IMPROVEMENT OF BEAM LIFE TIME DUE TO OPTIMIZATION OF VERTICAL ORBIT AND CORRECTION OF MODULATION OF VERTICAL BETA FUNCTION AT NEWSUBARU

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Abstract

An optimization of the vertical beam orbit improved the beam life time of NewSUBARU by about 40%. An additional 5% improvement was obtained by a correction of a modulation of the vertical beta function. They enlarged the effective acceptance in vertical direction and reduced a beam loss due to the Rutherford scattering with the residual gas.

1 INTRODUCTION

The synchrotron radiation facility NewSUBARU [1] is an EUV and Soft X-Ray light source at the SPring-8 site. The Laboratory of Advanced Science and Technology for Industry (LASTI) at the Himeji Institute of Technology is in charge of its operation collaborating with SPring-8. The ring has two operation modes: In the 1.5 GeV mode, the beam is accelerated to 1.5 GeV and stored. In the 1.0 GeV top-up mode, the beam current is kept at 250±0.15mA by an occasional injection with the undulator gap closed. The beam life and the number of electrons allowed by the radiation safety rule limit the stored beam current.

At the energy of 1GeV, with stored beam current of 250mA, mainly two kinds of beam lives contribute to the total life. One is the beam life came from the Rutherford scattering of beam electrons with the residual gas molecules that is estimated to be about 6 hrs. Another was Touschek beam life, estimated to be 12 hrs [2]. We paid great efforts to improve the vacuum pressure in these some years. It helped to push up the former beam life to the present level. However we also used our time to enlarge the effective beam acceptance, which also improved the former beam life. Here we report the optimization of the vertical orbit (COD) and the correction of vertical beta function, which enlarged the beam acceptance and improved the beam life by about 40% and 5%, respectively.

2 RUTHERFORD SCATTERING

The Rutherford scattering in vertical direction mainly determines the present beam lifetime, where an electron scattered with residual gas molecules is lost at the location of the minimum aperture. The cross section of Rutherford scattering σ_R with vertical critical angle ϕ_C is approximated by the equation

$$\sigma_R = 2\pi r_0^2 (Z/\gamma \phi_C)^2. \qquad (1)$$

Here r_0, Z and γ are classical radius of electron, nuclear number of gas nucleus and the Lorentz factor, respectively. The critical angle is roughly given by

$$\phi_C = (a_{YC}/\sqrt{\beta_{YC}})/\sqrt{\beta_{YAV}} \qquad (2)$$

Here a_{YC} and β_{YC} are vertical mechanical acceptance and the vertical beta function at where the effective acceptance ($a_{YC}/\sqrt{\beta_{YC}}$) takes the minimum. The β_{YAVE} is the average of vertical beta function. Fig.1 shows the design values of a_{YC} and $\sqrt{\beta_{YC}}$. It is clear that the edges of bending magnets facing to the dispersion free sections are the critical locations, where the effective acceptance was minimum. At these locations the designed values are, $a_Y = a_{YC} = 10$ mm and $\beta_Y = \beta_{YC} = 24$ m. The lifetime by the Rutherford scattering τ_R is proportional to $1/\sigma_R$. This means that

$$\tau_R \propto a_{YC}^2/\beta_{YC}. \qquad (3)$$

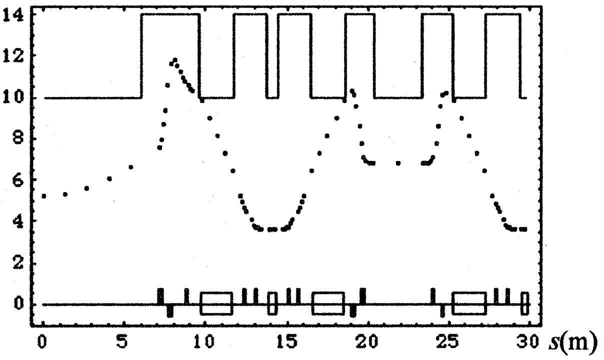

Figure 1; Vertical mechanical acceptance a_Y (solid line in mm) and the beam envelope ($2\sqrt{\beta_Y}$; dots in $\sqrt{\text{m}}$). The large and small white boxes represent locations and lengths of normal bending magnets and inverse bending magnets. The shaded blocks are quadrupole magnets.

3 OPTIMIZATION OF BEAM ORBIT

If the beam center is displaced at the critical location by ΔY in vertical direction, the a_{YC} is reduced to $a_{YC} = a_{YC0} - \Delta Y$. Here a_{YC0} is the ideal a_{YC} when $\Delta Y = 0$. The beam life became

$$\tau_R/\tau_{R0} \propto (a_{YC0} - \Delta Y)^2/a_{YC0}^2 \approx 1 - 2\Delta Y/a_{YC0} \qquad (3)$$

for a small ΔY.

We produced a vertical local bump, that is an intentional ΔY, at the edges of bending magnets and measured the lifetime with respect to ΔY. The height of the bump was monitored at the beam position monitor (BPM) nearby. There are 12 critical locations in the whole ring, 8 face to the short straight section (SSS) and 4 face to the long straight section (LSS). Each of them is referred by a number of BPM nearby, for example as 'BPM16'. Fig.2 shows a typical result of the measurement of beam life varying ΔY, in other wards an aperture survey. About 15% improvement of the lifetime was obtained by the 1.2mm displacement of ΔY_{BPM}. Here ΔY_{BPM} is a displacement at the BPM. The relation between ΔY_{BPM} and ΔY is calculated from the linear optic model and listed in Table 1.

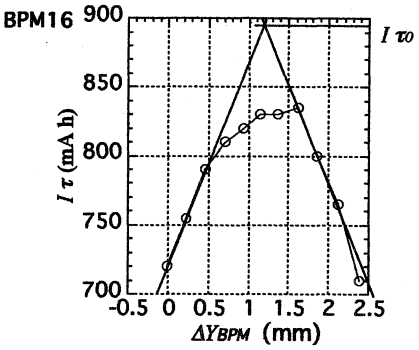

Figure 2: A typical result of the vertical aperture survey. Vertical axis is the beam current times the lifetime.

Table 1: Relation between the displacement at the BPM: ΔY_{BPM} and at the critical location: ΔY, produced by the local bump orbit.

Location (BPM#)	**$\Delta Y/\Delta Y_{BPM}$**	**straight section**
6, 9, ,15, 18	1.4	SSS
1, 7, 10, 16	1.25	SSS
3, 12	1.0	LSS
4, 13	1.0	LSS

The flat area at the top of Fig.2 meant that after the optimization of the orbit at this location (BPM16) there appeared a tolerance in vertical aperture because of the displacement at the other critical location. The slope at the top was thought to be an effect of the spill of the local bump orbit.

The expected slope calculated from Eq.(3) is

$$d(I\tau_R)/d\Delta Y_{BPM} = \pm 2\ (I\tau_{R0})(\Delta Y/\Delta Y_{BPM})/\ a_{YC0}$$
$$= \pm 220 \text{ mAhr/mm} \qquad (4)$$

here we used $I\tau_{R0}$=895 mAhr, $\Delta Y/\Delta Y_{BPM}$=1.25, and a_{YC0}=10mm. The τ_{R0} is a lifetime with perfect optimization, represented by the peak of the triangle made of extrapolation lines shown in Fig. 2. On the other hand the observed slope was $d(I\tau)/d\Delta Y_{BPM} = \pm 140$ mAh/mm, smaller than the expected. This difference suggests a contribution of other kind of lifetime than τ_R. In that case

$$d(I\tau)/d\Delta Y_{BPM} = (d\tau/d\tau_R)\ [d(I\tau_R)/d\Delta Y_{BPM}]$$
$$= \pm 2\ (\tau_0/\tau_{R0})\ (I\tau_0)(\Delta Y/\Delta Y_{BPM})\ a_{YC0}\,. \qquad (5)$$

Using the new value $I\tau_0$=895 mAhr, τ_0/τ_{R0} was calculated to be τ_0/τ_{R0}=0.64. The other kind of the lifetime was about twice of τ_{R0}.

We optimized the beam orbit at the critical locations and the total beam lifetime was improved from 2.74 hrs to 3.80 hrs (about 40% increase) with the stored beam current of 250mA. The required orbit displacements are shown in Fig.3

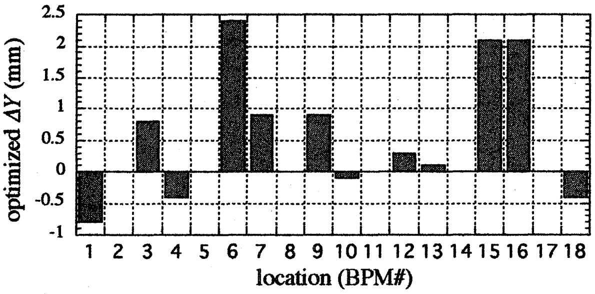

Figure 3: Optimized vertical displacement at the critical locations (at the edge of bending magnets).

4 MODULATION OF BETA FUNCTION

After the optimisation of the beam orbit we expect that there would be no flattop at any critical location because the a_Y and β_Y are almost the same at these locations. However there still exists a flattop at many of locations. Fig.4 shows a plot of the flattop width with respect to the vertical betatron phase. The flattop width propagated around the ring like a modulation of beta function with harmonic number of 4, roughly the twice of the betatron tune (ν_Y=2.2).

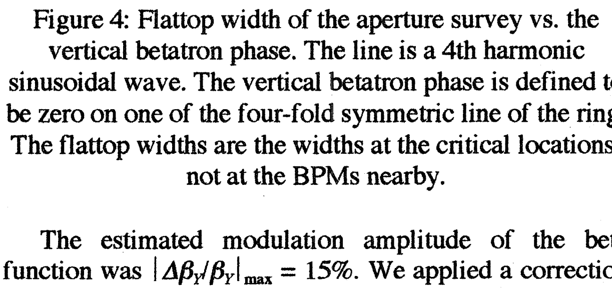

Figure 4: Flattop width of the aperture survey vs. the vertical betatron phase. The line is a 4th harmonic sinusoidal wave. The vertical betatron phase is defined to be zero on one of the four-fold symmetric line of the ring. The flattop widths are the widths at the critical locations, not at the BPMs nearby.

The estimated modulation amplitude of the beta function was $|\Delta\beta_Y/\beta_Y|_{\max}$ = 15%. We applied a correction of asymmetric modulation of the beta function (amplitude of 7%) using trim windings on the quadrupole magnets.

Finally we obtained about more 5% improvement of the total lifetime.

5 DISCUSSION

The required displacements shown in Fig.3 was larger than the expected from the measurements of heights of the BPMs and the vacuum chambers. We do not have good explanation for this inconsistency.

The optimization of the orbit and the correction of the modulation of the beta function changed the distribution of the radiation level around the ring. The highest radiation level had been observed at BPM6 since the first commissioning in 1998. Investigation of the mechanical structure around this area did not give any explanation of it. After the optimization and the adjustment the radiation level at BPM6 became low and now there exists no location of high radiation level.

The other lifetime than $I\tau_{R0}$ is thought to be mainly a Touschek lifetime. An intentional expansion of the beam emittance improved the total lifetime by about 30%. This support our hypothesis.

6 SUMMARY

The vertical orbit optimisation improved the beam lifetime by about 40%. More 5% improvement was obtained by the correction of the non-symmetric modulation of the vertical beta function.

6 REFERENCES

[1] A. Ando *et al.*, J. Synchrotron Rad. 5, 342-344 (1998).
[2] S. Hashimoto *et al.*, Presentation at the Meeting of Japanese Physics Society, Sendai, March, 2003.