Observation of Ion Effects at the SPring-8 Storage Ring

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Abstract

The SPring-8 storage ring is the high brilliant light source facility with an electron beam energy of 8 GeV. It is observed that the beam lifetime and the vertical beam size of the SPring-8 storage ring extend peculiarly near uniform filling. The beam size also changes with the stored current, and at the maximum stored current of 100 mA in uniform filling it reaches about twice as large as the nominal size. To investigate the sources of the vertical expansion of the beam size, we measured the dependence of the γ-photon (bremsstrahlung) count on the beam filling pattern. Near the uniform filling the excess of the γ-photon count similar to the beam size expansion is observed, which may imply the ion trapping. We discuss the vertical expansion of the beam size induced by the trapped ion.

1 INTRODUCTION

The SPring-8 storage ring consists of 44 double bend achromat cells and the 4 magnet free straight sections of 30 m long. The revolution time is 4.79 μs and the harmonic number is 2436. At present the maximum stored beam current is 100 mA. The natural emittance is 6 nmrad and the coupling ratio is below 0.1 %.

The beam lifetime of the SPring-8 storage ring singularly extends by reducing empty buckets without an electron. The dependence of the vertical beam size on the filling pattern was investigated by the visible light interferometer [1]. The vertical beam size also changed similarly. Although the beam energy of the SPring-8 storage ring is 8 GeV and high, the Touschek effect can not be neglected since the emittance and the coupling are considerably small. Therefore we convinced that the extension of the beam lifetime is caused by the enlargement of a bunch volume.

To confirm whether the beam size extension is caused by ion trapping, we detected bremsstrahlung from the stored electrons. If ions are trapped by the electron beam, bremsstrahlung is expected to increase. In this paper we report the results of bremsstrahlung measurement and discuss the ion effects.

2 EXPERIMENTAL SETUP

The detector for bremsstrahlung was lead-glass counter [2] placed in front of a beam line. The photon pulses above the cutoff energy of 1 GeV were counted up for 10 seconds just after beam injection.

Horizontal and vertical beam sizes were measured by the visible light interferometer at the bending beam line. The beam sizes are estimated by the visibility of the interference of a photon passing through a double slit.

Betatron tune was observed by signals from a stripline monitor.

The beam current of the SPring-8 storage ring is always monitored by the DC current transformer (DCCT). The lifetime is estimated from the decay rate of the stored beam current observed by the DCCT.

We got the turn by turn data of the transverse oscillation of an individual bunch by observing a signal from a beam position monitor by means of the oscilloscope whose ADC is operated with the external clock synchronized to the electron bunch. We can get the amplitude spectrum of the transverse oscillation of each bunch by Fourier transformation of the observed signal.

3 MEASUREMENT RESULTS

The measurements were performed under the various beam filling patterns and stored currents. The filling pattern was adjusted by a gap length. The gap means continuous empty buckets. We performed the measurement for the filling patterns with a gap length of 10 ns, 30 ns, 40 ns and 1600 ns as well as a uniform filling. Bremsstrahlung is generated by collisions of stored electrons with not only trapped ions but also neutral residual gas molecules. The gap length 1600 ns is so long that ions are not trapped by the stored electron beam and no excess of the γ-photon are observed. Figure 1 shows an excess of the γ-photon counts of the filling pattern with a short gap over those with a gap of 1600 ns. The excess of γ-photon count is generated by the collisions with ions and clearly depends on the filling pattern. The count of γ-photon at a stored beam current of 100 mA as a function of the gap length shown in Fig. 2 indicates the exponential dependence on the gap length.

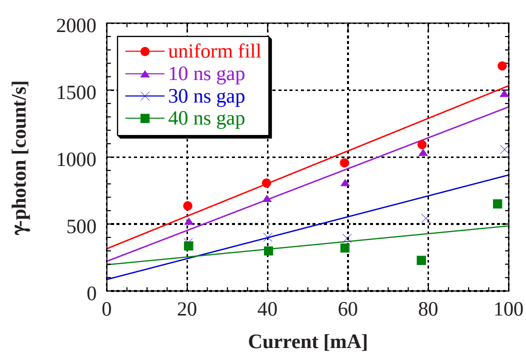

Figure 1: Count differences of the γ-photon in the contrast to that of the filling with a 1600 ns gap as a function of the stored beam current.

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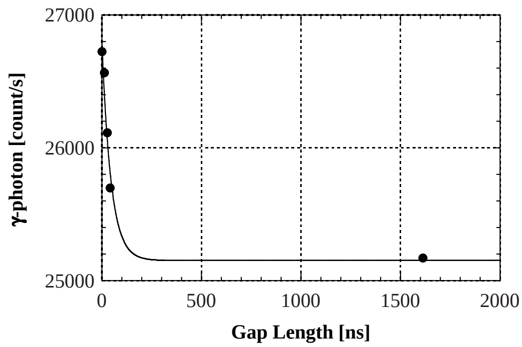

Figure 2: Counts of the γ-photons at a stored current of 100 mA as a function of the gap length.

Figure 3 shows changes in the vertical beam size with respect to the gap length and the stored beam current. The horizontal beam size is independent of the beam filling patterns. The change in the vertical beam size by the gap length in Fig. 4 is very similar to that of the γ-photon count in Fig. 2.

The fitting curve in Fig. 2 is described by

$$c_\gamma(g) = c_{\gamma 0} + A \exp\left(-g/g_\gamma\right), \quad (1)$$

where c_γ is the total γ-photon count, $c_{\gamma 0}$ the γ-photon count generated by the collisions of electrons with neutral gas molecules, g the gap length, g_γ the damping length of the count, and A the collision rate of electrons with trapped ions. At the SPring-8 storage ring the damping length g_γ is about 40 ns. On the other hand, the solid line in Fig. 4 indicates the supposed function for the vertical beam size as

$$\sigma_y(g) = \sqrt{\sigma_{y0}^2 + B^2 \exp\left(-2g/g_\sigma\right)}, \quad (2)$$

where σ_y is the total vertical beam size, σ_{y0} the nominal beam size, g_σ the damping length of the beam size, and B the excited beam size by trapped ions. Here we supposed that the extension of the beam size is independent of the radiation excitation. We adopt the root mean square to get the total beam size. The damping length of the vertical beam size g_σ is also 40 ns. This coincidence of the damping lengths means that the increase in the vertical beam size is proportional to the excess of the γ-photon count, i.e. the trapped ion density and the extension of the vertical beam size is caused by the ion trapping.

When ions were trapped by the electron beam, the betatron tune is expected to shift in proportional to the ion density [3]. The measured vertical betatron tunes are shown in Figs. 5 and 6. In Fig. 5 the decrease in vertical betatron tune by an increase in beam current is explained by the effect of the image current [4]. The parallel displacement of the tune corresponding to the filling pattern is attributed to the trapped ions. Figure 6 shows that the vertical betatron tune also changes with the same damping length as the γ-photon count and the vertical beam size.

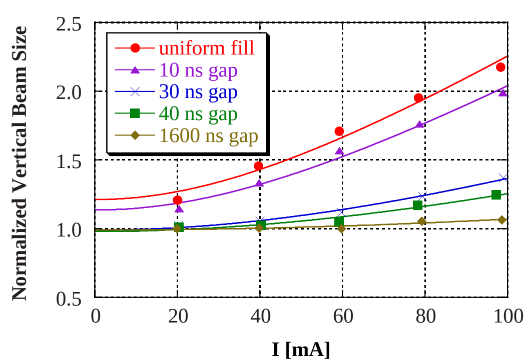

Figure 3: Vertical beam sizes as a function of the stored beam current.

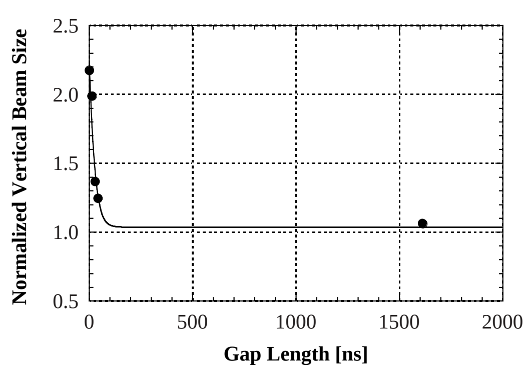

Figure 4: Vertical beam size at a stored current of 100 mA as a function of the gap length.

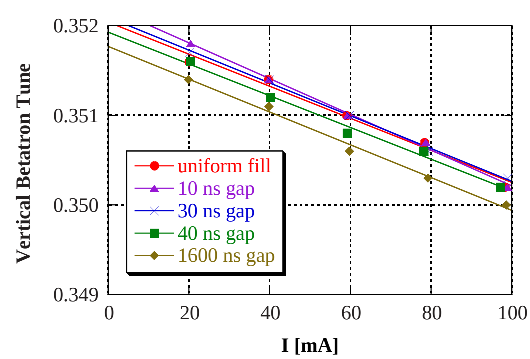

Figure 5: Vertical betatron tunes as a function of the stored beam current.

The measured beam lifetime at the maximum stored current is shown in Fig. 7. The beam lifetime goes shorter for the longer gap since the Touschek lifetime becomes shorter due to the increase in bunch current. A steep gradient of the beam lifetime for short gap lengths indicates that the electron beam oscillates not only coherently but also incoherently. The incoherent oscillation results in the beam size enlargement.

An oscillation of an individual bunch was measured by the bunch beam position monitor, and its spectrum is obtained through the Fourier transform. The spectrum around the vertical betatron tune in Fig. 8 shows the apparent dependence on the gap length. As expected, the peak ampli-

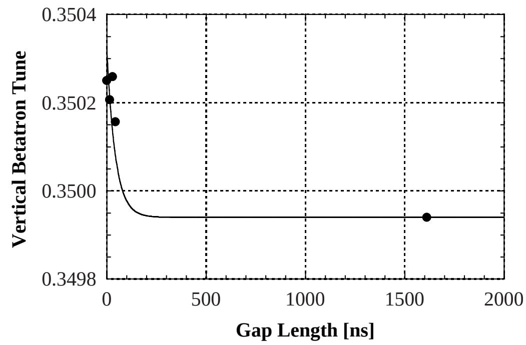

Figure 6: Vertical betatron tunes at the stored current of 100 mA as a function of the gap length.

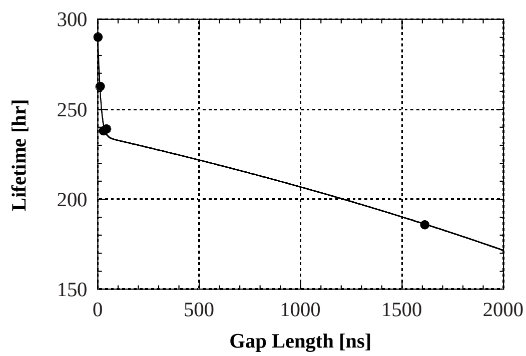

Figure 7: Beam lifetimes at the stored current of 100 mA as a function of the gap length.

tude of the excited oscillation also exponentially decreases with the same damping length as the γ-photon count.

4 DISCUSSIONS

The coherent betatron tune shift induced by the trapped ions is given by [3]

$$\Delta\nu_{x,y} = \frac{r_e C \beta_{x,y} Q_{ion} \lambda_{ion}}{4\pi\gamma\sigma_{x,y}\left(\sigma_x + \sigma_y\right)}, \qquad (3)$$

where r_e is the electron classical radius, C the circumference of a storage ring, $\beta_{x,y}$ the beta function respectively for horizontal and vertical motion, and Q_{ion} and λ_{ion} the charge of an ion (in units of the electron charge) and the line density, respectively. At the SPring-8 storage ring, in spite of the high beam energy of 8 GeV, due to the small vertical beam size the coherent betatron tune shift in the vertical motion can be observed. Since the coherent betatron tune shift is proportional to the ion density as given by Eq. (3), the tune shift has the exponential dependence on the gap length as well as the γ-photon count.

The trapped ions can also induce an instability, where the electron beam and the ion cloud are oscillating with respect to each other. The growth rate α for the instability is estimated to be proportional to the coherent tune shift [5, 6] as

$$\alpha = 2\pi^2 f_{rev} \Delta\nu, \qquad (4)$$

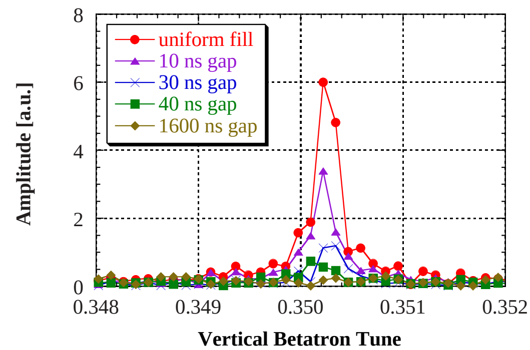

Figure 8: Amplitudes of the excited vertical betatron oscillation at the stored current of 100 mA.

where f_{rev} is the revolution frequency of a stored electron beam. Then the amplitude of the excited oscillation is also proportional to the trapped ion density. Experimental results shown in Fig. 8 support to this theory.

If the excited oscillation of the electron beam occurs, the beam size becomes larger due to the tune spread. This extension of a beam size is proportional to the amplitude of the excited oscillation, and then to the ion density. Thus the ion trapping gives rise to the extension of the vertical beam size.

It is well known that high chromaticity effects damping of the instabilities [7]. The vertical beam size extension could be partly suppressed by increasing the chromaticity.

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