VIBRATION MEASUREMENT AT DIAMOND AND THE STORAGE RING RESPONSE

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Abstract

Diamond is a 3GeV, 3rd Generation Synchrotron Light Source currently under construction at the Harwell Science and Innovation Campus, Chilton, Oxfordshire. Controlling and minimising the sources and transmission of vibration in Synchrotron Light Sources is an important factor in achieving the stability needed to generate the very brightest beams. This paper describes the equipment that has been used at Diamond to measure vibration and reports the results of measurements taken on the accelerator floor and on the girder structures carrying the storage ring. As specified by the Diamond Accelerator Physicists, the target for vertical and horizontal vibration limits for girder mounted magnets is 200 nm RMS integrated between 1 to 100 Hz. This is to achieve stability related to 10% of beam size. Measurements and analyses have been carried out to assess actual motion on the Diamond storage ring.

INTRODUCTION

The Diamond facility will comprise a 3 GeV electron storage ring, injected from a 100 MeV linac through a full energy booster synchrotron, and an initial complement of seven beamlines. The Booster has a circumference of 158.4 m and the storage ring is 561.6 m in circumference. The diameter of the building is 235 m and is shown in Figure 1. The availability of Diamond Light Source (DLS) in the UK will enable scientists to investigate the structure of matter, such as biological tissues, polymers and catalysts, at the atomic and molecular level. These studies will help them, for example, to design new medicines and high-tech materials, as well as to investigate environmental issues such as climate change.

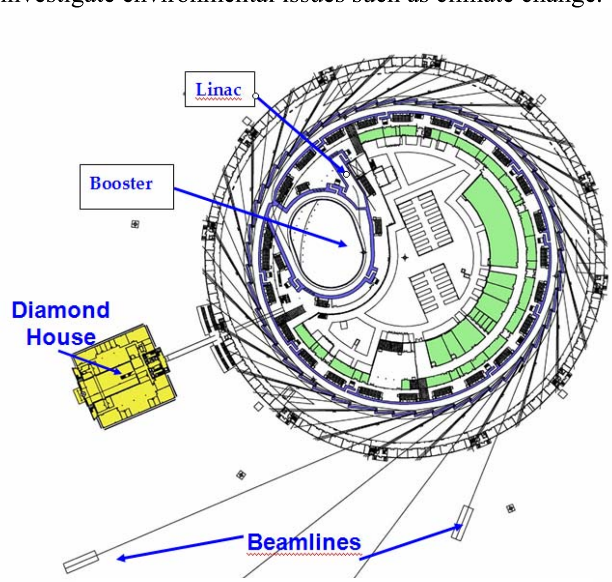

Figure 1: Layout of Diamond Light Source

To achieve the very high positional stability required of the electron beam in 3rd generation synchrotron light sources, both the ground motion (floor of storage ring) and the mechanical stability of the magnets on the girders have to be studied. After taking into account the amplification factors (typical factor of 25) that apply between magnet movement and the effect on the beam, maximum magnet movements of only a few microns are allowable. In addition, ground motion at the right frequency to drive the magnet's mechanical support natural frequencies adds further constraints to the permissible ground motion.

In order to predict the influence of natural and cultural vibration on DLS, various vibration measurements on the Diamond site have now been conducted to assess the vibration effects on the Diamond machine. The tests and analyses include measurements of ground motion and study of vibration behaviour of girders.

EQUIPMENT FOR VIBRATION TESTS

Sensors and Analyser

Diamond has invested in the equipment and expertise to analyse the vibrations transmitted by the ground, and by the equipment supports. Apart from PCB accelerometers from USA and IEM velocity-sensors from China, a Guralp tri-axial broadband seismometer has been purchased for measuring ground motion in the range 1/60s to 50 Hz and similarly a Geotech KS-2000M with frequency range of 1/120s to 50 Hz. The Geotech S-13 portable seismometers in 1 to 100Hz are used for correlation measurements. The Guralp has been permanently installed in a purpose built cabin on the experimental hall floor.

For dynamic signal analysis, the Data Physics SignalCalc Signal Analyser has been adopted which provides highly accurate measurements in the time, frequency and amplitude domains. There are two types of analyzer used in DLS: Quattro and Mobilyzer. Quattro has 4 inputs and 2 outputs and is a portable version. Mobilyzer with a compact network peripheral interfaces to a laptop or desktop computer via a standard Ethernet connection suitable for monitoring 16 channel simultaneously on the synchrotron site.

MEASUREMENTS & ANALYSIS

Ground motion

In Figure 2, the ground motion of the virgin site measured before construction (in March 2002) and after construction (in August 2005) measured on the experimental hall slab are compared. It can be seen that in fact vibration levels are now smaller than they were when measured directly on the ground before building construction started. The massive slab is clearly damping ground motion associated with the site.

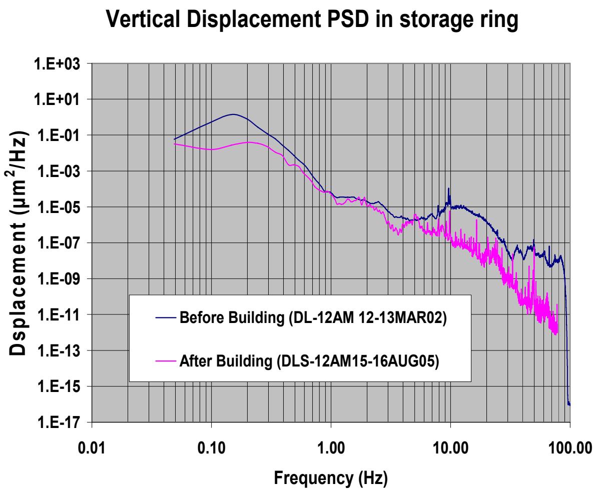

Figure 2: Ground PSD before and after DLS construction

Table 1: List of frequencies before and after building

Hz	8	9	10	12.5	14.4	25	32
Before	yes	no	yes	no	no	yes	no
After	yes	yes	yes	yes	yes	yes	yes
Hz	**33**	**42**	**50**	**63**	**68**	**70**	**87**
Before	no	no	yes	no	yes	no	no
After	yes	yes	yes	yes	yes	yes	yes

From Figure 2, it is apparent that some new frequencies have been discovered after building construction. Clearly, these frequencies would relate to the natural vibration of the slab. In Table 1, new frequencies in the range of 1-100 Hz are listed. Before building construction, only 10 Hz, 25 Hz and 50 Hz were apparent.

In order to verify the new frequencies discovered from the measurement, finite element analysis has been carried out for the slab including the storage ring tunnel and foundation in the experimental hall. Figure 3 shows the FE model of the slab with piles. In Figure 4, the modal shapes are shown and frequencies (10-100 Hz) from the FE analysis match the measurement after building construction (lower curve). Recent measurements indicate that these frequencies reduced further after additional mass was added through installation of the storage ring.

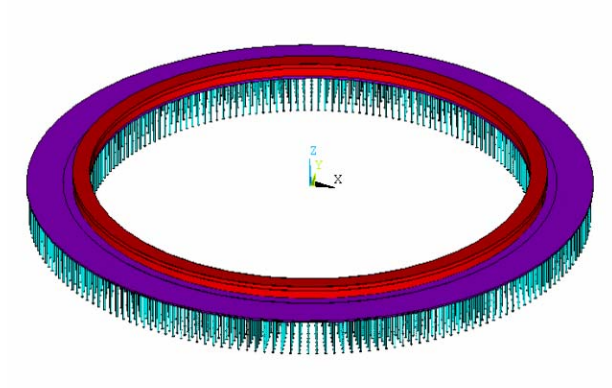

Figure 3: FE model of slab with piles

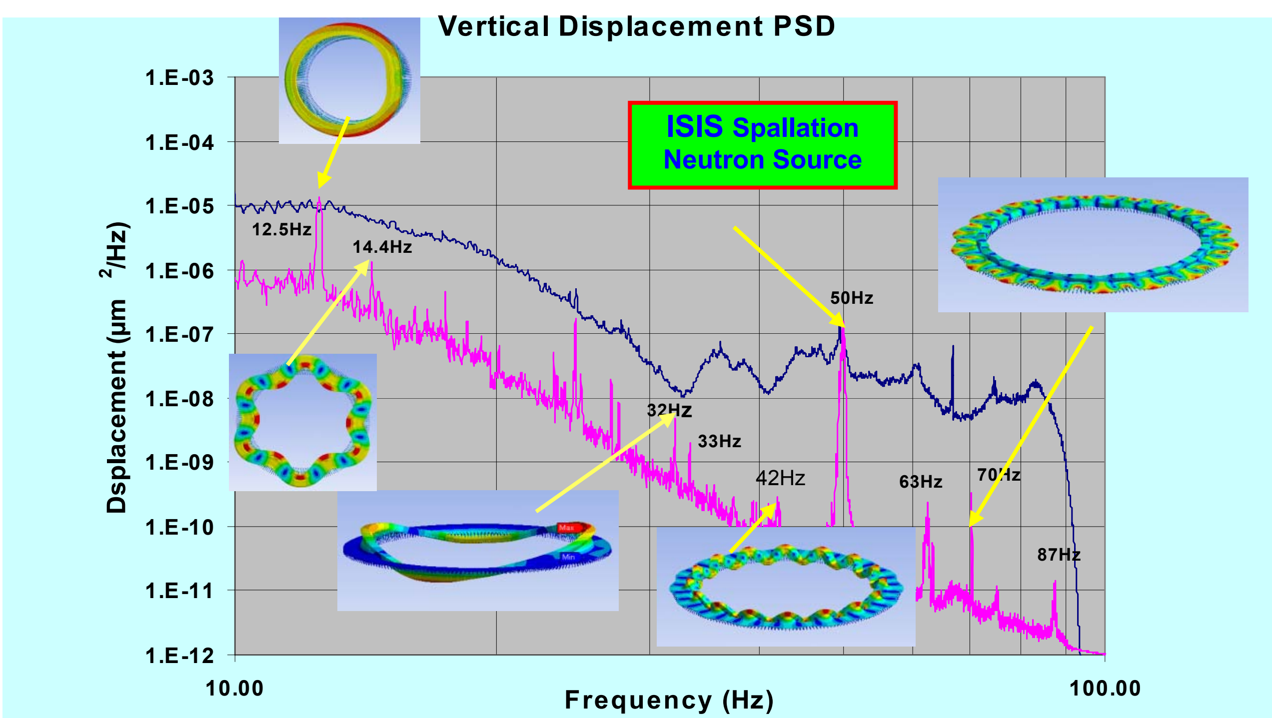

Figure 4: Natural frequencies and modal shapes of foundation slab in Diamond Light Source.

Girders and modal analysis

There are three types of girder in the DLS storage ring: Girder 1, 2 and 3. Among them, the Girder 2 is the heaviest and has been investigated thoroughly. Figure 5 shows the FE mesh used for modal analysis. The results of the modal shapes and frequencies are listed in Table 2. There is a reasonably good match between FE analysis and measurements for the first four frequencies. The first frequency of 16.285 Hz is a rigid motion rocking on the top of cam supports. With proper boundary conditions in the FE model, this shape was replicated successfully.

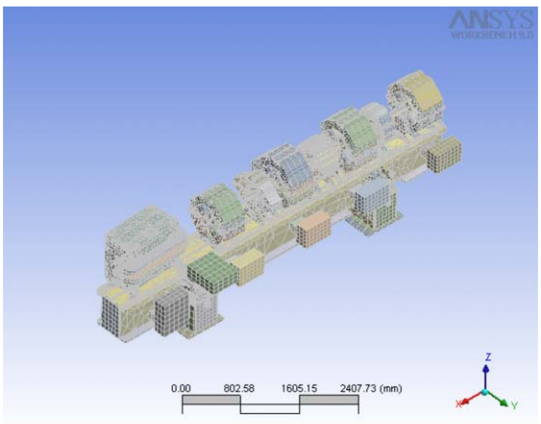

Figure 5: FE mesh for Girder 2

Table 2: Typical natural frequencies of Girder 2 (Hz)

Modal	**Rocking**	**Twist**	**H-bending**	**V-bending**
Test	16.3	30.1	37.7	43.9
FEA	15.1	31.8	43.6	49.2

Recent measurements on girders

Table 3 gives latest results from recent vibration measurements of the storage ring tunnel floor and the upper surface of the magnets. In general, the horizontal results are larger than the vertical. In the day time, the Girder 1 has horizontal RMS of 134 nm and Girder 2 has horizontal RMS of 132 nm. Sensors were fixed on the top of a sextuple on each Girder as close as possible to the beam axis.

The horizontal measurements on Girder 1 and the floor are shown in Figure 6. It can be seen that the strong 25 Hz signal appears in the floor spectrum, but the source has not been identified yet. Clearly, the 25 Hz frequency contributes most to the integrated displacement for both Girder 1 and Girder 2. It is suspected that both Girders 1 and 2 have a horizontal natural frequency close to 25 Hz after all the cable and pipe connections were fitted. Further study will look at the possible resonance of Girders 1 and 2 in the horizontal direction.

Table 3: Integrated (1-100 Hz) RMS displacement (nm) of ground and girders.

	Mid-day		**Mid-night**	
Location	**Vert.**	**Horiz.**	**Vert.**	**Horiz.**
Ground	20	14	13	9
Mag. on Girder 1	43	134	16	46
Mag .on Girder 2	58	132	19	42
Mag. on Girder 3	36	35	16	24

The same measurements will be carried out on Girders in other cells to see if the same type of girders have similar behaviour at different locations around the ring.

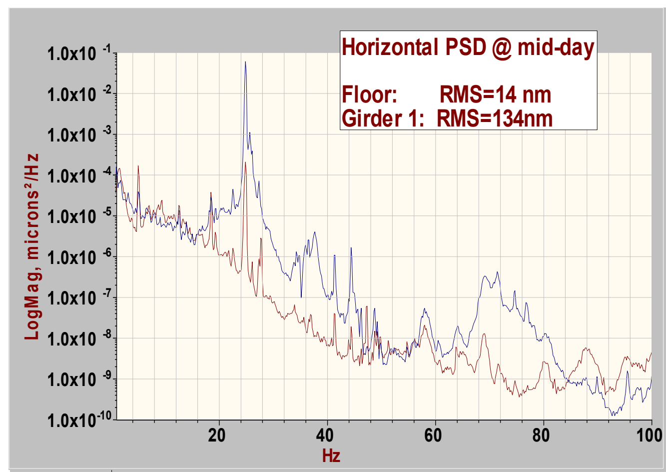

Figure 6: Horizontal PSD of Girder 1 (upper) and floor

All of the above tests were carried out without cooling water flowing. Some tests were conducted with and without water flowing during girder assembly in a different building. These results showed an increase in the response of the girder and this test is to be repeated in the tunnel once the water cooling systems are commissioned

CONCLUSIONS

DLS has established a comprehensive vibration measurement capability. The ground vibration level measured is modest, even in the daytime. However, there are stronger horizontal vibrations existing in Girders 1 and 2 at 25 Hz than expected. Such vibrations are due to background noise, the source of which needs to be identified as it causes higher displacement than expected. Further investigation is needed, especially after the water system is commissioned in the near future. Once commissioning with 3 GeV beam is underway, the stability of the electron beam can be assessed against vibration measurements and if necessary damping or other control measures investigated further.