MEASUREMENTS OF GROUND- AND GIRDER-VIBRATIONS AT BESSYII

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Abstract

Ground vibrations at different impact levels of cultural noise at the BESSY II site in Berlin-Adlershof, have been measured and the amplitudes and frequencies of the resulting girder vibrations have been extracted. As a result of these measurements the girder design has been modified and the girder feet were set up on low cost damping plates.

1 INTRODUCTION

BESSYII is a third generation synchrotron radiation source based on a 6 nm-rad double-bend-achromate structure with an 8-fold symmetry. All 144 quadrupoles and 112 sextupoles equipped with integrated orbit correction coils are mounted on 48 girders. There are three different types of girders. The central achromat structure has 5 quadrupole magnets the triplett structure has 3 quadrupols and the doublet has 2 quadrupoles. The mass of each girder structure together with its magnets (9.0 tons, 6.7 tons and 5.6 tons resp.) is supported by three girder jacks mounted on girder feet. The feet can be adjusted by using screws on a ball bearing.

Displacements and relative vibrations of the girders lead to closed orbit deviations which may cause an unacceptable blow up of the beam emittances. Like all strong focussing storage rings the BESSY II lattice has an amplification factor as high as 100 for these girder vibrations at the location of the beam. Hence to asure a beam stability of less than 20 μm horizontally due to ground vibrations, the relative horizontal girder vibration amplitude may not exceed 800 nm. The BESSY II site is an urban and rapidly developing area where major parts of the infrastructure are currently under construction. This situation will not change in the near future. There had been serious concern that the acceptable vibration limits might be continously exceeded and might harm the storage ring performance.

The velocity of ground waves on the BESSY II area is about 250 m/sec. It is therefore sufficient to to take only those ground waves into account which have frequencies above 2 Hz. At this frequency the wave length is 125 m. This is larger than the ring diameter of 76 meters. The beam dynamics will therefore not be affected at frequencies below this value, because the ring will move on the whole. The "dangerous frequencies" for the BESSY II optics, where the ground-waves have the same dimension than the betatron-wavelength and therefore may cause resonant beam excitations are:
vertical 5.6 Hz – horizontal 14.8 Hz.

The aim of our measurements was twofold:
first the quantification of ground motion on the BESSY II site during different phases and types of construction work, close to the storage ring hall and the resulting excitations of the girder structures. Second, the identification of the most typical frequencies which are present.

2 EQUIPMENT AND DATA ANALYSIS

The seismometers employ inductive sensors which measure the velocitiy. The amplitude distortion at its resonance frequency of 4.5 Hz is compensated internally by the amplifier[1]. The frequency response is linear within the range of 2-315 Hz (the deviation is less than -3dB) with a noise level of $5 \cdot 10^{-5}$ mm/sec, equivalent to a noise induced amplitude error of 4nm at 2 Hz.

The velocity/time tracks are recorded, written on a PC-disk (2.1 GByte allow a continous monitoring for 20 hours) The data are analyzed off-line on a PC. A FFT and a Transfer-Function tool for fast analysis are available on-line. For further evaluation the low frequency content of the tracks (below 2 Hz) was subtracted and the resulting signal was integrated numerically. Because of main interest are the absolute vibration amplitudes there is no emphazise on spectral densities or rms amplitudes but on the integrated amplitude vs. time. Several hundred tracks were taken in each measurement and monitored to find "typical" and "worst" cases. The mechanical transfer functions are calculated by correlation function methods. For a good statistics about 60 tracks of 4 sec duration are needed.

3 RESULTS

3.1 IMPACT LEVELS

By integrating over the frequency rang of 2-315 Hz one gets the follwing upper limits for the ground motion amplitudes on the BESSY II site at different stages of construction activities:

1. **100 nm vertical and 50 nm horizontal** on holidays where the BESSY water pumps, air conditioning and the electrical devices were switched off (no construction works done on the site)

2. **150 nm vertical and 50 nm horizontal** on holidays, where the BESSY infrastructure utilities were switched on.

3. **300 nm vertical, 150 nm horizontal**, during a normal working day where modest construction activities were

[1]The complete system was delivered by "Dr. KEBE GmbH", Halstenbeck.

going on at the site but not adjacent to the storage ring hall.

4. **200 nm vertical and 100 nm horizontal** in the evening hours (no construction near BESSYII but normal traffic on nearby roads).
5. **400 nm - 1 μm vertically**, with heavy construction work adjacent to the storage ring (ground being compressed for road construction).
6. **2 μm vertical** at 4 Hz, when a roller was passing by close to the storage ring.

3.2 GIRDER VIBRATION AMPLITUDES

As the vibration impact on the girder sharply increases at lower frequencies (see for eg [1], [4]) the first eigenmodes of the structures (which are rigid transverse modes) should be as high as possible.

A rough estimate of these frequencies can be made by modelling the girder jacks as vertical beams loaded by 1/3 of the weight of the girder structure. For the first eigenmode of a beam with radius R, length L and spring constant D, loaded by a mass $M/3$ we get [2]

$$f\,[Hz] = \frac{\sqrt{3}}{2\pi}\,\frac{\sqrt{D}}{\sqrt{M}} \approx \frac{2\cdot 10^5 \cdot R\,[m]^2}{L\,[m]^{3/2}\cdot M\,[kg]^{1/2}} \qquad (1)$$

As was pointed out by P. Wiegand [3] the most efficient way to raise the eigenmode frequencies is to position the girders center of gravity as close as possible to the beam support (reducing L), while keeping its mass as low as possible.

As in our case the design could not be changed in this way, we decided to reinforce the jack rods from R=30mm to R=50mm and to decouple them from ground by stacks of steel sheets, each covered with a layer of viscoelastic polymers (see [5]). We used material [2], which is normally used to reduce acustic noise in e.g. garage doors, car sumps and other engines and which is a very cheap mass product.

The horizontal girder amplitude of a free standing girder with no vibration bridges such as cable traces the beam pipe and tightened screws in the girder feet, was reduced from 500 nm (about 4 times larger than the ground motion amplitude of that time) to 250 nm under the same conditions. After mounting the cable traces and other bridges the amplitude increased to 400 nm under similar impact conditions (about 150 nm ground amplitude). The mechanical amplification factor of the completely mounted girder for the storage ring in operation is about 3. There is no mechanical excitation coming from the water flow of the magnet cooling. The White circuit of the BESSY II booster synchrotron, working at 10 Hz can be seen in the girder vibration spectra, but it causes no measurable excitation. Table (3.2) gives a summary of the measured upper limits for the horizontal girder amplitudes in the frequency range of 2-315 Hz under different conditions. The quantity Q denotes the mechanical amplification factor between the ground and the girder. The lowest modes are at 11.75 Hz (Achromat), 15.25 Hz (Triplet) and 17.25 Hz (Doublet). The transfer functions reach values as high as 80, but the resonance is narrow. For the free standing girder the maximum value of the transfer function in the resonance is lower than 10 but the resonance is broadened. The amplitude in the latter case is not much lower than for the mounted girder. For the amplitude of the girder oscillation the height of the transfer function seems not to be very important.

structure	amplitude	Q
Girder mounted, $R = 50$ mm, with damping plates	400 nm	~ 3
Girder mounted, $R = 50$ mm, with damping plates	250 nm	~ 2
Girder unmounted, $R = 30$ mm, without damping pl.	500 nm	~ 4

Table 1: Typical amlitudes of horizontal girder vibration

[2] “Bondal” from Krupp Hoesch Stahl AG, Dortmund

4 SUMMARY

Under normal working day conditions the BESSY II girder vibrations do not exceed their specified limits. Construction work adjacent to the storage ring hall would clearly affect its performance.

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