ANALYSIS OF BEAM ORBIT STABILITY AND GROUND VIBRATIONS AT THE DIAMOND STORAGE RING

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Abstract

With the aim of understanding and improving the beam orbit stability at the Diamond storage ring we launched an extensive campaign of ground and magnet vibration measurements in order to identify the sources of ground vibration and how they affect the beam orbit stability through the girder resonances. We present here the results of the measurements performed along with a discussion of the possible remedies and the implications for the orbit feedback systems.

INTRODUCTION

In a storage ring synchrotron light source the photon beam source point should be stabilised in position and angle over a large frequency range. The requirements on the stability that has to be achieved are customarily set to 10% of the beam size and angular divergence [1]:

$$\Delta x \leq 0.1\ \sigma_x \qquad \Delta x' \leq 0.1\ \sigma_{x'}$$
$$\Delta y \leq 0.1\ \sigma_y \qquad \Delta y' \leq 0.1\ \sigma_{y'}$$

These values have to be achieved at the centre of the ID or at the bending magnets. With the modern low-emittance lattices achieving emittance values of a few nm and coupling correction down to below 1%, the beam size at the IDs is squeezed down to ~100 μm horizontally and 10 μm vertically or lower. Therefore the beam orbit has to be stabilised to sub-μm level. In particular, for Diamond, 10% beam stability at the centre of the ID in the standard straight section would require

$$\Delta x \leq 12.3\ \mu\text{m} \qquad \Delta x' \leq 2.3\ \mu\text{rad}$$
$$\Delta y \leq 0.6\ \mu\text{m} \qquad \Delta y' \leq 0.4\ \mu\text{rad}$$

These requirements may be set more stringently at various machines (5% at APS [2]) and it is not uncommon that particular beamlines, e.g IR beamlines, require an orbit stability of 1% of the beam size and angle divergence. The frequency range over which the orbit stability has to be guaranteed is usually considered to extend up to 100Hz, although the upper limit set to 200 Hz is now being considered.

The path to sub-μm stability initially requires a careful analysis of the sources of beam vibrations in order to identify what passive measures can be undertaken in order to eliminate or reduce them. An accurate knowledge of the spectrum of the ground vibrations and of the mechanisms by which they are transmitted to the beam motion also provides important information for the design of the active damping of the beam vibrations with orbit feedback systems.

In this paper we report the results of the measurements of the ground vibration and quadrupole vibration spectra, including an experimental analysis of the girder resonances and a comparison with the computed amplification factors of the orbit vibration with respect to the girder vibrations.

FROM GROUND TO BEAM VIBRATIONS

Ground vibrations are one of the major sources of beam motion, extending over a wide frequency range up to hundreds of Hz. Ground vibrations are fed to the magnetic elements via the supporting girders, at which point the motion can be amplified by structural resonances leading to significant mechanical vibrations of the magnets. The effects of girder and magnet vibrations on the electron beam are further amplified due to the magnetic fields – mainly those of the quadrupoles. The so called amplification factors account for these effects and are discussed in a later section.

In the design phase of the girders, great care should be taken in order to avoid overlapping the girder resonant frequencies with the frequencies excited in the ground motion spectrum. To this end, the girder resonant frequencies are generally pushed as high as possible to the frequency region where the ground motion power spectral density (PSD) is naturally low.

Vibration data are recorded continuously by a set of mini-seismometers located on the ground and on each of the three girders which make up the Diamond cell. Beam position data were recorded using the so called "Fast Acquisition" (FA) BPM data, which are the orbit data sampled at 10 kHz used in the fast orbit feedback. Figs. 1-2 report the PSD of the ground vibrations, of the three girders in the Diamond cell and of the FA data for the beam motion up to 100 Hz. The corresponding integrated PSDs are summarised in Tab. 1. For the horizontal plane, the integrated PSD for the beam data shows that 0.7 μm are accumulated in the beam motion around 24.7 Hz, while 0.8 μm are accumulated around 16-18 Hz. The analysis of the quadrupole displacement PSD data shows clearly that girder 1 mainly amplifies the 24.7 Hz line, girder 2 is responsible for the 16 Hz excitation and girder 3 amplifies vibrations at 18 Hz. Indeed, the mechanical structure of girder 1 is shorter and lighter than that of girders 2 and 3, and this can explain their different frequency response. A careful experimental analysis of the girder resonances has confirmed these findings.

From Tab. 2 we see that the both the horizontal and the vertical integrated PSD up to 100 Hz are already within 10% of the beam size.

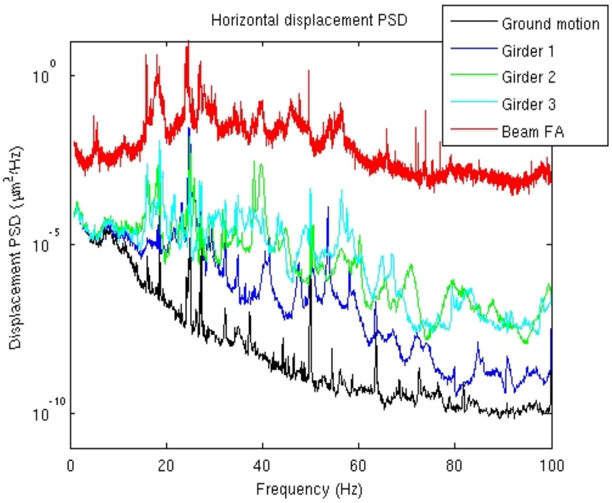

Fig. 1: Horizontal PSD of ground, girder and beam motion

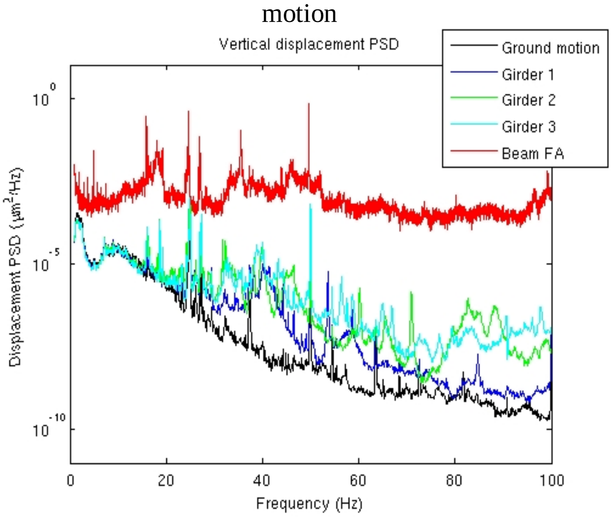

Fig. 2: Vertical PSD of ground, girder and beam motion

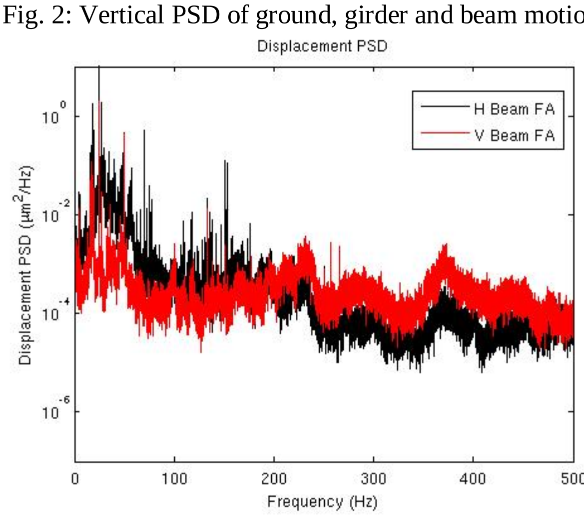

Fig. 3: Beam PSD extended up to 500 Hz

The beam PSD does not decay significantly at frequencies higher than 100 Hz especially in the vertical plane as shown in Fig. 3. In the range from 100 Hz to 500 Hz 0.24 µm rms are added to the integrated PSD making the vertical integrated beam PSD up to 500 Hz grow to 0.61 µm showing that the contribution of relatively high frequencies (100-500 Hz) is non negligible in this plane. This aspect has significant implications in the assessment of the performance of the fast orbit feedback system (FOFB).

Tab. 1 Integrated PSD (1-100 Hz) measured at Diamond

	Integrated H PSD (µm)	Integrated V PSD (µm)
Ground	0.018	0.026
Girder 1	0.090	0.028
Girder 2	0.088	0.035
Girder 3	0.072	0.032
Beam	2.53	0.37

Tab. 2 Comparison between measured and target integrated rms vibration (µm) in the range 1-100 Hz.

	Measured	Target
Position H	2.53	12.3
Angle H	0.53	2.42
Position Y	0.37	0.64
Angle Y	0.26	0.42

IDENTIFICATION OF VIBRATION SOURCES

A careful identification of the various sources of ground motion was carried out during a complete shut down of all power generators in the Diamond site in December 2007 [3]. After this shut-down, each source was switched back on in 5min intervals, enabling a correlation to be made with individual lines in the ground and girder vibration spectra with each driving source, see Fig. 4.

The analysis of the electron beam motion confirms that the largest beam oscillations occur around 25Hz. Many sources have been identified close to this frequency (Tab. 3), but the dominant source has been identified as the circulating pumps for the demineralised cooling water circuit A. Weaker oscillations at 16 Hz have been identified as air handling units in the control and instrumentation areas (CIAs). At frequencies above 30Hz, the ground motion shows no significant sources. However, the seismometers placed on top of the girders clearly show vibrations up to many hundreds of Hz. In particular, there are significant vibrations in the frequency range 200-250Hz, and this is the region of the spectrum at which the FOFB amplifies beam motion [4].

The dominant source of vibrations above 30Hz on the girders has been traced to be due to the flow of cooling water for the magnets. The contribution of this source appears sharply in Fig. 4 around 11:25 when the corresponding pumps were switched on. This source of vibration appears to be very challenging since it contributes to spectral components which are outside the closed loop gain of the FOFB and are actually amplified by the FOFB itself [4]. Two methods for tackling this problem are to adjust the bandwidth of the FOFB system to avoid the amplification around 200Hz, or to find methods for damping the effects of turbulent cooling water flow in the pipe-work.

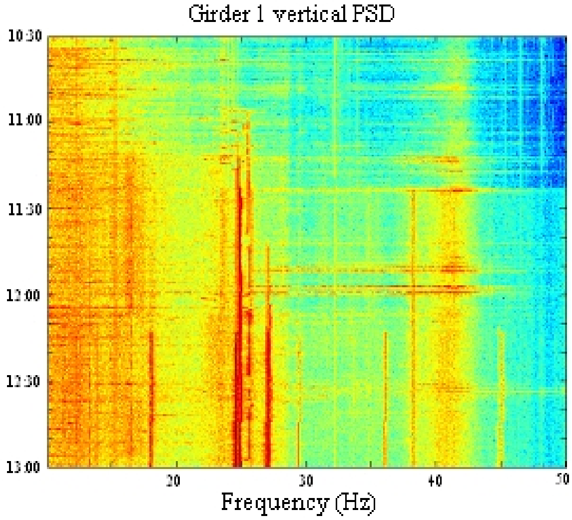

Fig. 4: Spectrogram of vertical magnet motion for a quadrupole resting on a type-1 girder.

Tab. 3 Vibration sources identified for the Diamond site

Frequency (Hz)	Source
16.0	Demineralised Water A
16.5	Air conditioning units
18.2	Air conditioning units / CIA5
24.6	Raw Cooling Water D
24.7	Chiller 1 / Air blast coolers
24.8	Process Water / Aluminium E
24.9	Demineralised Water A
25.5	Chiller 1 / Air blast coolers
26.9	Air conditioning units / CIA6
27.1	Air conditioning units

GIRDER RESONANCES

Girder resonances were measured in situ by mechanically exciting the girder structures with a hammer and recording the vibrations with an accelerometer. The resonant frequencies could be carefully identified for each of the three girder structures with realistic load, clamping and cabling. The main frequencies excited in girder 1 occurred at 24 Hz, 39 Hz, 55 Hz with some activity at 130 Hz and up to 300 Hz as shown in Fig. 5. The other girders show similar resonance patterns at slightly different frequencies in correspondence to their different structure and different load. Girder 2 resonates at 16.6 Hz, 54 Hz and a has broad resonance up to 350 Hz while girder 3 has resonances at 18.5 Hz, 29.5 Hz up to 140 Hz.

This characterisation of the spectral frequencies excited in the girders suggests the possibility to damp them by acting on the mechanical structure of the girder, using the knowledge about the oscillation mode patterns corresponding to the resonant frequencies which can be obtained by FEA studies.

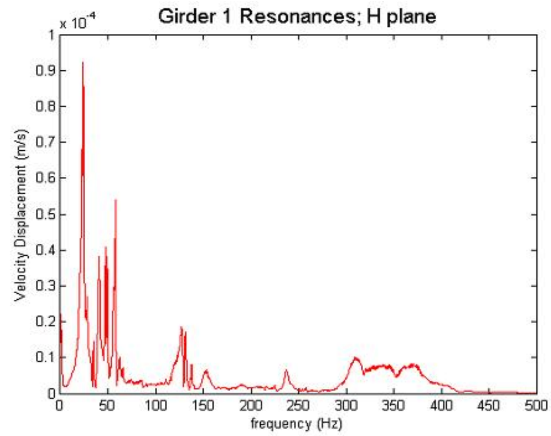

Fig. 5: Girder 1 resonances generating horizontal vibrations measured up to 500 Hz.

AMPLIFICATION FACTORS

Magnet vibrations generate orbit vibrations which generally have larger rms amplitudes than the magnet vibrations. The ratio of the rms orbit distortion to rms random misalignments of the quadrupole, for each plane, is a measure of the enhancement effect and is called the amplification factor. They depend on the particular machine optics and can be computed numerically from closed orbit simulations. For the Diamond lattice they are 60 in the horizontal plane and 45 in the vertical. Girders introduce a correlation in the random vibration of the magnetic elements. In this case we can define the amplification factor with respect to the girder vibrations. Numerical computation for Diamond shows that the amplification factors with girders are reduced to 35 in the horizontal and 8 in the vertical. This data is in reasonably good agreement with the PSD presented in Tab. 1, where the integrated magnet motion is 80 nm while the rms beam motion is 2.5 μm on a BPM with β value close to the average in the horizontal. This ratio of 31 is close to the ratio of 35 predicted by the simulations while in the vertical plane we have 30 nm which is amplified to 0.37 μm giving a girder amplification factor of 12, somewhat larger than the predicted value of 8.

CONCLUSION

A careful analysis of the sources of ground vibration has been carried out at Diamond and the impact of the most significant frequency components appearing in the beam spectra has been identified. The impact of cooling water contributions to very high frequencies and its implication in the design of the FOFB has been pointed out. Overall, though, the design aim of beam stability within 1% of the beam size and divergence has been reached up to 100 Hz.

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