Measurement of vibration characteristics of a magnet prototype girder for ALBA*

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Abstract

The 3 GeV third generation synchrotron light source ALBA is under construction near Barcelona. The machine is foreseen to operate with a low emittance (less than 5 nm·rad) and small size (under 150 µm in horizontal and 8 µm in vertical) electron beam. Uncorrelated mechanical vibrations of the magnets, amplified by the lattice transfer function, could degrade the beam stability and quality. Thirty-two girders will be used to position and align the 264 magnets of the storage ring (32 bending dipoles, 112 quadrupoles and 120 sextupoles). Girder design has been optimized using finite element analysis (FEA) tools in order to push mechanical resonant frequencies as high as possible and reduce, in this way, the amplitude of magnet vibrations excited by the ground motion and technical systems. Vibration characteristics of a full scale prototype of magnet girder (equipped with magnet dummies) are reported.
The data presented in this paper are available in http://vibration.desy.de.

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Introduction

A full scale prototype of girder (see Figure 1 and 2) has been recently built and installed in the ALBA workshop in Bellaterra (Barcelona). The installation procedure has also been tested and, from the mechanical point of view, the resulting setup can be considered an accurate replica of the final one in the storage ring. ALBA magnet girders have various lengths and are therefore divided into 6 types lengthwise, the maximum length being 5750 mm. However, the basic design remains the same for all girder lengths namely that the main body of the girder rests on three pedestals (Figure 1).

Figure 1: Magnet girder prototype of ALBA, fully attached to the floor and the magnet dummies. The red structure in the center is a dipole (dummy), the blue are quadrupoles and the yellows are sextupoles.

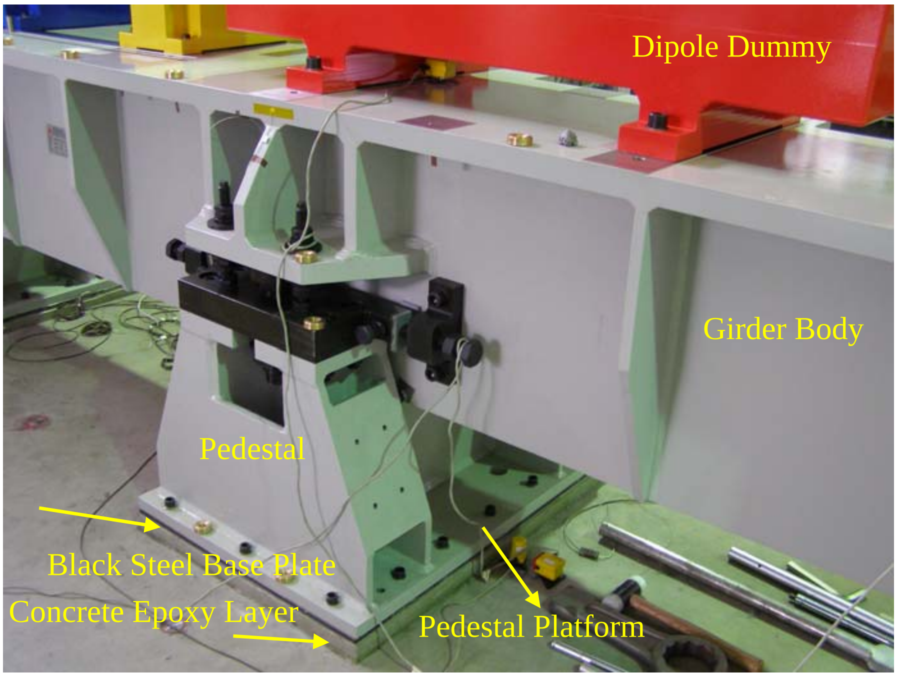

Figure 2: Current setup of the girder-floor interface.

The base of the girder pedestals, marked as 'Pedestal Platform' in Fig.2, is fixed, via screws, to steel plates, marked as 'Black Steel Base Plate' in Fig. 2, and the 'Black Steel Base Plate' is glued on top of levelling epoxy concrete pads. No anchoring fixtures are used between the pedestal and the floor.
The dynamic stability figure of merit of a magnet girder is usually given by the comparison between the displacement amplitude measured on the ground and the magnet position, which is obtained by the convolution of the ground motion spectrum (site dependent and the ultimate limit reachable without passive or active vibration isolation devices) with the magnet versus floor mechanical transfer function (TF) [1]. A detailed investigation on the TF was carried out on the prototype for different configuration of supports and fixtures; Preliminary ground motion data from the storage ring concrete slab are also reported.

Measurements & Analysis

Horizontal transverse and vertical TFs and root mean square (rms) displacement amplitudes were measured using single axis geophones and tri-axial seismometers and the ground motion as broadband excitation source therefore, no auxiliary external vibration excitation source was used. The equipment used and the analysis technique have been reported elsewhere [2, 3].

1.1 General Features

The girder top is connected to the pedestals on 6 points; Additional vertical fixation bolts are used to stiffen the system after the alignment. The torque on the vertical fixations was set to 350 Nm initially, but in the subsequent tests, it was stiffened to 400 and 450 Nm. No significant change in the frequency of the normal modes was detected in going from 350 to 450 Nm. To get a glimpse of its general vibration characteristics, horizontal geophones were first placed in the middle of the girder structure on the girder surface, on the pedestal, on the pedestal platform and on the ground (Figure 3).

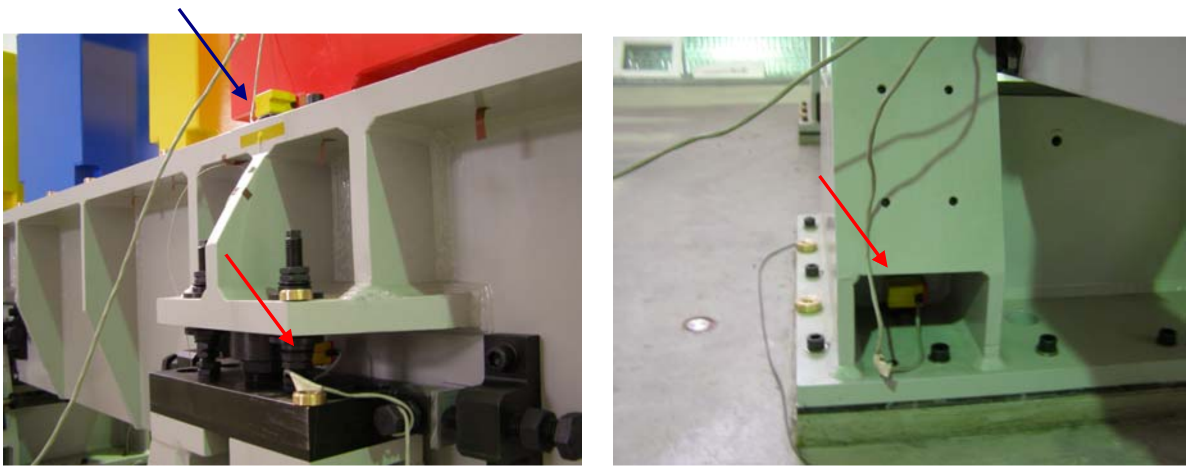

Figure 3: Positions of geophones to measure transfer function in going from the girder top (blue arrow left) to the pedestal (red arrow left) and the pedestal base plate (red arrow, right).

Horizontal transverse transfer functions of girder top versus the pedestal platform and the floor are shown in Fig. 4 together with the transfer function of the pedestal base plate versus the floor. Two modes are clearly visible: the first one at 28 Hz, and a second mode at 70 Hz.

The mode at 28 Hz starts to be visible even in the base versus ground TF and it seems to be due to the whole girder structure rocking on the floor. This mode, unpredicted by the existing ANSYS model [4] is most probably due to the way the girder structure has been attached to the floor. The horizontal transverse rocking mode does not change in frequency when the girder is stiffened or loosened by changing the number of girder fixation points or the torque applied. The mode at 70 Hz is only visible on the girder and can be considered as the first internal eigen frequency. This first eigen mode has been predicted, in ANSYS, to occur ~50 Hz [4].

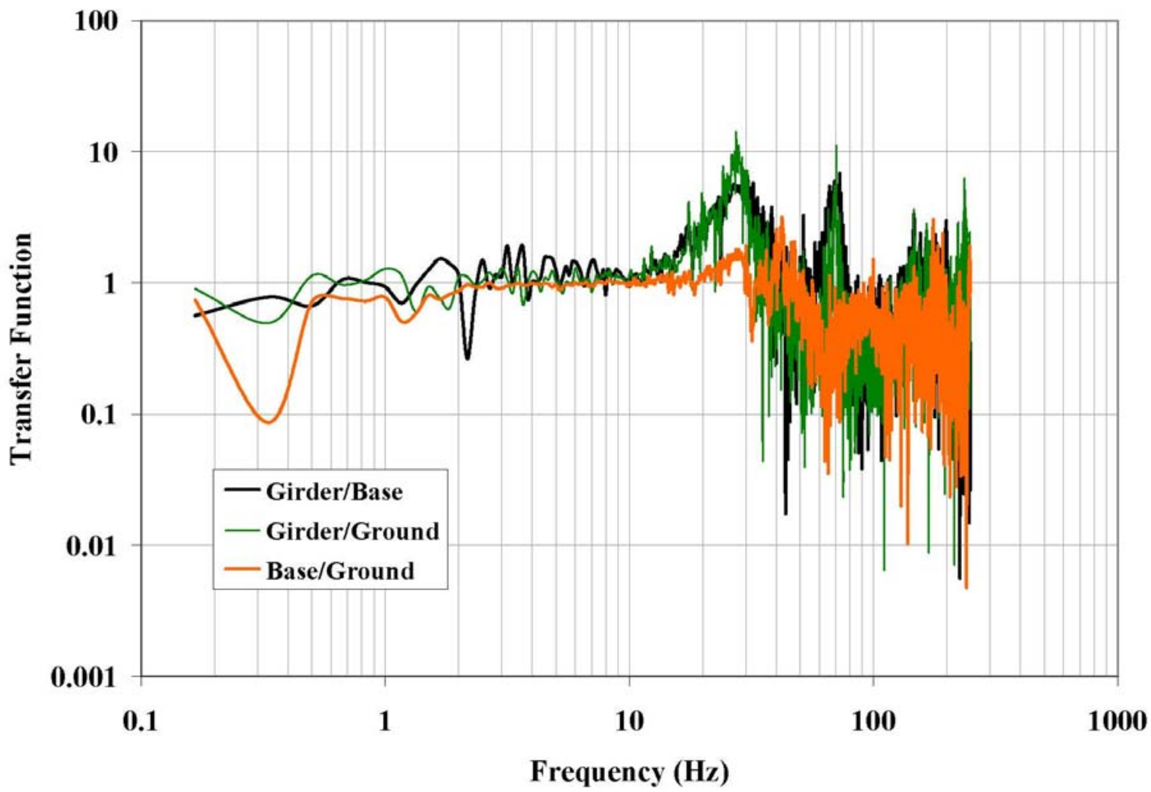

Figure 4: Horizontal transverse transfer functions of girder top versus pedestal platform (black), girder top versus floor (green) and pedestal platform versus floor (orange). In the legend, ‘Base’ refers to pedestal platform as shown in Fig.2 & 3.

In the vertical direction the girder has exhibited a very good figure of merit with an almost one to one transferring of the ground motion, as shown in the seismometer measurement comparison between the girder and the ground (Fig. 5). The rms of displacement integrated from 1 to 80 Hz is ~60 nm. The TF of the signals in Fig. 5 is shown in Fig. 6. It clearly demonstrates that the girder is substantially rigid in the vertical direction, i.e., TF ~ 1 up to 40 Hz at least.

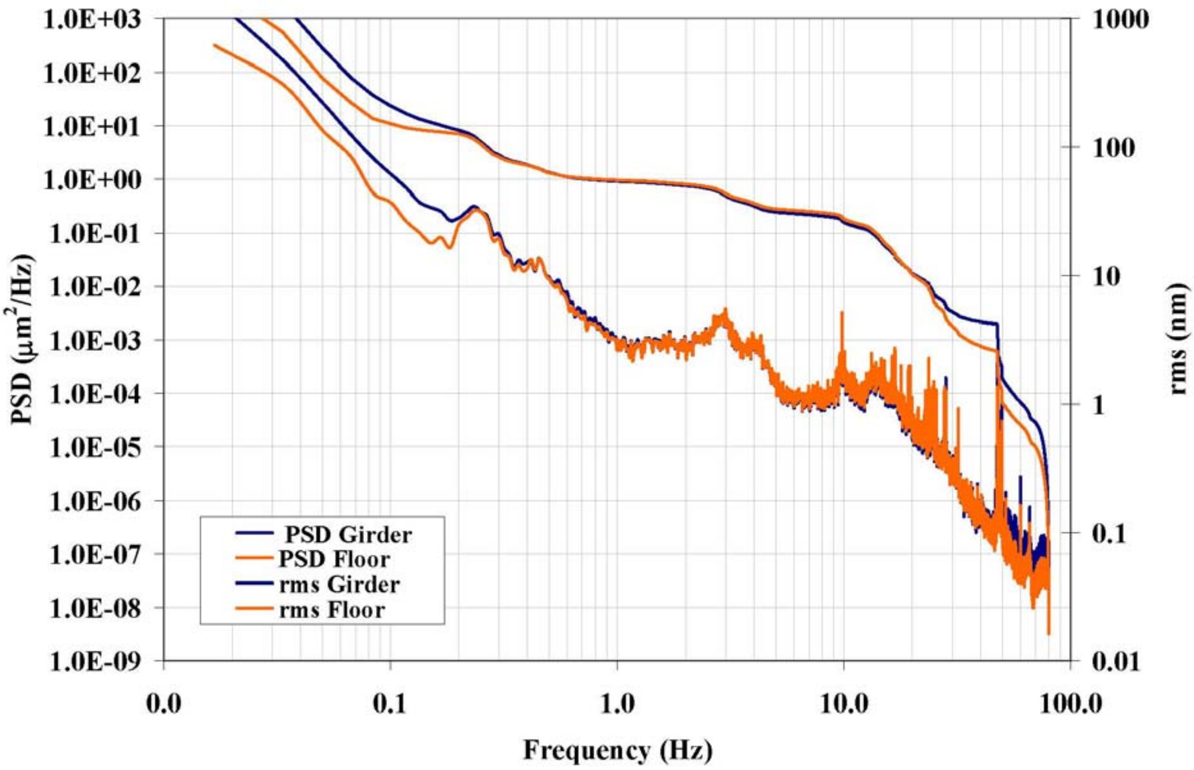

Figure 5: Average displacement PSD of the girder versus the floor nearby, and the integrated PSDs in the range 1< f< 80 Hz (rms displacement amplitude) in the vertical direction.

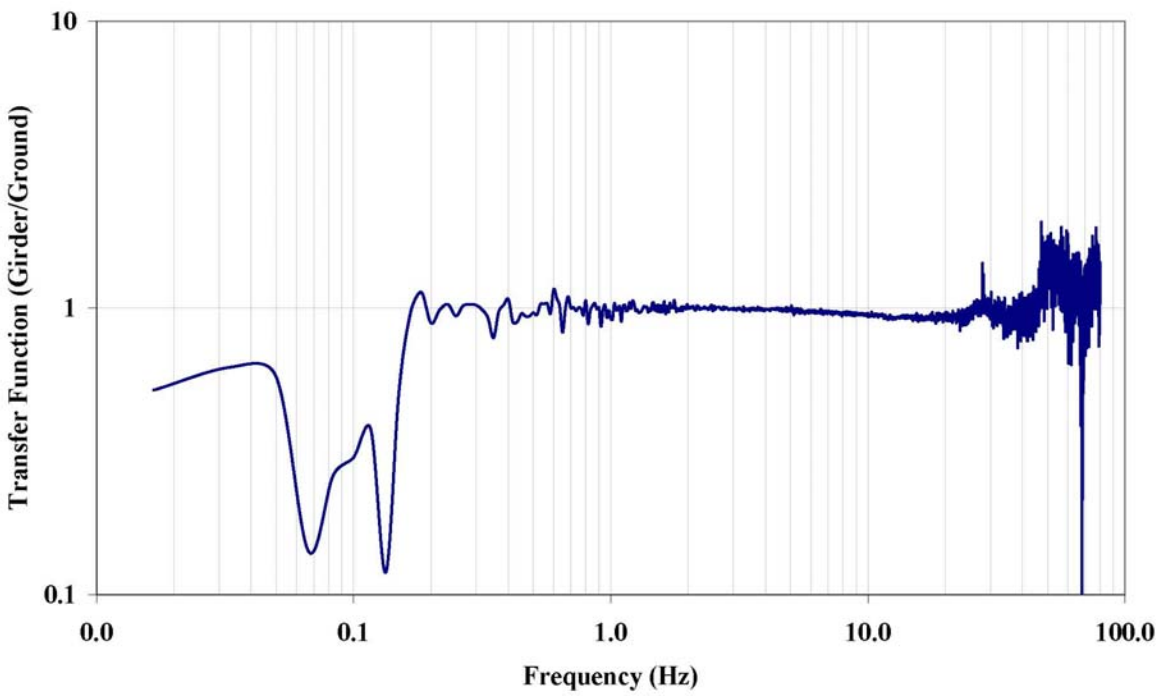

Figure 6: Transfer function of the signals shown in Fig. 5 is 1:1 up to a frequency of 40 Hz at least. At higher frequencies the measurement is noisier but no resonance patterns are identifiable.

1.2 6-Point Support Versus 3-Point Support

In its baseline design, the girder body is supported, on 6 points, on the pedestals. The effect of changing the number of the support points from 6 to 3 was investigated. Displacement PSD and displacement rms plots of these configurations are displayed in Figs. 7 and 8. Results are compared to the measurements on the floor. In going from 6-point to 3-point setup, the frequencies seen on the surface of the girder are pushed backwards. The most dramatic effect is seen in the case of 3-points with no vertical fixation and can be directly compared with the case of 6-points with no vertical fixation. The 28 Hz mode is pushed down to 18 Hz, probably because of the re-distribution of the weight on the contact surface between the pedestals and the pedestal platforms. The 70 Hz eigen mode is pushed down to 63 Hz. The 24 Hz line visible in all the spectra is due to the vibrations produced of a rotary vacuum pump nearby. In the 6-point layout, the peak is much higher because it's next to the first mechanical resonance (the 28 Hz mode) of the system. The difference in the frequencies seen with/without vertical fixations, measured in the case of 6-point support, is less marked. The 70 Hz eigen mode is pushed down to 66 Hz and the 28 Hz to ~25 Hz. The resultant amplitude ~24 Hz is therefore high due to the existence of the peak from the vacuum pump as was mentioned above.

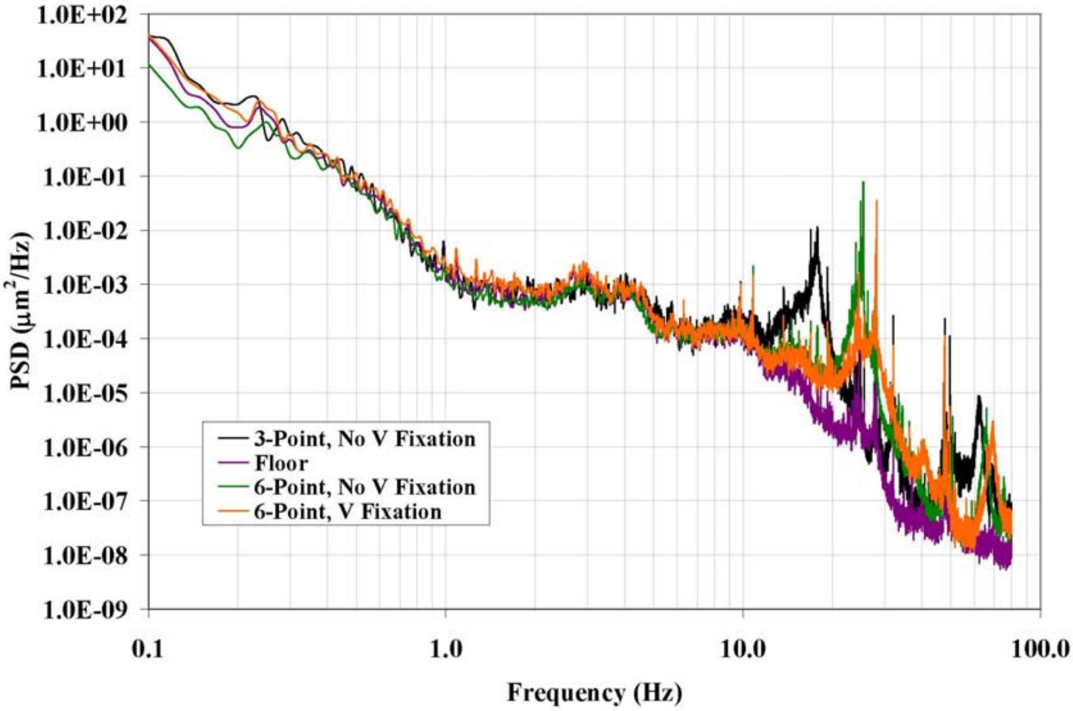

Figure 7: Horizontal transverse displacement PSDs of the floor, girder surface resting on the pedestals on 6-points (additionally, with and without vertical fixation) and 3-points (without vertical fixations) measured with CMG-6TD Güralp seismometers.

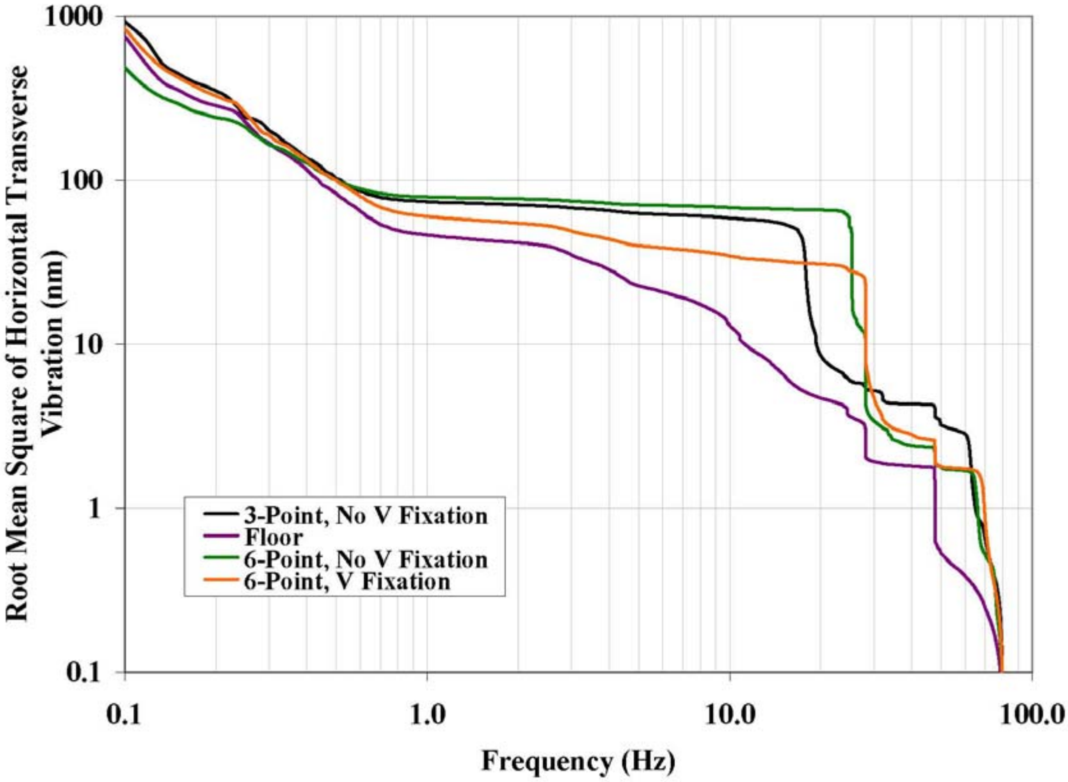

Figure 8: Root mean square displacement spectra calculated from the PSDs shown in Fig. 7.

1.3 Twist Mode

A twist mode mostly affecting the two ends of the girder was predicted by the ANSYS model [4] to exist around 64 Hz. To validate this picture, two horizontal geophones were placed at the extreme corners on the girder surface and the correlation (coherence) between the signals was computed (Figure 9). A girder twist-mode at ~40 Hz is clearly seen as a change in phase in the computed real component of the correlation versus frequency. The resonant frequency is much less than expected (~ 64 Hz in the model); a possible explanation is once again the effect of the pedestal-floor layout which seems to introduce a ‘zero’ order mode structure involving the motion of the girder as a whole.

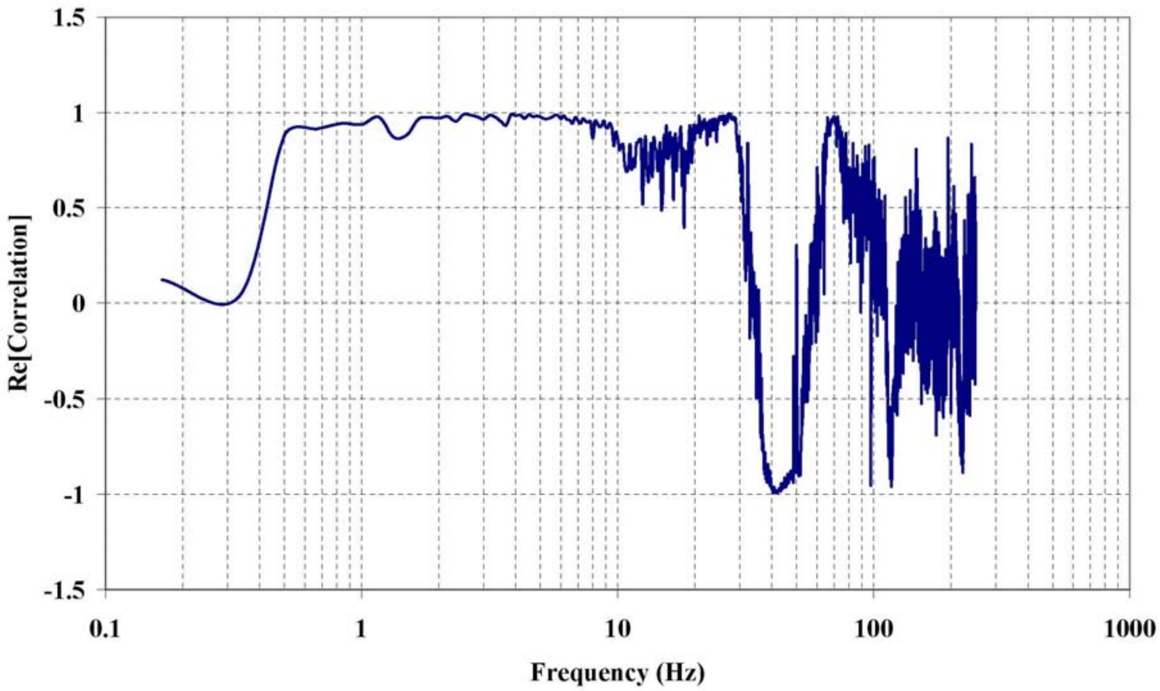

Figure 9: Real correlation of two geophone signals placed on the extreme left and right corners of the girder surface.

1.4 Measurement on Top of the Magnet Dummies

The magnet dummy arrangement is shown in Fig. 1 and the order of the arrangement consists of a dipole in the middle (shown in red), two sextupoles on either side (shown in yellow), followed by two quadrupoles (shown in blue) and two sextupoles and one additional quadrupole at one end of the girder. Transfer function of all the magnet dummies, from ground to the top of the magnet, was measured in both transverse and longitudinal directions in the case where the girder's vertical fixations were loosened. Fig. 10 shows the transfer function measured for the dipole in the transverse direction. The two structures seen are in the ~25-28 Hz frequency range and ~66 Hz, the second being the first eigen mode of the girder. TF at 28 Hz is greater than 10 for the dipole. This rocking mode, due to girder pedestal-floor connection proves to be a dominant source for magnet displacement and should be pushed to higher frequencies by choosing a more rigid girder-floor interface design. In addition the twist mode, measured at 40 Hz, will affect the sextupoles (not shown) as they are most vulnerable because of their position on the girder.

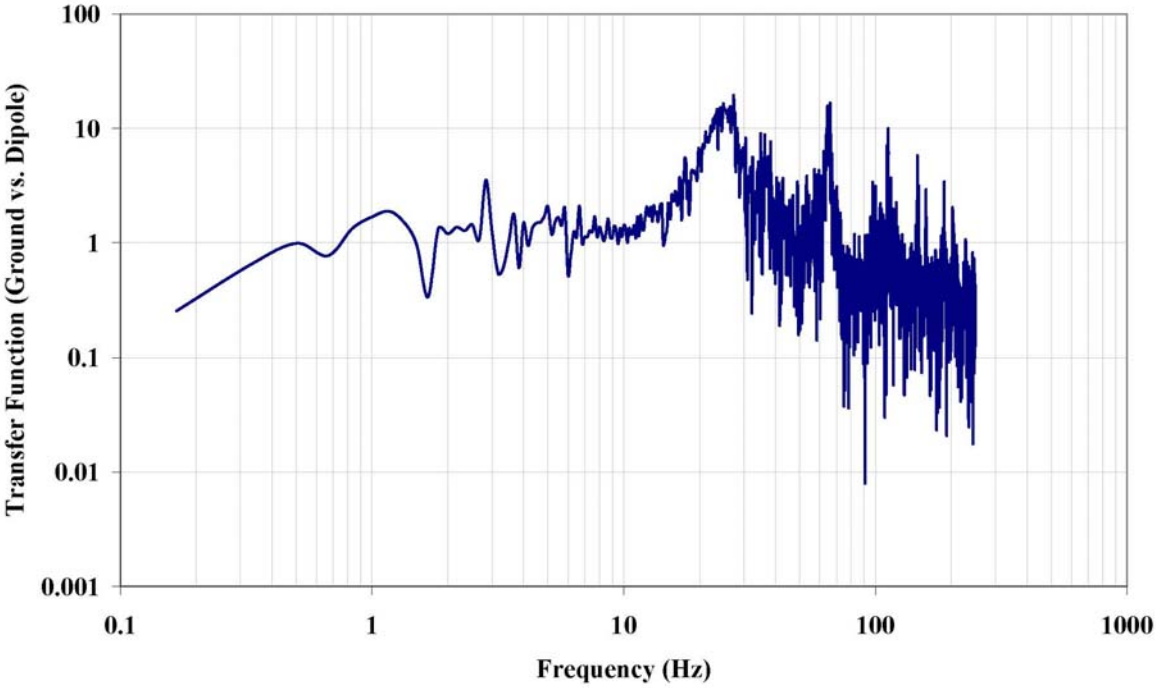

Figure 10: Horizontal transverse transfer function of the ground to the top of the dipole dummy, measured with no vertical fixations.

1.5 Ground Vibrations Measurement of the ALBA Floor Slab

Ground vibrations of the ALBA site, before its construction, were measured in 2004 and reported [3, 5, 6]. In this section, a preliminary measurement of a floor slab of ALBA was attempted. The one meter thick concrete slab will act as the floor of the storage ring.

A seismometer was utilized and the measurement was carried out one evening from ~19:00-20:00 after a working day. An electric power generator in the vicinity of the construction site was used but its influence on the amplitude of the rms spectra was minimal. In order to minimize the effects of temperature fluctuations on the seismometer, it was placed in a carton box covered in Aluminium foil. The resultant spectra are shown in Figure 11.

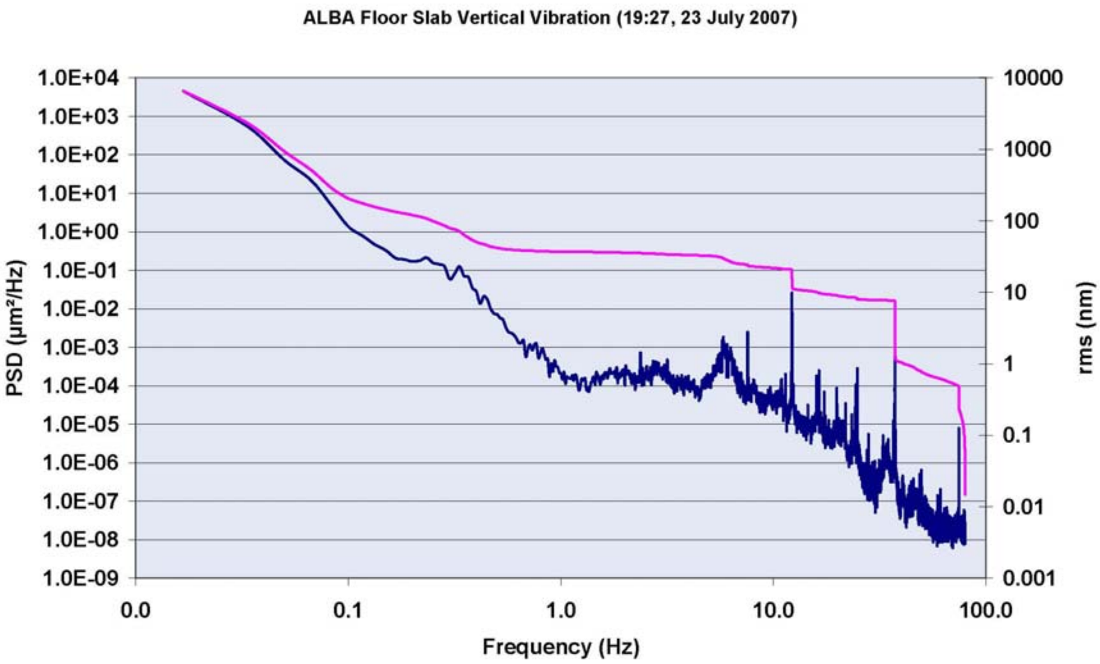

Figure 11: A 15 minute average of vertical displacement PSD measured in one location on the floor slab of ALBA (Blue) and the integrated PSD (magenta) showing the vibration amplitude in nm.

The average vertical vibration amplitude, integrated in the 1-80 Hz band, is 34 nm at 1 Hz, at this time of the day. The most prominent features of the PSD are the wide peak at ~6 Hz which may be due to a bridge nearby the site and the subsequent traffic, the line at 7.8 Hz due to the power generator, and the line at 12.3 Hz due to operation of the nearby ceramic factory. There are other lines at 37.6, 25.0, 74.4, 15.9 and 19.9 Hz whose sources are mostly electrical motors in operation.

Summary & Future Work

It has been shown that the girder structure is rigid in the vertical direction with a 1:1 TF computed between the girder and the ground up to a frequency of 40 Hz at least. In the horizontal transverse direction, its first internal mode is at ~70 Hz with 6-point fixations. It has a twist mode at ~40 Hz in going from one extreme corner to another.
However, the girder rocks with a frequency of ~28 Hz on its interface between its pedestal platforms and the floor. Further study of the interface between the girder and the ground is needed. Also a measurement of the transfer function of ground to magnet dummies with the girder in its design configuration in both vertical and horizontal transverse will be useful to evaluate the effect of ground motion on the beam.

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