BEPC-II c. m. s. energy studies. Continue.

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May 30, 2014

Abstract

In the previous part of these studies it was stated that some deeper understanding of the possible beam energy behaviour within BEMS measurement time may help to understand BEMS accuracy and systematic effects. With the great help of Zhang Jianyong we have some records from the BEPC-II BPMs system, which are going to be studied here. All of the measurements mentioned further are supposed to be obtained during normal BEPC operation in collider mode with high luminosity.

1 Coherent (dipole) synchrotron oscillations

First, let's have a look at turn-to-turn beam positions (X and Y) measurements. We've chosen the R1OBPM08 for these measurements due to large horizontal dispersion function ($D_x = 1.841$ m) at this place.

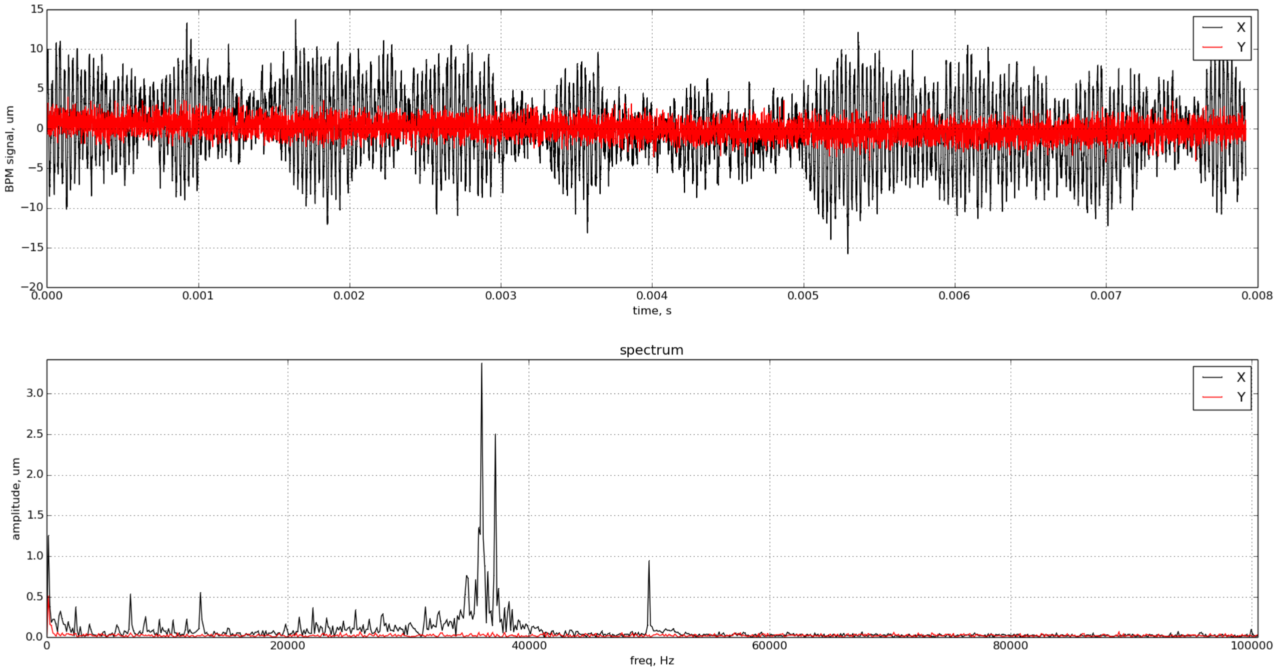

Figure 1: A signal from R1OBPM08 (BER) and its spectrum. Sampling rate $f_s = 1.2621$ MHz, 10^4 records.

On Fig.1 one can clearly see the horizontal (radial) oscillations within $\Delta X \simeq \pm 10\mu$m. The corresponding beam energy oscillations are $\Delta E/E = \Delta X/D_x \simeq 5 \times 10^{-6}$. This is just 10 keV for a 2 GeV beam. The spectrum of the BPM signal, presented in the lower plot of Fig.1, shows the peak which is supposed to be the BEPC synchrotron oscillations frequency. The influence of this effect to the c.m.s. energy determination with BEMS is negligible – about few keV. It was checked also that these oscillations are not present at another BPM where $D_x = 0$.

2 Slow oscillations

2.1 Observations

Let's have a look at two measurements concerning the slow transverse beam position behaviour in BEPC-II. Figures 2 and 3 show the BPMs signals and their spectra for R1OBPM08 (BER[1]) and R1IBPM08 (BPR[2]) correspondingly.

These measurements (see Fig. 2 and Fig. 3) have the following common properties:

- Presence of narrow spectral lines for basic and higher odd and even harmonics (upto 40 × 50Hz = 2000 Hz !) of AC power line (further - AC).
- The basic AC 50 Hz spectral line is present in both radial (X) and vertical (Y) directions, having similar amplitudes, while the higher harmonics are only visible in X for both BEPC rings.
- Some wider spectral lines are present at 1175 Hz and 2350 Hz, which seems to be the basic and second harmonic of something that I don't know. It was checked that these lines disappear from the spectrum at the BPMs where $D_x = 0$, while the AC lines remain there. So these lines are supposed to be coupled with the close orbit distortion mechanism, having the same small influence to the beam energy as was discussed here in the previous section.

2.2 Discussion

Despite the fact that the oscillations amplitudes on Fig. 2 and Fig. 3 are less then 1 μm, these oscillations are not reasoned by BPMs electronics, etc., cause the electronics is the same for X and Y measurements, while the spectra are different. So the BEPC BPM system is definitely capable to detect sub-micrometer oscillations in beam transverse movement.

Let's assume that the AC oscillations are reasoned by the B-field variations in the dipole magnets[3]. If so, the B-field variations, being a very slow process relative to the accelerator revolution frequency, will mainly cause the mean beam energy variations, while the equilibrium orbit and revolution frequency will remain the same due to RF cavity.

However, when the beam exits the RF cavity with some certain mean energy and propagates along the ring with varying in time bending field, for one passage along the ring beam orbit radius will be changed as:

$$\left(\frac{\Delta R}{R_0}\right)_{\text{turn}} = \left(\frac{\Delta B}{B}\right)_{\text{turn}} , \tag{1}$$

where R_0 is the equilibrium orbit radius. Let the $\Delta B/B$ in (1) to be so small that corresponding radius and orbit length variation are much smaller then those defined by beam energy spread and synchrotron motion. In this case the RF cavity will slightly change the mean beam energy, keeping the same R_0 for the next turn. Let's consider the case when B-field variation in time is described by harmonic oscillations with amplitude ΔB and frequency ν_b:

$$B(t) = B_0 + \Delta B \sin(2\pi\nu_b t) . \tag{2}$$

Then the beam orbit radius change in time will behave as:

$$\frac{\Delta R}{R_0}(t) = \mathcal{F}\frac{\Delta B}{B_0}\cos(2\pi\nu_b t)\frac{\nu_b}{\nu_r} , \tag{3}$$

where $\nu_r = c/P$ is the beam revolution frequency. For BEPC $P = 237.53$ m, so $\nu_r = 1.262$ MHz. Factor $\mathcal{F} = 1$ in case when RF cavity compensates the orbit radius change by corresponding mean beam energy change after 1 beam pass through the cavity gap. In general $\mathcal{F}$ can be higher.

According to eq. (3), oscillations in beam radius are much smaller then those in B-field. If $\nu_b = 100$ Hz and $\mathcal{F} = 1$, the attenuation factor for relative amplitudes will be $\nu_b/\nu_r \simeq 8 \cdot 10^{-5}$. Also this attenuation becomes weaker at higher frequencies, which explains why we do see high AC harmonics in BPM signal.

If $R_0 = 10$ m (BPC case) and BPM has the sensitivity of $\Delta R \lesssim 1\mu$m, it can show the relative radius variations at the level of $\Delta R/R \lesssim 10^{-7}$. With eq. (3) one can calculate the beam energy oscillation amplitude from the measured orbit radius oscillation amplitude:

$$\frac{\Delta E}{E_0} \simeq \frac{\Delta B}{B_0} \simeq \frac{1}{\mathcal{F}} \times \frac{\Delta R}{R_0} \times \frac{\nu_r}{\nu_b} . \tag{4}$$

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[1] BER - electron ring

[2] BPR - positron ring

[3] the large amount of AC harmonics is typical for high-power 3-phase AC/DC converters

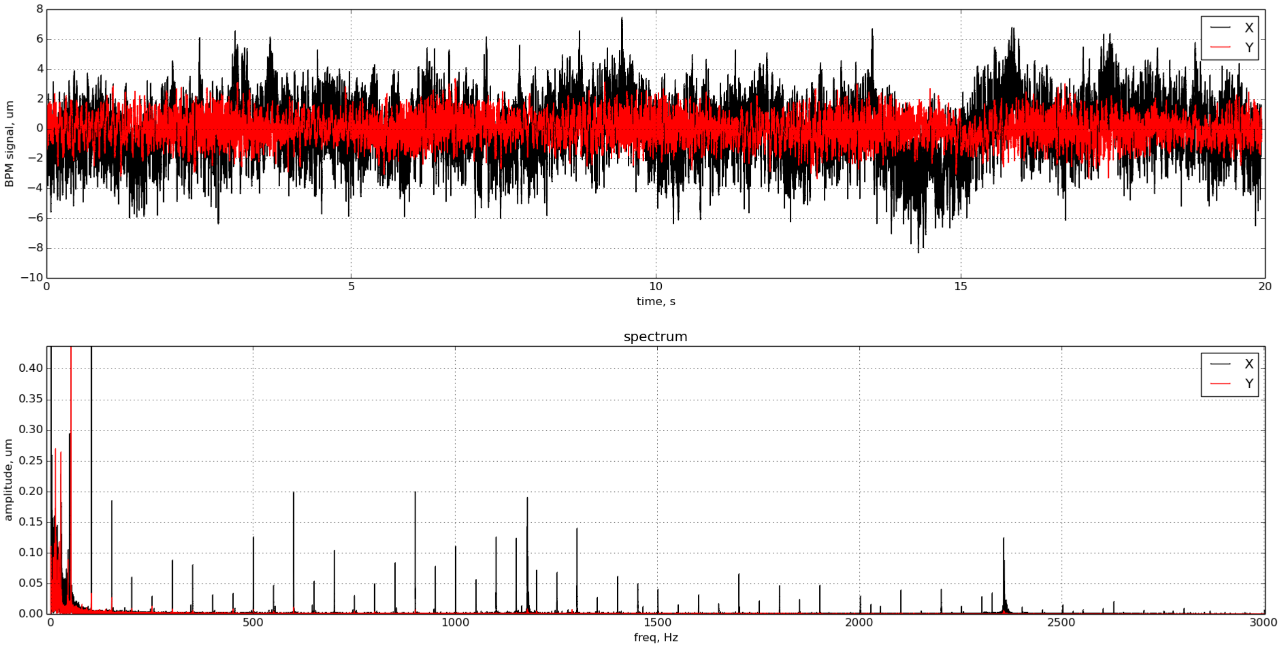

Figure 2: A signal from R1OBPM08 (BER) and its spectrum. Sampling rate $f_s = 10$ kHz, 2×10^5 records.

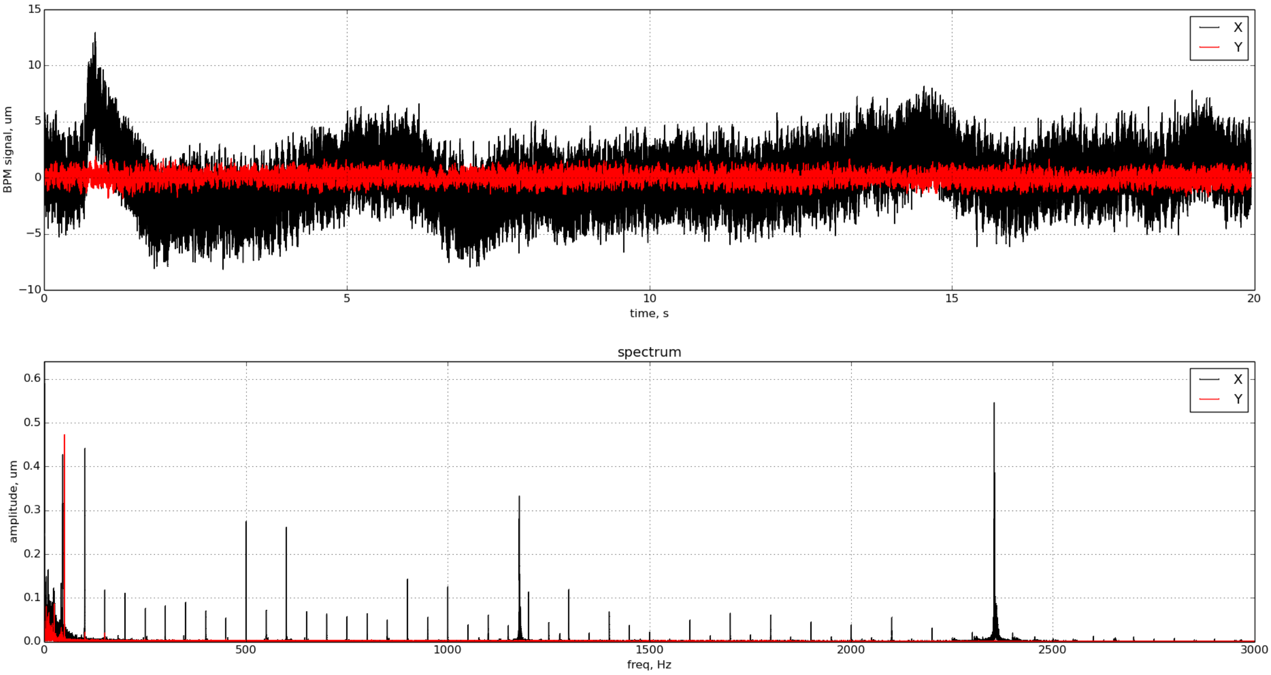

Figure 3: A signal from R1IBPM08 (BPR) and its spectrum. Sampling rate $f_s = 10$ kHz, 2×10^5 records.

3 Conclusion

What I did is that I removed from the BPM radial (X) spectrum everything except AC harmonics of 100 Hz and higher. Then, according to eq. (4) I obtained the spectrum and "signal" for mean beam energy oscillations for both rings. The results are presented below. The influence of such an energy behaviour, if it exists, to the c.m.s. energy distribution will strongly depend on the way how the AC/DC converters are connected to the power line.

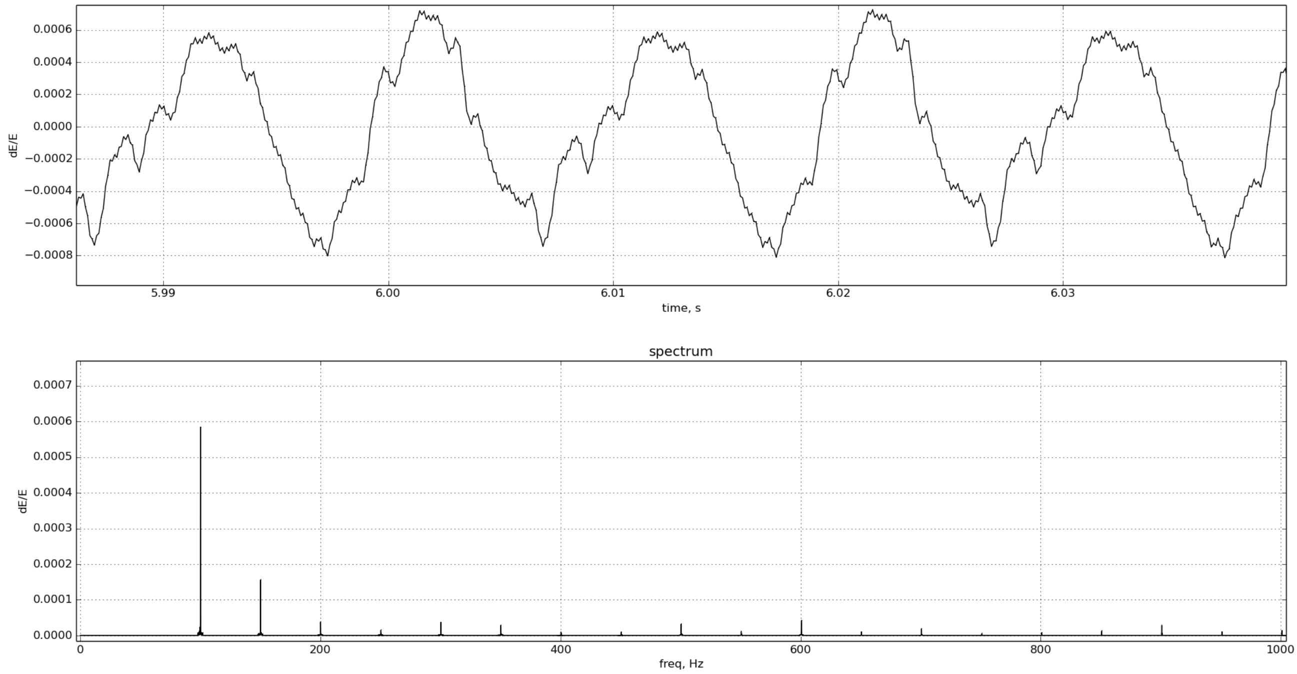

Figure 4: $\Delta E/E$ variation according to eq. (4) in BER and its spectrum.

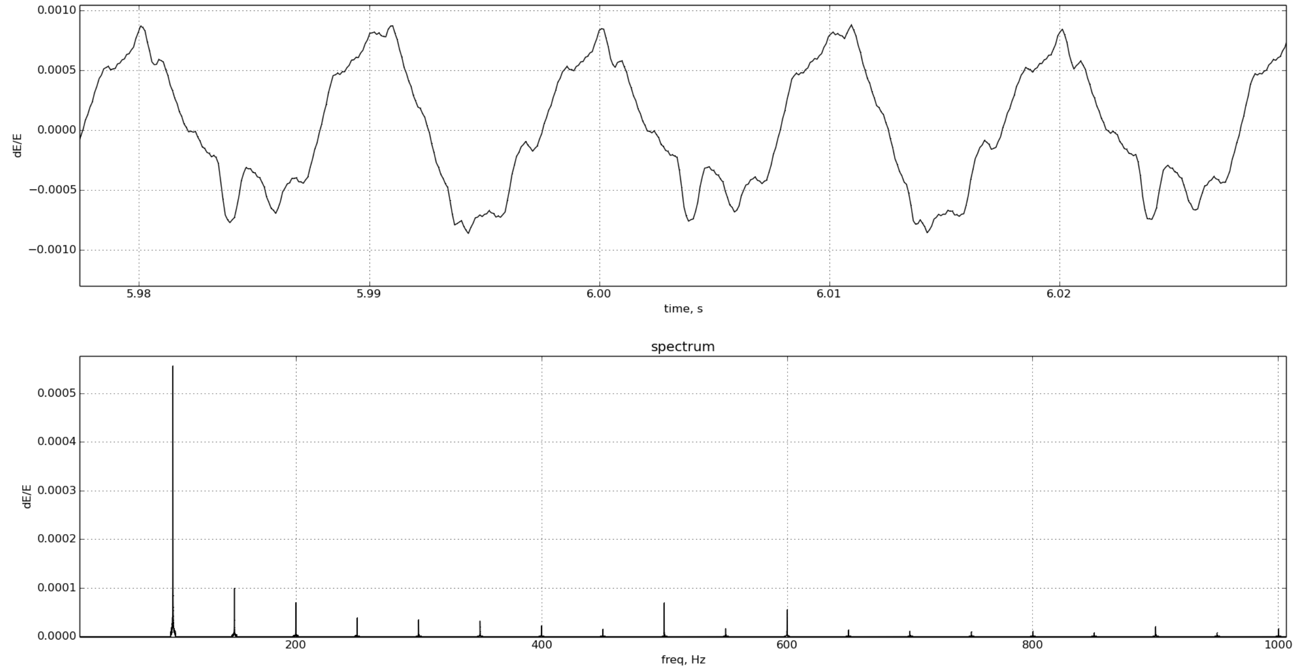

Figure 5: $\Delta E/E$ variation according to eq. (4) in BPR and its spectrum.