measurement obtained when ISIS was not in operation, the same 25Hz excitation still present but the 50Hz component is of lesser extent of contribution. Similar vibration levels are seen in other survey areas of the EPAC building.

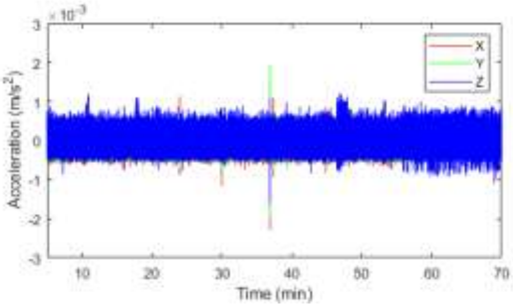
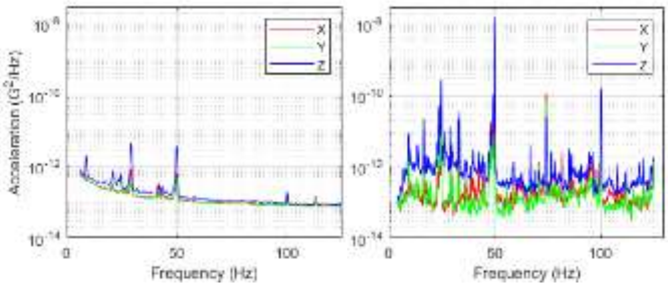


Figure 2 Acceleration Data, Experimental Area 1 Survey



a) Experimental Area 1, EPAC **b) Gemini Area**

Figure 3 Acceleration Power Spectrum Experimental Area 1 vs Gemini

Figure 3 (b) illustrates the comparison of the power spectrum between the Experimental Area 1 and the existing Gemini area. It in shows that the spectrum is cleaner the case of EPAC building, with peaks around 25, 50 and 100Hz notably lower than those in Gemini area. The End-To-End values of the vibration in both measurements are listed in Table 2. It confirms that lower level of vibration is observed in the EPAC building.

Zone	Survey	Vibration End-To-End Value (nm)	Remark
Gemini	TA3-01 (ISIS on)	X: 42 Y: 40 Z: 49	Calculated for 6-125Hz, 3σ criteria
Experimental Area 1, EPAC	26 July 2022 (ISIS on)	X: 33 Y: 44 Z: 76	

Table 2 Comparison of Vibration End-To-End Values

As a conclusion, it is regarded that the background vibrations presented in all surveyed areas are relatively low. In future install and operation, appropriate vibration control methods should be introduced to minimize the impact and noise from human activities and operational machineries.

Stability Analysis of High Level Upper Chamber

This analysis is for the upper chamber located at the high level floor and the attached vacuum pipes. The upper chamber houses two motorized mirrors which divert the laser beams to lower level target area. Due to the size and location of the assembly, the mirrors may be sensitive to ground excitation and introduce fluctuation in beam propagation. The purpose of the analysis is to evaluate the vibration stability of the assembly with a focus on the response of mirrors.

Modal and response analysis based on finite element analysis (FEA) were used to investigate the vibration characteristics of the structure. Modal analysis is a study that determines the natural frequencies and mode shapes of a mechanical structure under specific dynamic loading. The natural frequencies and modes shapes provide important information on how the structure behaves in the frequency domain. The results can be used to reveal possible resonance and identify features for improvement, e.g. under-strengthened support. However, modal analysis alone is unable to quantify the response of the structure associating with specified excitations. In this case, harmonic (steady state) and random response analysis can be carried out. The former studies the steady-state behaviour of a structure under cyclic loads condition, whereas the latter determines the response of a structure subject to excitations that are random in nature.

Mode	Frequency (Hz)	Comment
1	22.8	Limited influence on mirrors. Involving mainly vertical pipe and gate valve.
2	22.8	
3	38.0	
4	38.1	
5	43.4	Mirror assembly modes.
6	44.5	
7	55.2	Modes involving vertical pipes and mirrors, and other higher order modes.
8	59.0	
9	59.8	
10	61.6	
11	62.0	
12	63.2	

Table 3 Modal Frequencies

The modal frequencies of the assembly is listed in Table 3 and selected vibration modes of the upper chamber assembly are illustrated in Figure 4. The lowest modal frequency was found to be at 22.8Hz. Mode 1-4 are mainly related to the gate valves on the vertical tube, their impact on the mirrors is expected to be limited. The mirror related modes are found in mode 4-5 and higher order modes.

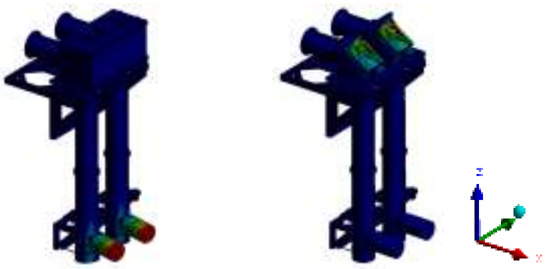
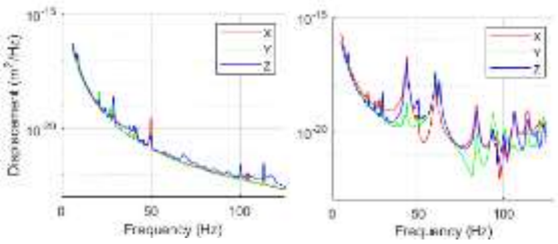


Figure 4 Selected Vibration Modes of Upper Chamber Assembly (Mode 1 and 5)

The stability of the structure was further evaluated through response analysis. The data of the EPAC building survey in room 202 was used as the input in this analysis. The input and output spectrum is illustrated in Figure 5. The translational and angular End-to-End values were calculated for the mirror centre from the output spectrum, as shown in Table 4. No significant amplification was seen in the translational response and the angular motion was under 103.3 nrad in all axis. This indicates satisfactory stability for the structure.



a) Ground Vibration Spectrum **b) Response Spectrum**

Figure 5 Vibration Spectrum, Ground Vibration and Response at Mirror Centre

	End-to-End Value	
	Input	Output
X	95.1 nm	101.7 nm
Y	63.7 nm	67.1 nm
Z	71.0 nm	76.3 nm
R_X	--	68.1 nrad
R_Y	--	103.3 nrad
R_Z	--	60.0 nrad

Table 4 Response of Mirror Centre

Conclusion

The vibration survey of the new EPAC building showed that low vibration levels were seen in all measured rooms. The data obtained can be used as reference in future design and operation. The survey highlighted that impulsive events such as undamped doors slamming can result in impact be felt in these area. This suggested proper access and vibration control would be necessary in future installation and operation to minimize vibration impact.

In addition, this report presented the stability analysis of the high level upper chamber. The modal analysis illustrated motions related to mirrors and vertical pipes/gate valves. Response analysis for the mirror centre suggested that the ground vibration was not amplified in a significant way in translational and angular responses. This design was therefore considered to show satisfactory structure stability.

References

1. British Standards Institute, BS 5228-1:1997, “Code of practice for noise and vibration control on construction and open sites – Noise”

2. British Standards Institute, BS 5228-2: 2009, “Code of practice for noise and vibration control on construction and open sites – Vibration”

3. British Standards Institute, BS 7385-1: 1990, “Evaluation and Measurement for Vibration in Buildings. Guide for Measurement of Vibrations and Evaluation of Their Effects on Buildings”