LOW ENERGY INJECTION SCHEME OF COMPACT ELECTRON STORAGE RINGS

K. Nakayama and Y. Gomei
Research and Development Center, Toshiba Corp.
4-1, Ukishima-cho, Kawasaki-ku, Kawasaki
Japan

Abstract

Multi-turn injection scheme was studied for small electron storage rings with a low energy injector. The number of the injected turns was calculated by estimating beam loss at the inflector wall considering the injected beam emittance and the ring acceptance. Beam slice due to energy spread of the injected beam was also considered, since small rings have non-zero energy dispersion at the injection point. The injected turns are generally increased in small rings because of low momentum dispersion and small β-function at the injection point. For example, if the energy dispersion and the β-function at the injection point are 1 m and 2 m, respectively, and the energy spread of the injected beams is ±1 %, the injected turns estimated are 10 with other conditions realistically assumed. These results show that a suitable injector of 100 mA will supply a stored current of some hundreds mA by single multi-turn injection in compact storage rings.

Introduction

Several proposals [1∿4] have been reported to make electron storage rings compact and economical. The important technology applied in these proposals is to perform both acceleration and storage in one ring. The point in this case is how much current can be injected into synchrotrons by single multi-turn injection. If this current is enough, we can rely on low energy injectors. If this is not the case, multicycle injection becomes necessary [4]. This requires higher injection energy so that the beam is shrinked by radiation damping within the period between injections.

It has been reported that SURF-II at NBS achieved the stored current of 180 mA at 284 MeV with using the low energy (10 MeV) microtron as an injector [5]. It is obvious that single multi-turn injection is applied in this case. A way to increase the stored current with this injection scheme would be to increase the current of an injector. An answer to this is to use linacs as an injector. Unfortunately, the energy spread of the linac beam is usually larger than the one of the microtron, and small rings usually have non-zero energy dispersion at injection points. It, therefore, is interesting for us to study how many turns of the beam can be injected by single multi-turn injection depending on the energy spread of the injected beam.

Multi-turn injection

In multi-turn injection, local orbit distortion is provided by pulsing magnets located upstream and/or downstream from the injection point. Beams are continuously injected until the orbit distortion decreases to zero in the horizontal direction. Fig. 1 shows the effect of energy deviation of the closed orbit distortion (COD) at the injection point. As is well known, the orbit distortion, x_η, due to energy deviation is given by

$$x_\eta = \eta \cdot (\Delta E/E)_{inj} \quad , \qquad (1)$$

where η is the energy dispersion function at the injection point and $(\Delta E/E)_{inj}$ is the energy deviation ratio of the injected beam. The amplitude of β-tron oscillation of the injected beam, X_β, is given by

$$X_\beta = X_{inj} - (X_0 \pm x_\eta) \quad , \qquad (2)$$

where X_{inj} represents the position of beam injection and X_0 the position of the distorted orbit with no energy deviation. The amount of injected beam is given by

$$I_{inj} = I_0 \sum_{i=1}^{n} \varepsilon_i$$
$$= I_0 n_{eff} \qquad (3)$$

where I_0 is the injector current and ε_i is the injection efficiency for each injection turn i. The n_{eff} thus defined is the effective turns of the beam injected by single multi-turn injection.

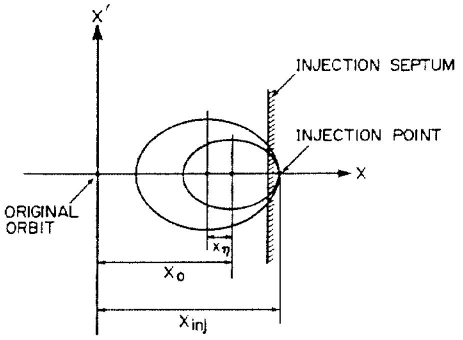

Fig. 1. The effect of the energy deviation of the injected beam expressed in the phase space.

To determine the value of ε_i, beam slice at the septum was estimated for each injection turn by taking into account the variation of X_β until the distorted orbit recovers its original position. The distribution of the injected beam was assumed to be Gaussian in X, X' and E. Fig. 2 shows how the beam is sliced by the injection septum while performing β-tron oscillation expressed as an ellipse in the phase space. The value of ε_i is given by the ratio of the beam which is alive after the final turn of the i-th beam.

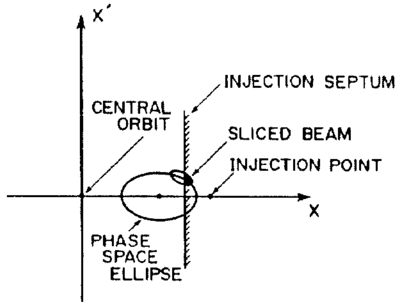

Fig. 2. Beam motion in the phase space of β-tron oscillation.

Table 1 shows the conditions applied in this calculation. The twiss parameter at the injection point, α_X, was taken to be zero, meaning that beam oscillation along the flat ellipse in the phase space was assumed at the injection point. It is evident that the ellipse is inclined depending on lattice designs. It is noteworthy that the general trends of the results shown in this paper is still valid for the case with the inclined ellipses. We also assumed that the beam with the relative energy deviation of more than 2 % is lost somewhere in the ring because of large COD.

Table 1 Parameters of the ring and the injector used in this calculation.

a) Ring parameters	
Twiss parameter at the injection point	$\alpha_X = 0$
Energy acceptance	±2 %
Position of inflector septum	X = 33 mm
Position of injection	X = 40 mm
b) Injector beam parameters	
Beam diameter	4 mm
Angle dispersion	±1 mrad

Results

Fig. 3a shows the dependence of n_{eff} on the tune value of β-tron oscillation in case of $\beta_X = 2$ m where β_X is the twiss parameter. The axis of abscissa is $\delta\nu_X$ which is the decimal fraction of the tune of the horizontal β-tron oscillation. There exists two peaks in n_{eff}: a broad one around $\delta\nu_X = 0.25$ and narrower one around $\delta\nu_X = 0.4$. These tendency is quite similar for the two x_η at the injection point. We thus chose the ring operation point at $\delta\nu_X = 0.25$ which is also convenient to avoid beam loss due to resonance in β-tron oscillation.

Fig. 3b shows the dependence of n_{eff} on the speed by which the distorted orbit for injection is moved to its original position. This speed is called a collapsing rate in this paper. The value of n_{eff} has a maximum at v = 2.25 mm/turn in this study. It should be noted that this condition needs to be changed when the parameters of table 1 and $\delta\nu_X$ are different.

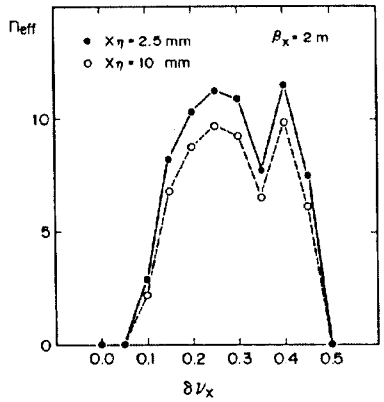

Fig. 3a. n_{eff} as a function of the tune number $\delta\nu_X$ where $\delta\nu_X$ is given by ν_X = integer $\pm\delta\nu_X$.

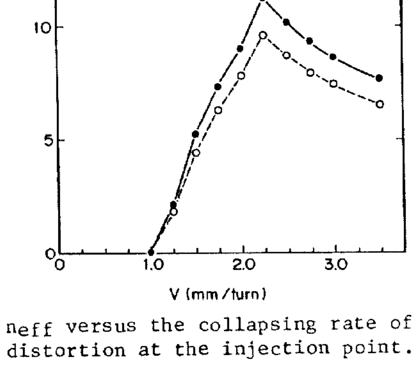

Fig. 3b. n_{eff} versus the collapsing rate of the orbit distortion at the injection point.

Fig. 4 shows the dependence of n_{eff} on the orbit distortion shown in Eq. (1) for the three different β_X values. It is natural that the value of n_{eff} is the highest at $x_\eta = 0$ meaning $\eta = 0$ (an achromatic straight section) or $(\Delta E/E)_{inj} = 0$. The n_{eff} value at $x_\eta = 0$ is 11.7 to 9.6 for $\beta_X = 2$ to 12 m. When x_η is increased, n_{eff} is monotonically decreased. The n_{eff} value at $x_\eta = 40$ mm is still 7.1 to 5.6 for $\beta_X = 2$ to 12 m. This is because beam slice was only estimated at the injection septum. The n_{eff} value for large x_η will be more decreased, if beam slice at the location other than injection septum, where η is large, is taken into account.

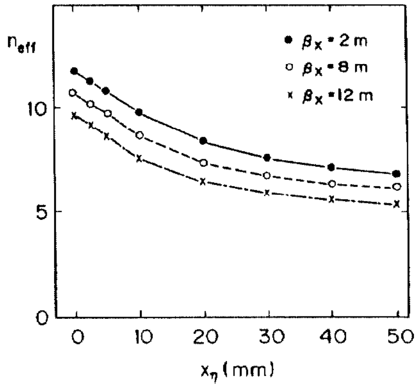

Fig. 4. The dependence of n_{eff} on the orbit distortion due to beam energy dispersion at the injection point.

Discussion

The stored current I_S in the ring is given by

$$I_s = I_0 n_{eff} \varepsilon_{cap} \qquad (4)$$

where ε_{cap} is the beam capture efficiency in bunching process. It has been reported that the capture efficiency of the order of 50 % can be achieved by utilizing detuning of RF cavity in Electron Synchrotron [6]. Suppose $(\Delta E/E)_{inj} = 1$ %, $\eta = 4$ m and $\beta_X = 8$ m, which are considered to be typical conditions for low energy linacs and normal conducting compact storage rings, n_{eff} is 6.3 from Fig. 4. If the linac current is assumed to be 100 mA, I_S given by Eq. (4) is 315 mA. It is very important to reduce the value of $(\Delta E/E)_{inj}$ in this case, because the beam loss at the location other than the injection septum can be expected.

In case of superconducting compact rings, this situation is much more alleviated, because η and β_X are smaller. If we choose $\eta = 1$ m and $\beta_X = 2$ m as an example, n_{eff} is 10 from Fig. 4. The stored current in this case is 500 mA.

In conclusion it was shown that the beams of several hundred mA can be effectively injected with single multi-turn injection from a low energy linac in compact storage rings.

Acknowledgement

We would like to thank S. Sukenobu and H. Yamato for valuable discussions.

References

[1] Y. Miyahara, K. Takata and T. Nakanishi, "Superconducting Racetrack Electron Storage Ring and Coexistent Injection Microtron for Synchrotron Radiation", Internal report, ISSN 0082-4798, Ser. B, No. 21, pp. 1-29, September 1984.

[2] A. Heuberger, "Comparison of different X-ray sources: X-ray tubes, laser induced plasma sources, compact and conventional storage rings", SPIE, 448, PP 8-16, 1983.

[3] U. Trinks, F. Nolden and A. Jahnke, "The Table-Top Synchrotron Radiation Source "KLEIN ERNA" ", Nucl. Instr. and Meth. 200, pp 475-479, 1982.

[4] N. Takahashi, "Compact Superconducting SR Ring for X-ray Lithography", Nucl. Instr. and Meth. B24/25, pp 425-428, 1987.

[5] G. Rakowsky, "Coherent Synchrotron Relaxation Oscillation in an Electron Storage Ring", IEEE Trans. Nucl. Sci. NS-32, pp 2377-2379, 1985.

[6] T. Katayama, T. Fukushima and T. Yamakawa, "Beam Loading Effect on Capture Efficiency in Radio Frequency Acceleration in Electron Synchrotron", Jpn. J. Appl. Phys. 19, pp 2229-2238, November 1980.