OBSERVATION AND ANALYSIS OF BEAM POSITION MOVEMENT DURING THE ACCELERATION OF NTT NORMAL CONDUCTING RING

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Abstract

RF frequency modulation is not thought necessary for an electron synchrotron above a few MeV at which electrons attain relativistic velocities[1]. In our ring, however, though electrons are injected at 15 MeV; a slight increase in electron velocity(β_e) has proved to cause serious horizontal beam position movement if electrons are accelerated in constant RF frequency.

Introduction

The NTT normal conducting ring[2] is an 800 MeV storage ring dedicated to synchrotron radiation applications, which also functions as a booster synchrotron for NTT superconducting storage ring[3]. A 15 MeV injection energy is adopted in order to conduct a feasibility study of a low energy injection scheme.

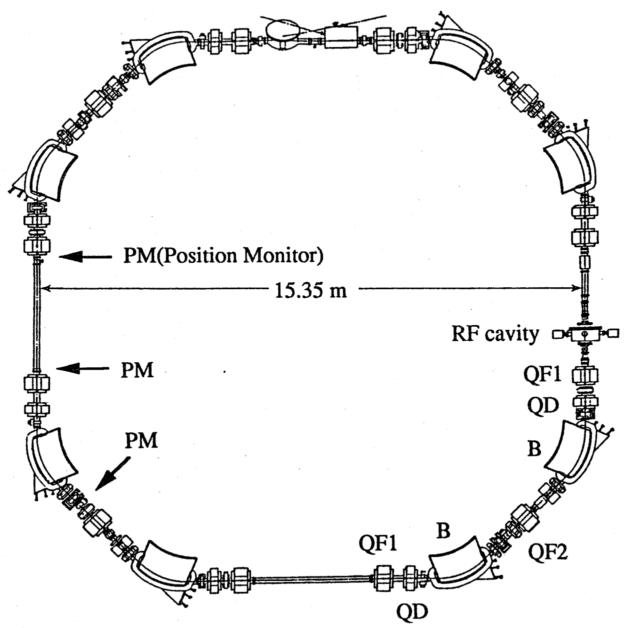

Fig.1 Layout of the ring

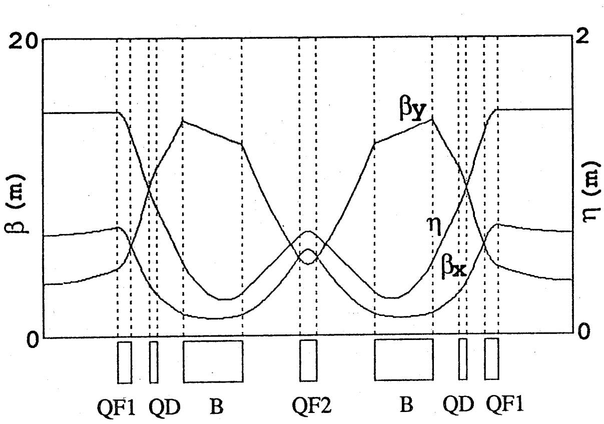

Fig.2 Lattice functions in operation

According to the beam position measurement performed with twelve position monitors, 10 to 20 mm horizontal movements are observed in the early stage of the acceleration. The analysis has shown that these movements are due to the increase in β_e. To solve this problem, the RF frequency is modulated in proportion to β_e, which makes it possible to accelerate electrons nearly on the constant orbit.

Lattice parameters

The ring has four long straight sections and four short straight sections with eight bending magnets (Fig.1). The designed lattice parameters are described in Ref.2. For insertion devices in the future, a Chasman-Green type lattice is adopted to obtain low emittance and to realize achromatic condition at long straight sections.

However, we are operating in a non-achromatic condition. The reason for this will be described later. The lattice functions derived from the operating conditions are shown in Fig.2. Typical lattice parameters are listed in Table 1.

Table 1

Lattice parameters referred to in this paper

		Designed	In operation
Operating point	ν_x	3.25	~3.14
	ν_y	1.25	~1.11
Momentum comp. (α)		0.022	0.042
Dispersion function (η)	at QF1	0.0 m	1.5 m
	at QF2	1.8 m	0.7 m
RF frequency		125 MHz	
Circumference		52.76 m	

Beam position measurement

Twelve sets of four button type electrodes are placed in the ring in order to measure beam positions in the storage mode (Fig.1,3). The structure and the calibration method of the monitor are referred to in the system used in Tristan AR[4,5].

To measure a beam position during the acceleration, a set of four electrodes is selected and the signal from each electrode is coax-switched every 2 msec to a heterodyne detection circuit. The raw data are stored in a data logger and are analyzed with a personal computer into position data after a cycle of the acceleration.

As a position data is reconstructed from a series of four raw data, the beam position can be measured every 8 msec. Beam losses in a short time(within 8 msec) are so small that no serious measurement errors are expected. The beam size is large (over 10 mm) near injection energy because of the long damping time while the calibration data are derived from a test bench system with an antenna which imitates the line beam. This may cause calibration errors.

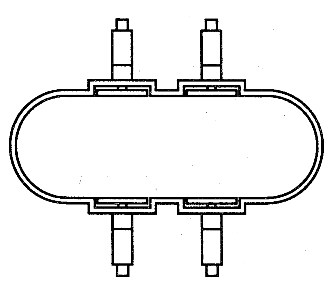

Fig.3 Beam position monitor

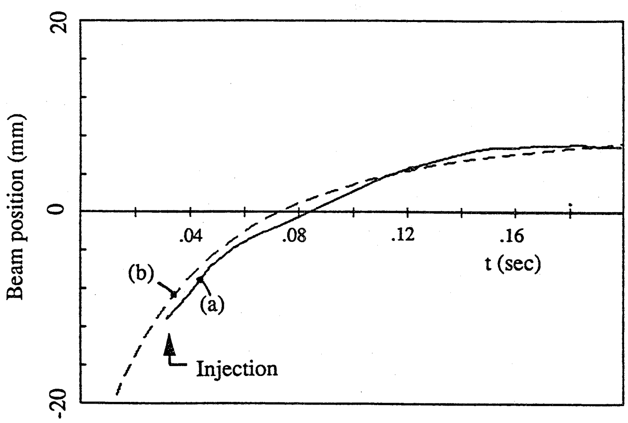

Fig.4 Beam position movement
(a) measured (b) calculated

The simulation has estimated this kind of errors to be less than a few millimeters on the assumption that the horizontal beam size (σ_x) is about 10 mm.

The beam position vs. time measured at one of the focusing quadrupoles (QF1) is shown in Fig.4(a). The ramping rate is 150 MeV/sec. The beam position moves outwards in a horizontal plane about 20 mm in 200 msec just after the injection.

Analysis

Electrons above a few MeV can be accelerated with constant RF frequency in the first electron synchrotrons which are small and circular shape. Normalized electron velocity is expressed as

$$\beta_e = (1 - m^2c^4 / W^2)^{1/2} \tag{1}$$

$$= (1 - m^2c^4 / (E + mc^2)^2)^{1/2} \tag{2}$$

where W is total energy and E is kinetic energy of an electron while mc^2 is electron rest energy. At E = 2 (MeV), β_e is about 0.98 and orbit radius (R) is 2 % smaller than the final radius (R_0) after the acceleration. If R_0 is 50 cm, R increases only 10 mm during the acceleration.

On the contrary, this is not the case for the latest electron synchrotrons, which are larger and have straight sections. In general, the beam position movement is calculated as a function of electron energy as shown in below.

When E is sufficiently larger than mc^2, Eq.(2) is approximated to

$$\beta_e \sim 1 - m^2c^4 / 2 (E + mc^2)^2 \tag{3}$$

If accelerated in constant RF frequency, the closed orbit displaces so that orbit length(L) is proportionate to β_e. So L changes as

$$\Delta L/L = - m^2c^4 / 2 (E + mc^2)^2 \tag{4}$$

which corresponds to momentum error

$$\Delta p/p = 1/\alpha \cdot \Delta L/L \tag{5}$$

$$= - m^2c^4 / 2\alpha (E + mc^2)^2 \tag{6}$$

where α is the momentum compaction factor. As a result, horizontal displacement is derived from dispersion function η

$$\Delta x = \eta \, \Delta p/p \tag{7}$$

$$= - \eta \, m^2c^4 / 2\alpha (E + mc^2)^2 \tag{8}$$

According to the lattice parameters in Table 1, electron rest energy mc^2=0.51 (MeV), and injection energy E=15 (MeV), fatal movement (> 40 mm at QF2) is expected in the achromatic(designed) condition while the movement remains allowable (< 20 mm at QF1), though still large, in the operation condition. This is the reason why we are operating in the non-achromatic condition.

Fig.4(b) shows calculated movement from Eq.(8), which is in good agreement with the experimental results (Fig.4(a)).

Frequency modulation

From Eq.(3), 1 - β_e is only 5.4×10^{-4} at 15 MeV injection energy, which quickly disappears in proportion to $1/(E+mc^2)^2$. The RF signal frequency from the synthesizer can easily be modulated in proportion to β_e (from 124.93 MHz to 125.00 MHz) in providing a modulation pattern to the synthesizer from an arbitrary function generator (Fig.5). No resonance frequency control of RF cavity itself is required because of the low RF voltage at injection energy.

As a result of this frequency modulation, electrons are accelerated practically on the constant orbit.

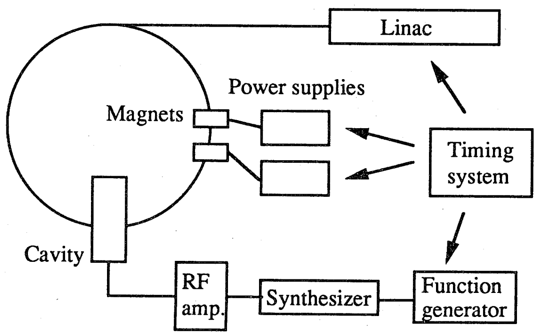

Fig.5 Block diagram of RF frequency modulation system

Conclusion

Beam positions were measured during the acceleration. Horizontal movement due to the increase in β_e is observed. This problem can easily be solved in modulating the frequency of the RF signal generated from the synthesizer.

Acknowledgements

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References

1. M.S.Livingston, J.P.Blewett, "Particle Accelerators", McGraw-Hill, New York (1962) p.397
2. A.Shibayama, T,Kitayama, T.Hayasaka, S.Ido, Y.Uno, T.Hosokawa, J.Nakata, K.Nishimura, and M.Nakajima, Rev.Sci.Instr., Vol.60, 1779 (1989).
3. T.Hosokawa, T,Kitayama, T.Hayasaka, S.Ido, Y.Uno, A.Shibayama, J.Nakata, K.Nishimura, and M.Nakajima, Rev.Sci.Instr., Vol.60, 1783 (1989).
4. M.Tejima, H.Ishii, H.Ishimaru, T.Ieiri, Y.Mizumachi, and A.Ogata, Proc. 4th symposium on accelerator science and technology, Saitama, Japan, p.153 (1982)
5. T.Ieiri, H.Ishii, Y.Mizumachi, A.Ogata, T.Shintake, and M.Tejima, Proc. 5th symposium on accelerator science and technology, Tsukuba, Japan, p.154 (1984)