ENERGY WIDENING AND SKEW QUADRUPOLE FIELD IN NEWSUBARU

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Abstract

The beam sizes were measured by observing SR radiation with a CCD camera. The horizontal size blows up as the stored current increases in the single bunch mode and this is explained by microwave instability with the coasting beam approximation. The vertical size is determined by linear coupling and the distribution of skew quadrupole field is measured.

1 INTRODUCTION

The newSUBARU storage ring[1] has twelve normal bending magnets (BM's), six inverse bending magnets(BI's), two ∼15-m long straight sections (LSS's) and four ∼4-m short straight sections (SSS's) as seen in Fig.2. The designed horizontal emittance (ϵ_x) is 38 nm at 1 GeV and the vertical one (ϵ_y) is estimated as less than 1 nm from the spot size of the SR monitor. In order to correct the linear coupling resonance, two skew quadruple magnets (SkQ_3, SkQ_4) at the long straight section (see Fig.2) were used to obtain the minimum vertical beam size. But this correction is not used in user times because the beam life becomes shorter.

2 BEAM SIZE MEASUREMENT

Visible light from synchrotron radiation from the center of BI and the entrance of BM is observed by the CCD camera through the mirror(Au-coated copper block) and a quartz window. The source point is selected by adjusting the focus and the TV spot is analyzed by a PC with the scale of 0.073 mm / pixel. The spot of the source point, BM, has halos or asymmetric shapes due to the spill from the upstream source point, BI. The root-mean-square (rms) beam size is determined by ignoring these halos.

3 BEAM SIZE IN SINGLE BUNCH

The rms beam size is the sum of the purely betatron oscillation term and the contribution from energy spread. The energy spread always increases as the stored current (I_b) increases in single bunch mode and this energy spread is caused by the so-called microwave instability. Once this instability occurs, the stable energy spread is almost proportional to $I_b^{1/3}$. In newSUBARU the threshold current would be smaller than 1 mA, the square of horizontal beam sizes are plotted against $I_b^{2/3}$ as shown in Fig.1, that is,

$$\sigma_x^2 = B + (D_x * A)^2 * I_b^{2/3}, \qquad \sigma_p = A * I_b^{1/3},$$

where D_x is the horizontal dispersion (measured value : 0.31 m), σ_p is the rms of $\Delta p/p$ and p is the momentum of the electron beam. From this figure we have $B = 9.5 \times 10^{-2}(mm^2)$, $(D_x * A)^2 = 3.5 \times 10^{-2}(mm^2/mA^{2/3})$, $A = 6.0 \times 10^{-4}(mA^{-1/3})$ for the stored current larger than 2 mA. Setting $\sigma_p = 4.7 \times 10^{-4}$ (designed natural spread), the threshold current is estimated as 0.48 mA. From this, the horizontal beam size under the threshold is $\sigma_x^2 = 0.12(mm^2)$ and the natural emittance is calculated as $\epsilon_x = 38(nm)$, where the envelope functions are assumed to be the designed values, $\beta_x = 2.49(m)$. The accuracy of this value would be ± 1 nm if the error comes from reading error of 1/2 pixel.

The horizontal beam size of the stored beam to be less than 1 mA was also measured by scraping the beam at the vacuum chamber of the injection septum magnet with the injection bump magnets. From the magnitude of the bump orbit (19.2 and 19.8 mm) at 16.6 % and 50 % beam loss, the ϵ_x is estimated as 36 nm using β_x = 10 (m) at this point. Assuming the error source is the bump shape, the accuracy is estimated as ± 10 %.

Similarly we have $B = 2.2 \times 10^{-2}(mm^2)$, $(D_y * A)^2 = 1.6 \times 10^{-3}(mm^2/mA^{2/3})$ for the vertical size.

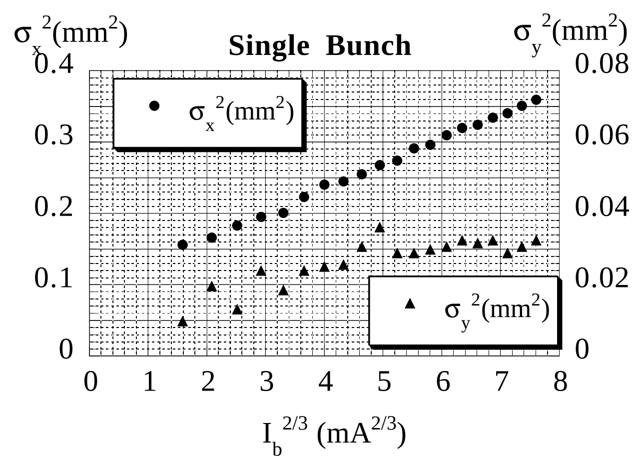

Figure 1: Beam size versus stored current.

4 MICROWAVE INSTABILITY

Energy widening or bunch-lengthening due to microwave instability or turbulence is calculated using the coasting beam approximation[2]. This gives,

$$\sigma_p^3 = \frac{\nu_s I_b}{(2\pi)^{1/2} E \alpha_p^2} |Z/n|,$$

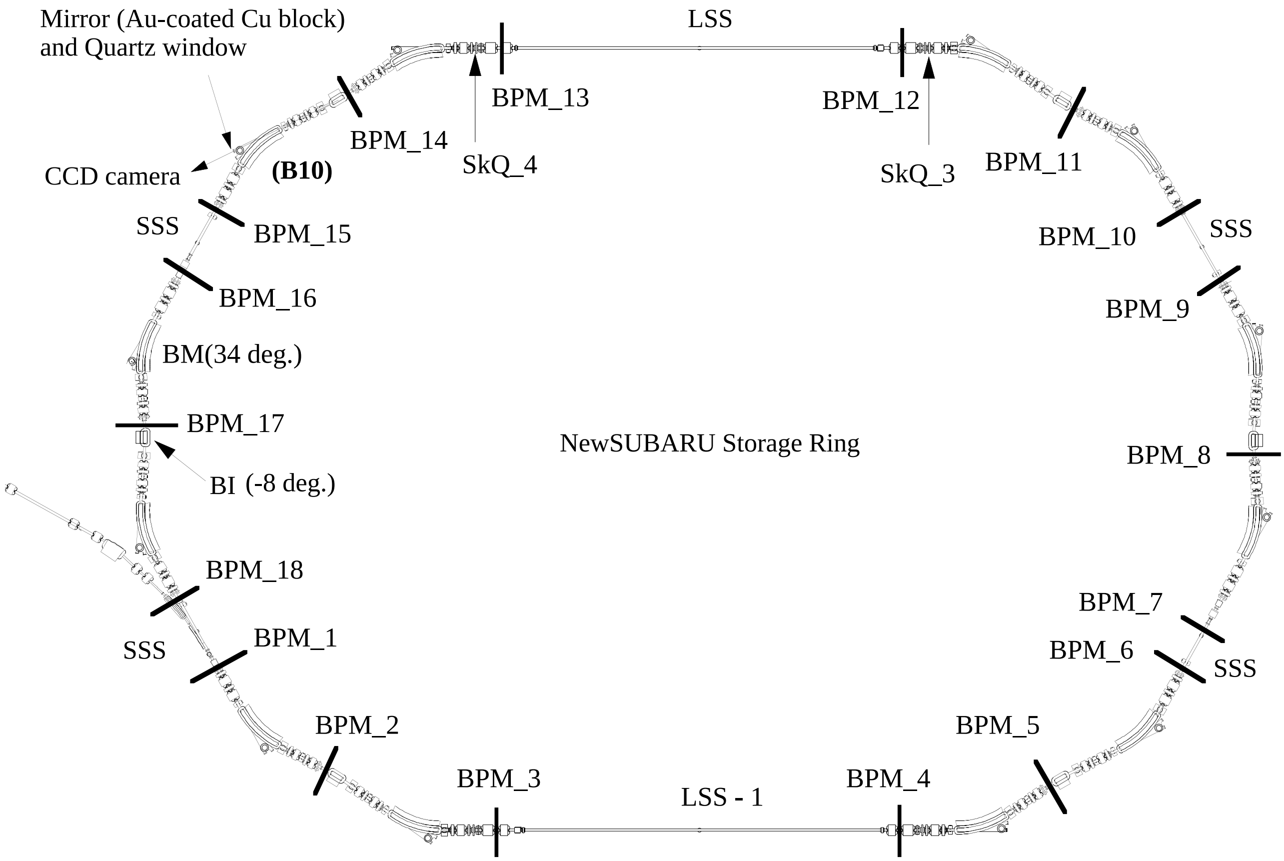

Figure 2: Plane view of the ring.

where ν_s is the tune of synchrotron oscillation at the stored current of 0 A, E is the beam energy in eV and α_p is the momentum compaction factor. For the measured ν_s is $\simeq$ 0.0023, the above equation gives $\sigma_p^3 = 6.4 \times 10^{-10} I_b(mA) * |Z/n|(\Omega)$. Comparing the value of A obtained in the previous section, we have $|Z/n| = 0.34(\Omega)$.

The cavity is the HOM-damped 500-MHz cavity developed at KEK and ISSP, Univ. of Tokyo[3] (effective broadband impedance is ∼0.22 Ω) and the above result is compared with the numerical calculation by the program ZAP[4] as shown in Fig.3. In ZAP, free space, space charge and resistive wall effects are neglected. Assuming the broadband impedance in the ring is 0.1 Ω, the agreement is very good.

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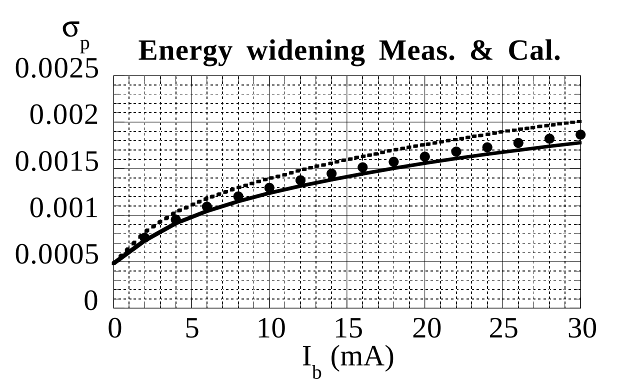

Figure 3: Relative momentum spread versus stored current. circle:data from beam size, lines:ZAP calculation with effective broadband impedance of cavity is 0.22 Ω and $|Z/n|_{BB}^{ring}$=0(real) or 0.1 (Ω)(dotted).

5 SKEW QUADRUPLE FIELD SEARCH

There are 18 beam position monitors to measure the closed orbit distortion (COD) as seen in Fig.2. At first, COD was corrected using the steering magnet so that the maximum value is about 20 μm or less at the both horizontal and vertical planes. Then the vertical local bump (+ 2 mm) was made at two adjacent beam position monitors (BPM's) (for example BPM_1 - _2) on the basic orbit, and the horizontal COD was measured after that. The horizontal COD shift were caused by the effective horizontal steering fields (kicks), which were caused by the coupling between the vertical COD and skew quadruple fields. To find the most effective contribution, the energy change corresponding to the change of the orbit length is included in the COD analysis. The main sources of the skew quadruple field are the tilts of quadruple magnets, so the positions of kicks would be distributed randomly along the ring. But to make the problem simple, the most effective single kick, its position and strength, for each COD were searched. The measurement and analysis were done for 18 places along the ring. As seen in Fig.4, the single kick solution is not complete to find the exact distribution of skew quadrupole field, but it must show the essential aspect of this distribution.

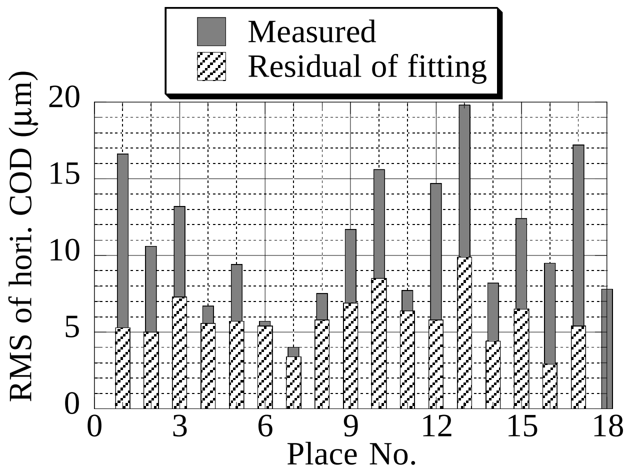

Figure 4: Rms values of horizontal COD. Measured and residual after single kick fitting.

6 LINEAR COUPLING RESONANCE

The amount of single kick for each place is shown in Fig.5. The driving term of the linear coupling difference resonance was calculated using the following equation[5],

$$\lambda\, e^{i\chi} \,=\, (4\pi)^{-1} \sum_j \{(\beta_x\, \beta_y)^{1/2}\, g\, e^{i\phi}\}_j\,,$$

$$\phi \,=\, \psi_x \,-\, \psi_y \,-\, \theta\Delta, \quad \Delta = \nu_x - \nu_y - p,$$

where j denotes the location of a skew quadrupole field component, $g = l\,(\frac{\partial B_x}{\partial x})/(B\rho)$, l is an effective length of each component, β_x and β_y are the horizontal and vertical beam envelope functions, ψ_x and ψ_y are the phases of betatron oscillation with the tunes (wave numbers) ν_x and ν_y, θ is an azimuthal angle, and p is the harmonic number of the Fourier component of the skew quadrupole field. The result is,

$$\lambda \,=\, 5.35 \times 10^{-3}, \quad \chi \,=\, -1.3\,(rad.),$$

where the origin of phases and angle is the center of the opposite long straight section (LSS-1) in Fig.2.

In the other hand, the parameters of the correcting skew quadrupole magnets are given in Table 1. These values give

Table 1: Parameters of SkQ.

Name	g	β_x	β_y	ψ_x	ψ_y	θ
unit	1/m	m	m			
SkQ_3	-0.00492	6.97	30.2	18.3	6.10	2.69
SkQ_4	0.00369	6.97	30.2	21.2	7.85	3.60

the correcting terms of the coupling resonance as,

$$\lambda \,=\, 5.30 \times 10^{-3}, \quad \chi \,=\, -1.34 + \pi.$$

The strengths of λ are almost same and the differences in χ is almost π. That is, the single kick solution for the horizontal COD shift due to the vertical bump orbit gives the distribution of the skew quadrupole field.

ϵ_y is then ∼0.6 nm from the linear coupling at $\Delta = \nu_x - \nu_y - 4 = 0.035$. Considering that the resolution of the SR monitor is $\simeq$ 0.09 mm, σ_y^2 becomes 0.0069 mm^2 from 0.015 mm^2 at 0 mA given in Fig.1 and this gives ϵ_y = 0.65 (nm) using β_y = 10.6 (m).

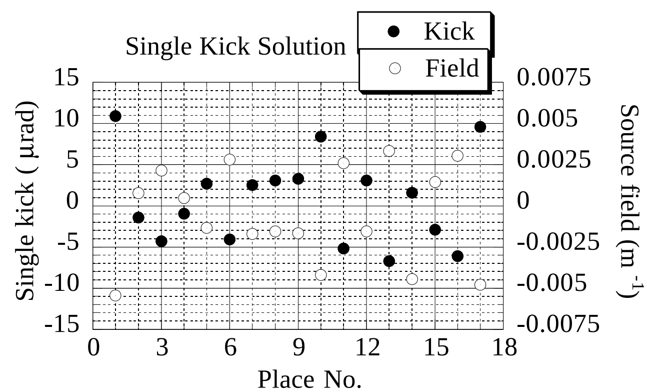

Figure 5: Strength of single kick solution.

7 ACKNOWLEDGMENTS

The authors wish to thank all the members of the accelerator, safety and utility group of SPring-8 for the stable operation of NewSUBARU.

8 REFERENCES

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