Observation of Betatron Oscillation in SPring-8 Storage Ring

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Beam oscillation at the betatron frequency was observed in the SPring-8 storage ring. The values of betatron tunes fluctuated ±0.003 during one SR user dedicated operation time. The frequency of the fluctuation was about 1Hz. The tune-shift due to the change of gaps of insertion devices was less than 0.004 at that time.

1. Introduction

The values of the betatron tunes were measured using strip line electrodes attached to the vacuum chamber at the cell 4 of the SPring-8 storage ring. To enhance the signal from the beam oscillation, two signals from strip line electrodes located in opposition were subtracted. Here we call the voltages of the two signals V2 and V4. We assume that V2 oscillates at an angular frequency of ω and at the amplitude of V_0. V4 oscillates at the same frequency but has a phase offset φ and at the amplitude of V_0 (1+δ). The difference between V2 and V4 is shown as follows.

$$
\begin{aligned}
&V2=V_o\sin(\omega t)\\
&V4=V_o(1+\delta)\sin(\omega t+\phi)\\
&V2\text{-}V4=\\
&V2\text{-}V4=V_o\left\{\sin(\omega t)-(1+\delta)\sin(\omega t+\phi)\right\}\\
&\qquad=V_o\left\{\left(1-\left(1+\delta\right)\cos(\phi)\right)\sin(\omega t)-(1+\delta)\sin(\phi)\cos(\omega t)\right\}\\
&\qquad=V_oA\sin(\omega t+\theta)\\
&A^2=\left(1-\left(1+\delta\right)\cos(\phi)\right)^2+\left((1+\delta)\sin(\phi)\right)^2\\
&\quad=2(1-\cos(\phi))+2\delta(1-\cos(\phi))+\delta^2\\
&\theta=\cos^{-1}\left(\frac{-(1+\delta)\sin(\omega t)}{A}\right)
\end{aligned}
\tag{1}
$$

By adjusting the values of the attenuation (δ) and the phase (φ) of one signal, we can set the value A and θ at near zero. Next, if the beam position changes at a frequency of ω_b, the difference between V2 and V4 is shown as follows.

$$
\begin{aligned}
&V2=V_0(1+\sin(\omega_b t))\sin(\omega t)\\
&V4=V_0(1-\sin(\omega_b t))\sin(\omega t)\\
&V2\text{-}V4=V_0 2\sin(\omega_b t)\sin(\omega t)
\end{aligned}
$$

Figure 1 shows the experimental setup. The signal from a strip line electrode passed through a 508.58MHz band pass filter and a variable attenuator. Two signals were fed into a hybrid and the difference of the two signals was amplified. The spectrum of this signal is analyzed. The oscillation amplitudes are expressed as the following equations in a unit of millimeters:

$$
X\approx\frac{V4\text{-}V2}{V2+V4}\frac{1}{0.063}
$$
$$
Y\approx\frac{V4\text{-}V2}{V2+V4}\frac{1}{0.051}\ .
$$

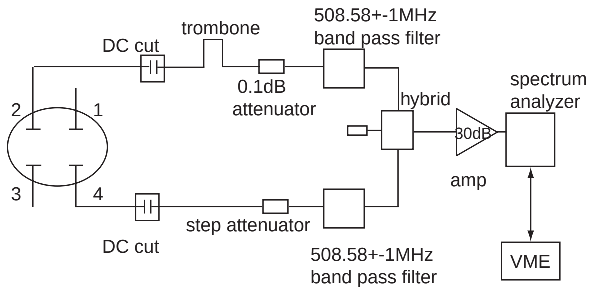

Fig. 1. Experimental setup.

By changing the position of the trombone (φ) attached to the strip line 2, the subtracted signal amplitude was measured. Figure 2 shows the result. There is minimum of -30dBm at a position of 423ps. The solid line shows a fitting curve using the formula of (1) and it agrees well with the measured points. Figure 3 shows the subtracted signal amplitude as a function of the attenuation attached to the strip line 4. The solid line also shows a fitting curve.

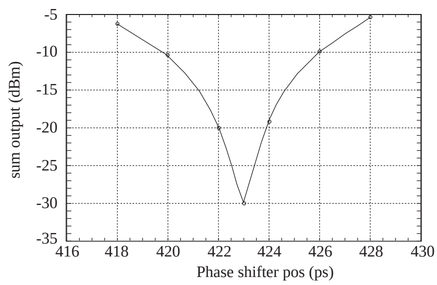

Fig. 2. The signal amplitude of the subtracted signal as a function of the position of the trombone.

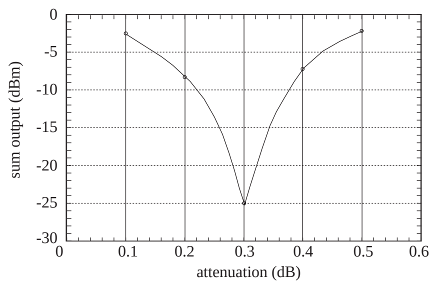

Fig. 3. The amplitude of the subtracted signal as a function of the attenuation of the strip line 4 signal.

2. Results

The spectrum of the subtracted signal was measured. Figure 4 shows an example of the spectrum on 17 Dec 1999. The beam current was 100mA and it was filled with 21 ten-bunch -trains. The settings of the spectrum analyzer were as follows; a span of 100kHz, a resolution bandwidth of 1kHz and a reference level of –10dBm. We can see three main peaks, one is the residual carrier signal at 508.58MHz, another corresponds to the horizontal betatron tune at 508.615MHz and the other corresponds to the vertical betatron tune at 508.655MHz. The amplitude of the carrier signal was adjusted to -25dBm one day before this measurement. The amplitude was increased to -15dBm. This may occur because the beam position was changed by COD correction, or because of the change of the attenuation or the phase of components such as a 28m-long BPM cables. The amplitude of the horizontal tune was -70dBm and that of vertical tune was -92dBm after passing through an amplifier with a gain of 30dB. The amplitude of the sum of the two signals was –0.5dBm. These values correspond to 0.17μm and 0.016μm for horizontal and vertical displacements at the position of the electrodes, respectively.

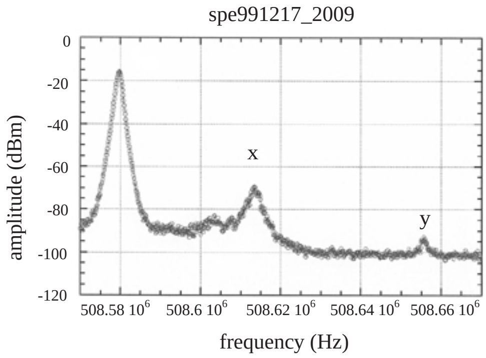

Fig. 4. The measured spectrum.
Span of 100kHz.

The value and the amplitude of oscillation at the betatron tune can be measured using a peak search function of the spectrum analyzer. To obtain higher resolution, the span and the resolution bandwidth were changed to 10kHz and 100Hz, respectively. Figures 5 and 6 show examples of spectra at the horizontal and the vertical tune, respectively. We can see side bands at 1.4kHz apart from main peak. These are sidebands caused by a synchrotron oscillation. From the Fig. 5, the amplitude of the synchrotron sideband was –7dB to the main peak. This amplitude is consistent to the calculated value under a finite chromaticity of ξx=6.7 and an energy spread of 10^{-3} [1]. From the Fig. 6, the amplitude of synchrotron sideband was –9dB to the main peak. This amplitude is also consistent with the calculation under a finite chromaticity of ξy=6.0 and an energy spread of 10^{-3}.

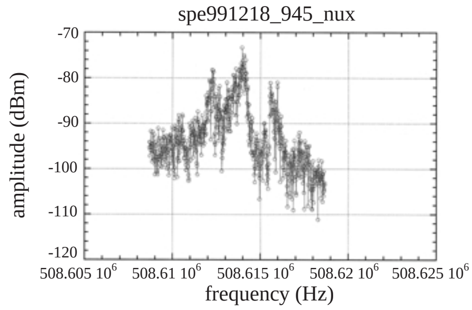

Fig. 5. The measured spectrum at the horizontal tune.
Span of 10kHz.

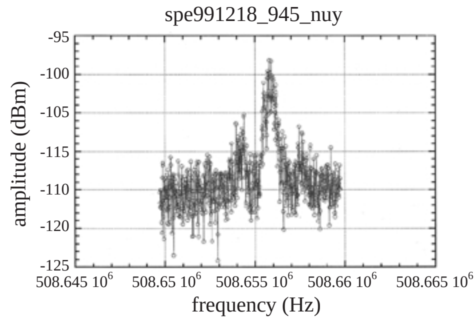

Fig. 6. The measured spectrum at the vertical tune.
Span of 10kHz.

The line width of the tune is determined by the damping time. The damping time of betatron oscillation is 8ms, which corresponds to the line width of 250Hz. But the measured width was about 1kHz. So the fast modulation of the tune was investigated using another spectrum analyzer (Sony Tektronix 3056). The settings of the analyzer were as follows; a span of 10kHz and a frame rate of 10ms/frame. We can see a tune modulation with a period of about 1Hz and an amplitude of about ±0.003. One candidate for this variation may be a modulation of the strength k of the quadrupole magnets. The tune shift is expressed as

$$\Delta\nu=\beta\ \Delta\kappa\ \Delta S\ /\ 4\pi\ *N.$$

For example, if $\Delta\kappa/\kappa=10^{-4}$, k=0.5, ΔS=0.5m, β=10m and number of quadrupoles N=100, then $\Delta\nu=2\ 10^{-4}$. In an actual case, things may be more complicated because there are many quadrupole families, different values of beta functions, some effect from the Eddy current in the vacuum chamber etc..

A change in the tunes during user time was observed

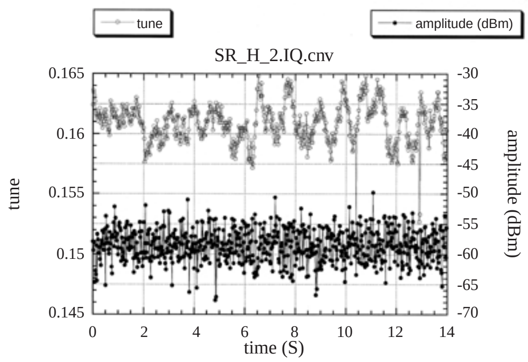

Fig. 7. The tune variation during 14 sec.

on 19 Dec 1999. Figure 8 shows the result. The horizontal tune was about 0.165 and had a fluctuation of about ±0.004 to the averaged value. The vertical tune was about 0.367±0.03. The beam injection was carried out at 8:00 and 20:00. The value of the tune at injection had fluctuated because the signal intensity had increased during the sweep of the spectrum analyzer, and this caused a misreading of the spectrum peak. Before and after injection, the gaps of insertion devices (IDs) were moved and the tunes were changed slightly. The variation in the tunes caused by IDs was less than 0.004.

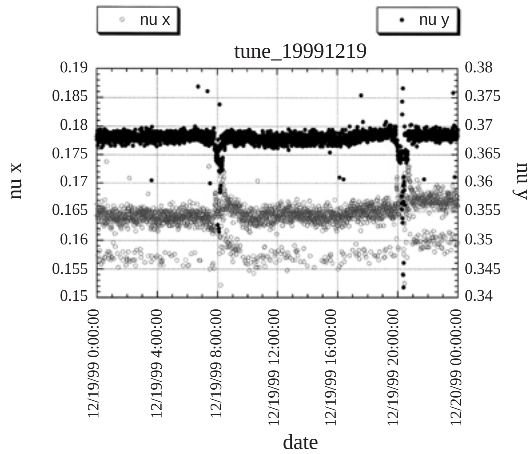

Fig. 8. The tune variation for one day.

3. Conclusion

The oscillation amplitude of the electron beam of the ring was observed at a frequency of betatron tunes. The value of the tunes fluctuated ±0.003. By measuring the fast changes in the tunes it was found that they fluctuated at about 1Hz. The variation in the tunes caused by the IDs was less than 0.004.

References

[1] T. Nakamura, SPring-8 Annual Report 1998 (1998) 121.