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DYNAMIC APERTURE OF THE PHOTON FACTORY STORAGE RING

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Abstract The dynamic aperture of the Photon Factory storage ring is strongly affected by the octupole magnets. The observations on the beam lifetime and the injection rate are consistent with the calculations on the dynamic aperture.

INTRODUCTION

The Photon Factory storage ring (PF ring) is a 2.5 GeV electron/positron storage ring dedicated to the synchrotron radiation experiments. In this ring, eleven octupole magnets (OCT's) are installed to suppress transverse instabilities[1]. When these OCT's are excited strongly, the beam lifetime and the injection rate are significantly reduced. In this paper, we present some results of the calculations on the dynamic aperture with the OCT's strongly excited. They are compared with the observations on the beam lifetime and the injection rate.

OCTUPOLE MAGNETS

In Figure 1, the present optics of the PF ring is shown. The locations of the OCT's are also indicated in the figure. The field strengths of the OCT's are shown in Figure 2 as functions of the currents. Three octupole magnets, OCT9,10,11, are not used in this work and omitted from this figure.

DYNAMIC APERTURE

The OCT's can produce large amplitude-dependent tune shifts and make betatron motions with large amplitudes unstable. We calculated the dynamic apertures for the various currents of the OCT's. For simplicity, the currents of all the OCT's (OCT1-8) were set to the same value. We used a lattice, whose betatron tunes were those of the present operation, 8.41 (horizontal) and 3.11 (vertical), respectively. The sextupole magnets were also included in the calculations. Figure 3 shows the calculated dynamic apertures at the north symmetry point (see Figure 1), where the physical aperture is smallest in the ring (its half height: 11 mm)[2]. As the currents of the OCT's (I_{oct})

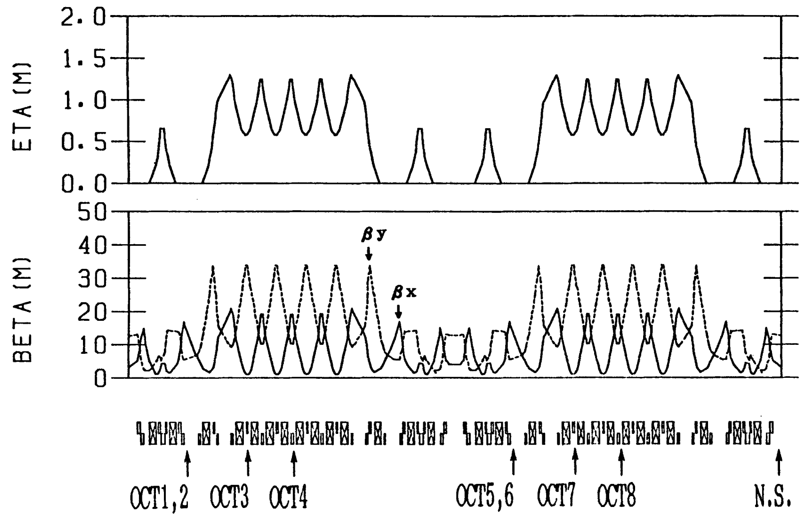

FIGURE 1 Optics of the PF ring. The locations of the OCT's are indicated by arrows with their names. The north symmetry point is also indicated by "N.S.".

TABLE 1 Parameters of PF ring.

Circumference		187 m
Beam energy		2.5 GeV
Natural	(H)	128 nmrad
emittances	(V)	~2 nmrad
Energy spread		0.00073
Betatron tune	(H)	8.41
	(V)	3.11
Natural	(H)	-15.8
chromaticity	(V)	-8.6
RF bucket height		0.0075

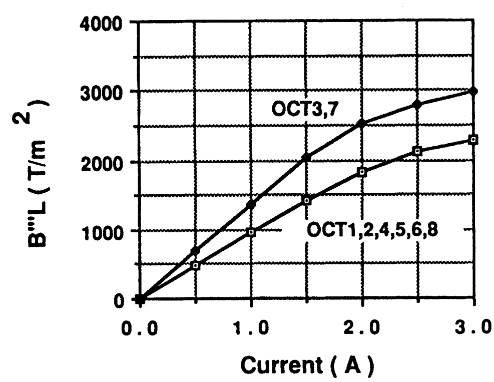

FIGURE 2

Excitation curves of the OCT's.

increase, the dynamic aperture shrinks drastically. When the value of I_{oct} is negative, the dynamic aperture becomes smaller than the physical aperture.

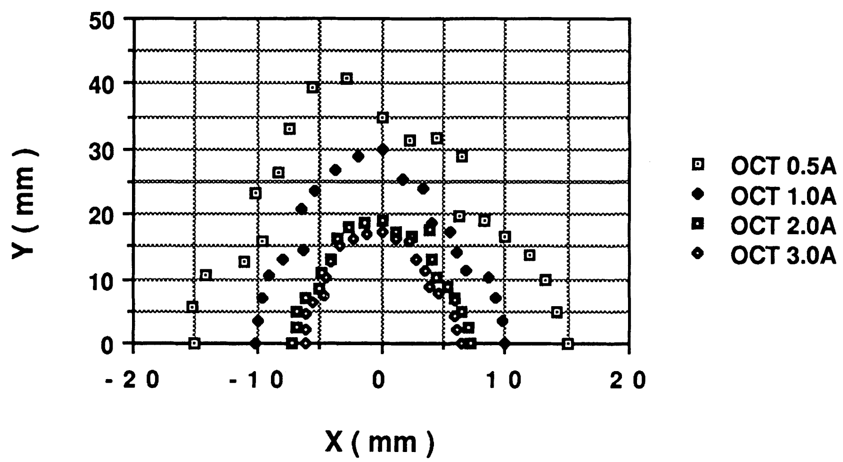

FIGURE 3a Dynamic aperture at the north symmetry point for the positive values of I_{oct}.

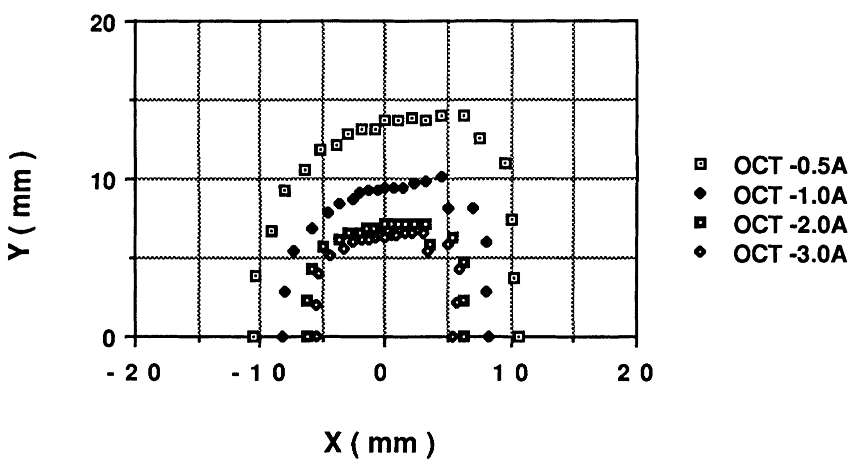

FIGURE 3b Dynamic aperture at the north symmetry point for the negative values of I_{oct}.

BEAM LIFETIME

When the OCT's are excited strongly, it is observed that the beam lifetime becomes shorter, as shown in Figure 4 (in the discussions below, we will use the beam lifetime multiplied by the beam current, $I\tau$ [A·hr], as a measure of the beam lifetime). For the PF ring, $I\tau$ is mainly determined by the gas scattering[3]. We can then calculate $I\tau$ as a function of the smallest aperture as follows[3];

$$I\tau\,[A\cdot hr] = (\ 1/I\tau_b + 1/I\tau_c\ )^{-1}\ ,$$

$$I\tau_c[A\cdot hr] = 12\cdot f_c\cdot (A[mm]/11)^2\{(P/I)[nTorr/A]/4.8\}^{-1}\ ,$$

$$I\tau_b[A\cdot hr] = 7.9\cdot f_b\cdot \{(P/I)[nTorr/A]/4.8\}^{-1}\ ,$$

where;

$$f_c = (\sum_i Zi^2/100)^{-1}(E[GeV]/2.5)^2(\beta_{av}[m]/10)^{-1}(\beta_u[m]/13)^{-1}\ ,$$

$$f_b = [\{4/3\cdot \ln(1/\eta)-5/6\}/5.7]^{-1}$$

$$\times\ \{\sum_i Zi(Zi+1)\ln(183Zi^{-1/3})/520\}^{-1}\ .$$

Here, $I\tau_b$ is the lifetime due to "Bremsstrahlung" and $I\tau_c$ the lifetime due to "Coulomb scattering". The A is the minimum aperture around the ring, the E the beam energy, the β_{av} the

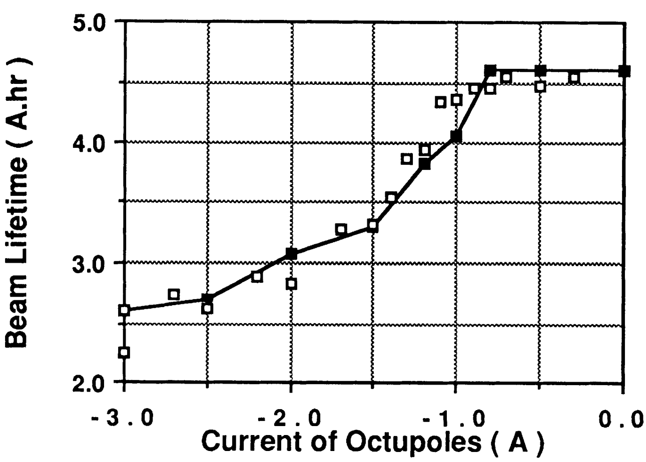

FIGURE 4 Dependency of the beam lifetime on I_{oct}. White squares are the measured values. The solid line is the calculated value.

averaged value of the betatron function, the β_u the betatron function at the minimum aperture, the η the RF bucket height. The Zi is the atomic numbers of the residual gas components. We assumed here that the residual gas is only composed of CO. The (P/I) is the averaged gas pressure in the ring divided by the beam current. The measured value of (P/I) is 1.2 nTorr/A. The actual vacuum pressure on the beam orbit is considered to be larger than this value, since the pressures are measured at the places near the vacuum pumps[4]. The calculated Iτ is shown in Figure 4 as a function of I_{oct}, assuming the value of (P/I)=4.8 nTorr/A, which can give the best fit to the observed data. The calculated Iτ agrees well with the observation. When $|I_{oct}| \leq 1$A, Iτ is determined by the physical aperture and does not depend on I_{oct}. As $|I_{oct}|$ gets larger than 1 A, the dynamic aperture becomes smaller than the physical aperture and then Iτ decreases.

INJECTION RATE

The OCT's also affect the injection rate as shown in Figure 5. When $|I_{oct}| \geq 1$A, the injection rate becomes almost zero. This indicates that the dynamic aperture in the horizontal direction becomes as small as the amplitude of the injected beam, which is

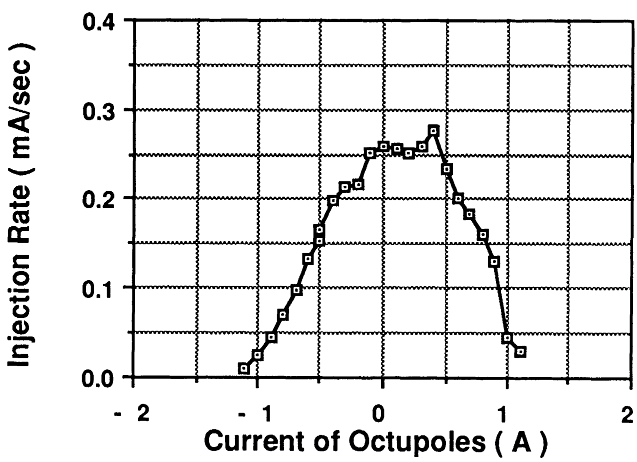

FIGURE 5 Dependency of the injection rate on I_{oct}. The measurement was done for the positron injection.

estimated to be about 7 mm at the north symmetry point. Actually, the calculation shows that the dynamic aperture becomes smaller than 10 mm in the horizontal direction when $|I_{oct}| \geqq 1A$ (see Figure 3).

SUMMARY

The excitation of the octupole magnets makes the dynamic aperture seriously small. The calculations show that the dynamic aperture becomes smaller than the physical aperture. The reductions of the beam lifetime and the injection rate can be explained well by this small dynamic aperture.

REFERENCES

1. Sakanaka, S. et al., in this proceedings (1989).
2. Kitamura, H., private communication (1989).
3. Kamada, S., KEK Report 79-28 (in Japanese) (1979).
4. Kobayashi, M., private communication (1989).