# An Observation of the Long Term Stability of the Electron Beam Trajectory in the Storage Ring of SPring-8

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## 1. Introduction

The storage ring of SPring8 had been commissioned during a period from March to July 1997 and it have been under the operation dedicated to synchrotron radiation users since October, 1997. During these periods, the main effort has been made towards stabilizing electron beam orbits near a disigned one. This requires to monitor the orbit from time to time during the operation and clarify all causes of changes in the orbit. To do this, it is a reasonable manner to Fourier decompose the orbit as a function of the phase of the revolution along the ring and observe the components as a function of time. The $n$th component is defined as

$$X_n = \frac{<\sqrt{\beta}>}{2\pi} \int_0^{2\pi} d\phi e^{-in\phi} \frac{x}{\sqrt{\beta}}, \qquad (1)$$

where the COD $x$ and the betatron amplitude $\beta$ are functions of the normalized phase $\phi$ and $<\ldots>$ denotes the average over the ring. Direct observable in Eq.(1) is a set of values of $x$ at positions of beam position monitors (BPMs) distributed on the storage ring. Each of fourty eight cells in the storage ring of SPring-8 has six BPMs and thus $x$ is composed of 288 data points over the ring. The function $\beta$ characterizing the local envelop of the beam and values of $\phi$ measuring the phase of the revolution in modules of $2\pi$ at the positions of BPMs are taken from a numerical calculation using a model of the optical lattice [1]. To distinguish the vertical COD from horizontal one, we denote the former one by $y$ and its components by $Y_n$. The horizontal and vertical tunes of the closed orbit are respectively 51.2 and 16.3 so that $2|X_{51}|$ and $2|Y_{16}|$ represent the amplitudes of the main oscillation modes in each direction.

## 2. Data and Observation

Data on $X_n$ and $Y_n$ presented in this report were taken for every 30 seconds during three terms of the machine operation in 1997 spanning respectively from October 23 to 31, November 7 to 14 and December 4 to 18. The beam orbits were tuned at the begining of each term by minimizing their $r.m.s.$ distances from a reference orbit to provide the beams for synchrotron light users. After the initial beam orbits were defined, the condition of the operation had been kept unchanged except for periods of the beam injection which took place about twice a day. Throughout all terms, the beam currents were kept in a range between 16 to 20 mA and the beam lifetime during them were 80 to 90 hours. The RF frequencies were 508.579225 MHz in the first two terms and 508.579360 MHz in the third term.

The statistical error of the readout from one BPM is estimated [2] as $\sigma \approx 4.5\mu$m for BPMs in the nondispersive regions and $\sigma \approx 2.5\mu$m for BPMs in the dispersive regions, respectively. The main source of the statistical error is considered as the electric noise in readout circuits of the BPM system. The systematic difference between those errors for different regions is conceivably due to different lengths of signal cables attached to BPMs in those regions.

Figure 1 shows data on $2|X_{51}|$ and $2|Y_{16}|$ taken during a period from December 4 to 18, 1997. Spikes in the both data correspond the periods of the beam injection. Those data show an achievement of the stability of the beam to an order of 10 to 20$\mu$m/day in the oscillation amplitudes. The gross change in a longer time period, say a week, is within 50$\mu$m of the amplitudes. Further refinements in the stability require better understanding of the offsets and errors in BPMs.

In short time periods, those amplitudes exhibit periodic changes as shown in Figure 2. The changes

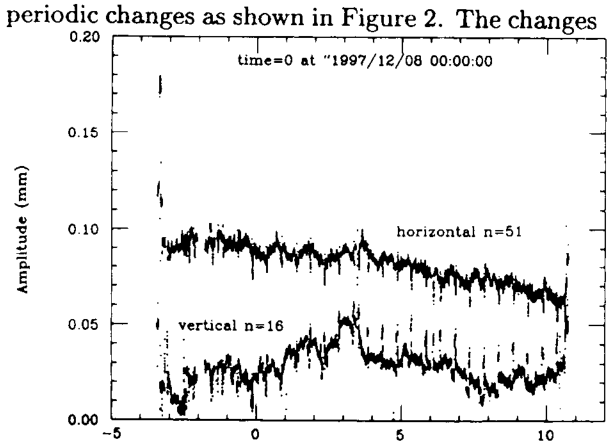


Fig. 1: Horizontal and vertical amplitudes of the main oscillation modes.

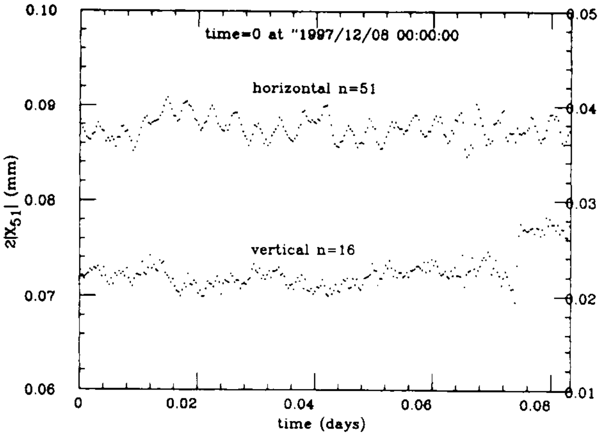

Fig. 2 Detailed time structure of the amplitudes.

have a period of approximately 6 minuits. In other time of measurement, we observe a component of changes with a period of about 20 minuits besides the one mentiond. These changes have apparent correlation with changes in temperature of the cooling water of the magnets.

Figure 3 shows an example of observing a large amplitude in the vertical oscillation due to hard rain falls. The amplitude well exceed the case in Figure 1. The amplitude grows shortly after hard rain falls and slowly decreases down to about the initail level. Time period during which the effect continues is though not very clear. By checking the readout of each BPM, we could identify a location on the storage ring where the shape of the base for the accelerator was changed as an effect of the rain. The location is found to be just above a cut in the hard rock base which is supporting the whole structure of the storage ring.

Figure 4 shows there is a long relaxation time after magnets are powered on after a few days of power off. This is due to a vertical deformation of magnet girders due to the generation of heat from power cables and magnet coils on them.

## 3. Effect of the Earth Tides

As data on the horizontal DC component, $X_0$, were accumulated under the same condition of ma-

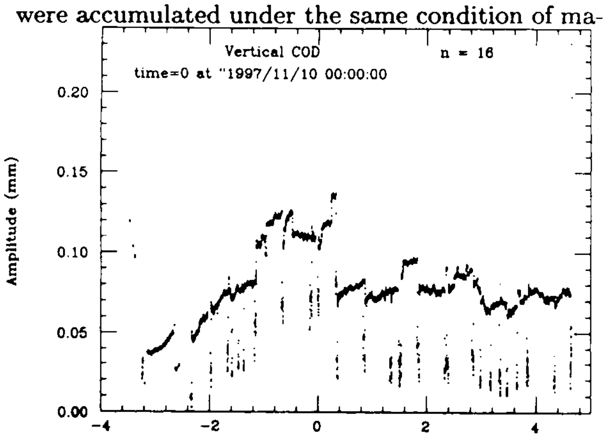

Fig. 3: Large vertical amplitude after a hard rain fall.

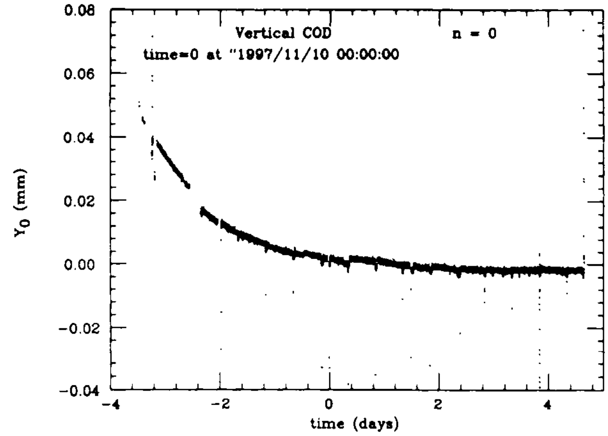

Fig. 4: A long relaxation time after magnet power on.

chine operation, they exhibited pseudoperiodic changes with a period a little longer than one day. The approximate periodicity of the changes became apparent when an operation of the machine continued first time for more than two days in May, 1997. Figure 5 shows a plot of recent data on $X_0$ against time. The data were taken during the three terms mentioned before. The time axis for each term is translated in a unit of day keeping the order between the terms for a technical reason of drawing the figure. Data points corresponding to these periods of the beam injection are removed from this figure.

The data show apparent signatures of pseudoperiodic changes with a period of approximately a day besides slow monotonic increases in each term. For the statistical error in BPM, we estimate that $\sigma \approx 0.3\mu$m for the quantity $X_0$ combining 96 BPMs in dispersive regions and 192 BPMs in nondispersive regions. Thus, the statistical error is well below the size of the systematic changes. The plot also reflects in the thickness of the curves an effect of changes in magnetic fields due to changes in the temperature of the cooling water on which we have mentioned before.

The systematic changes are attributed to the earth tide.[3] The observation of effects of the earth tide in a large circular accelerator is first performed

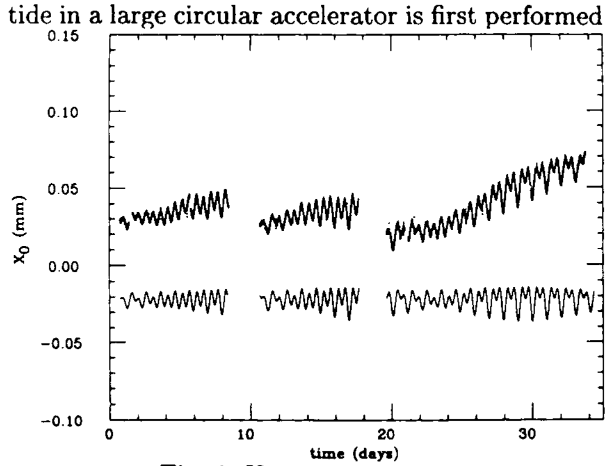

Fig. 5 $X_0$ against time.

[4, 5] in the LEP storage ring at CERN in 1992 through a precise measurement of the beam energy by resonant depolarization method. When a storage ring is firmly attached to the ground and the ground deforms, the centers of Qs shift their positions which define the potential mimimum for electron beams. Since the deformation occurs in a period of time much longer than that of damping of horizontal and longitudinal oscillations of the beams, it can be regarded adiabatic in terms of dynamical variables of the beams. Thus, their orbits follow the shifts of the centers of Qs. When the deformation causes a change in the circumference of the ring, it is however not possible for a beam to keep synchronized with a fixed RF frequency without modifing its orbit relative to one defined by the centers of Qs. To achieve the synchronization, the beam tunes its circulation time by modifing the orbit in dispersive regions, namely, by shifting its energy. The shift in the enrgy, $\Delta E$, and the change in the circumference, $\Delta C$, are related through the momentum compaction factor $\alpha$ as [5]

$$\frac{\Delta E}{E_0} = -\frac{1}{\alpha}\frac{\Delta C}{C_0}\,, \tag{2}$$

where $E_0$ is the nominal energy of the beam and $C_0$ is the reference value of the machine circumference.

$X_0$ as given in Eq. (1) with $n = 0$ is composed of the contribution from the horizontal COD in the dispersive regions, $x_{disp}$, and one from that in the nondispersive regions, $x_{nondisp}$. If the signatures in $X_0$ are actually due to the chages in the machine circumference, they should not show up in $x_{nondisp}$. We have confirmed this point. [3]

Changes in $x_{disp}$ due to the chages in the machine circumference can be written as

$$\Delta x_{disp} = -\frac{D}{\alpha}\frac{\Delta C}{C_0}\,, \tag{3}$$

where $D$ denotes the local dispersion function at the position of the measurement. In the SPring-8 storage ring, parameters in the above equation are given as $\alpha = 1.460 \times 10^{-4}$, $D = 0.266$m and $C_0 = 1435.948$m and we have a relation

$$\Delta C = -0.79 \times \Delta x_{disp}\,. \tag{4}$$

The change in $X_0$ is related [3] with the average $< \Delta x >_{disp}$ as $\Delta X_0 = 0.430 < \Delta x >_{disp}$ so that

$$\Delta C = -1.84 \times \Delta X_0\,. \tag{5}$$

The maximum amplitude of the pseudoperiodic changes in $X_0$ is about 20 $\mu$m which corresponds to $|\Delta C| \approx 40\mu$m.

If the monotonic increases in $X_0$ are attributed to changes of the machine circumference, they amount to shrinkages of the ring by 20 to 40 $\mu$m per week. However, we also observe slight monotonic increases in $x_{nondisp}$ ,which is not shown here, and it is not clear if these increases are totally attributed to changes of the machine circumference.

In Figure 5, also shown as solid curves below data are theoretical calculations [3] for phases and relative strengths of a variation in $X_0$ expected as an effect of the earth tide. The vertical scale for this curve is arbitral. The agreement of phases of the pseudoperidoc changes in the data and the theoretical curve is exellent. The relative amplitudes of the changes are also well reproduced by the calculation.

As for the absolute amplitudes of the earth tide effect, we merely note that an elongation by 40 $\mu$m in a distanse of 1500m in the horizontal plane amounts to a 20 cm rise of the ground, which is a typical order of the earth tide, when we assume an isotropic expansion of the ground.

## 4. Summary

We have observed the long term behaviour of the electron beams in the storage ring. Fourier components of the main oscillation modes provide useful information on the stability of the beams. The DC component of the normalized horizontal excursion showed a very clear signature of the earth tides as pseudopriodic changes which correspond to changes of the 1436 m circumference of the storage ring of SPring-8 by a few 10 $\mu$m. The clear observation have been made possible by a set of 288 BPMs, high stability of the beam orbit and accurate control of the RF frequency.

## Acknowledgements

We are grateful to Dr. S. Takano for his useful discussions and careful reading the manuscript.

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