COMPACT STORAGE RING NIJI-II

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Abstract

The compact storage ring named NIJI-II was designed and constructed for the purpose of the development of free electron laser (FEL), lithography and SR-CVD experiments. The storage ring has two achromatic basic lattices of double-bend achromat type, interspersed with two 2 m straight sections, and the circumference of 17.04 m. One of straight sections provides a room for an optical-klystron for FEL and various insertion devices such as polarizing undulator. The first beam storage was made in this summer. The improvement of the lattice structure for FEL electron beam is discussed.

Introduction

The majority of the application of compact storage rings is focused on SR lithography[1]. Recently, much attention has been paid to the use of compact rings in SR-CVD technology. The development of compact SR rings for FEL generation is also important to realize the wide application of FEL in chemical industry.

The storage rings providing the electron beam for FEL experiments have to be built especially for this purpose. Moreover, extensive machine work on the storage rings should be sufficient to obtain FEL oscillation in the visible and near UV ranges. Compact SR ring with straight sections specially designed is useful to curry out the development of FEL[2] and polarizing undulator[3] as an improved source of synchrotron radiation. For FEL performance, the storage ring should store high density (high peak current, small emittance) electron beams with small energy spread. This requirements on beam quality are demanding few hundred amperes of peak current (20 mA per bunch), emittance of the order of 10^{-8} m-rad, and relative energy spread less than 0.001. Designing such a compact ring with small circumference is difficult, because the characteristic for low emittance strongly depends on the bending angle per dipole magnet. The low emittance storage rings, in many cases, require many lattice cells to keep the bending angle small. This paper describes the lattice structure and the lattice functions of NIJI-II calculated by the use of the computer code, MAGIC[4], and the present status of NIJI -II and the improvement for FEL experiment. We have studied three kinds of lattice structures; (a) FODO lattice, (b) modified FODO, (c) double bend achromat, DBA. It is found that FODO lattice has small stability region in the tune diagram. The type of modified FODO can not include the straight section of dispersion free. In the case of type of DBA, the small dispersion is obtained at the straight section, however, the emittance is relatively large.

Outline of 600-MeV Compact Storage Ring NIJI-II

The available space for NIJI-II is 8 m x 10 m in the medium energy experimental laboratory of the ETL linac building. The length of 1 ~ 2 m is necessary around NIJI-II for the experimental space so that the size of the ring itself should be about 5 m x 8 m or less. NIJI-II is required to include straight sections

Table 1
Fundamental parameters of NIJI-II

Beam energy	150 ~ 600 MeV
Injection energy	150 MeV
Circumference	17.06 m
Available straight section	2.04 m
Number of bending magnets	4
Bending radius	1.4 m
Bending magnet field index	0
Edge angle	16°
Periodicity	2
rf frequency	158.2 MHz
Harmonic number	9
rf power	2 kW
Energy loss per turn	0.247 keV at 250 MeV

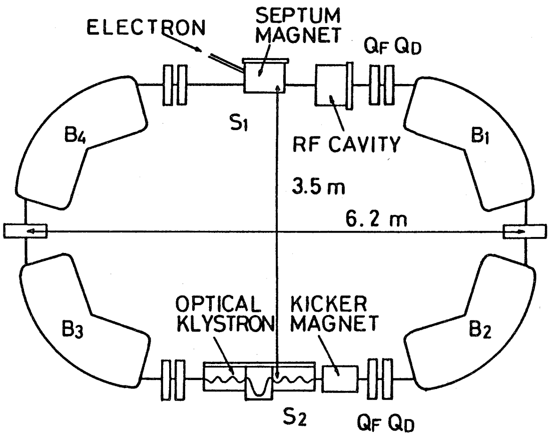

Fig.1 Plane view of NIJI-II

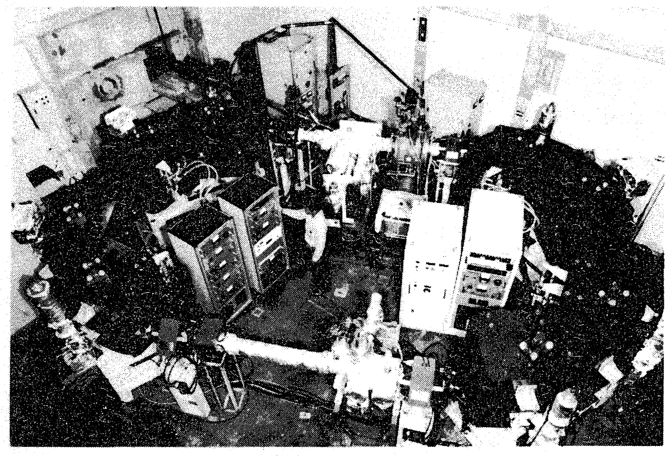

Fig.2 Photograph of NIJI-II

without dispersion for the study of FEL and its length is preferable as long as possible. The racetrack design and 90° slanted bending magnets are taken from this point of view. NIJI-II consists of four bending magnets and two long and short straight sections as shown in Fig. 1. Figure 2 is a photograph of NIJI-II. Electrons transported from the medium energy section of ETL linac "TELL" are injected into NIJI-II using a septum magnet and a kicker magnet which forms a bumped orbit. The electron beam is supplied by the linac at the energy of 150 MeV, with a pulse width of 0.5 μ sec, and the peak current 100 mA. The injection from the linac is repeated at 3 pulses per second. After the accumulation of electrons at 150 MeV, the electron energy is gradually increased up to 250 MeV for FEL experiment and up to 600 MeV for lithography and SR-CVD experiments. The RF cavity is installed in the straight section S_2 and supplied by a 2 kW power amplifier.

Lattice Structure Consideration

NIJI-II was constructed to dedicate for the studies of the lithography and SR-CVD experiment at 600 MeV and the generation of FEL at 250 MeV. The improvement of the lattice structure was necessary to obtain the low beam emittance for FEL experiments.

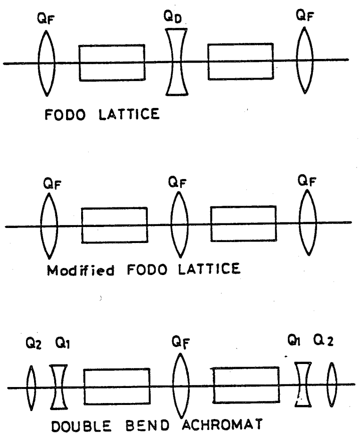

Fig.3 Types of magnetic lattices

We have examined three types of lattice structure, types of FODO, modified FODO, and DBA (double bend achromat) shown in Fig. 3. The basic lattice in each case consists of double-bending magnets with three or five quadrupole magnets. The FODO lattice is the most used lattice because of its very compact structure. It is reported that this lattice allows stable motion for electron beams with much lager amplitudes, and, consequently, provides a large dynamic aperture. The DBA lattice is superior to realize the long dispersion-free straight section in a limited circumference. This lattice has the strong sensitivity to the energy errors of electron beam because of strong focusing required to get a low beam emittance. Field errors in magnets can significantly reduce the dynamic aperture. We have not calculated the dynamic apertures in this time and also can not discuss on various beam dynamic effects.

With an explicit lattice design, the ring parameters ; energy, circumference, radius of the bending magnet etc., are determined. The electron energy is ~ 250 MeV. We choose an rf frequency to be 158 MHz. The harmonic number is then 9 for the circumference of 17.04 m.

The generation of FEL requires the high density electron beam, the minimized transverse beam emittance, and small energy spread. In the limited circumference of the storage ring, the bending angle of dipole magnets is taken to be 90° , therefore, the number of dipole magnets is 4. The characteristic scaling for the beam emittance is given

$$\varepsilon \sim E^2 (2\pi /N)^3$$

in both cases of FODO and DBA, where E is the beam energy and N the number of dipole magnets[5]. As a result, in the compact storage ring, the beam emittance becomes large. In this way, the interdependence of various parameters leads to conflicting requirement.

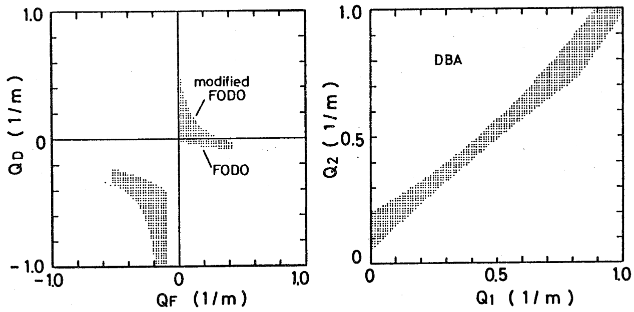

Fig.4 Tune diagrams for FODO, modified FODO, and DBA

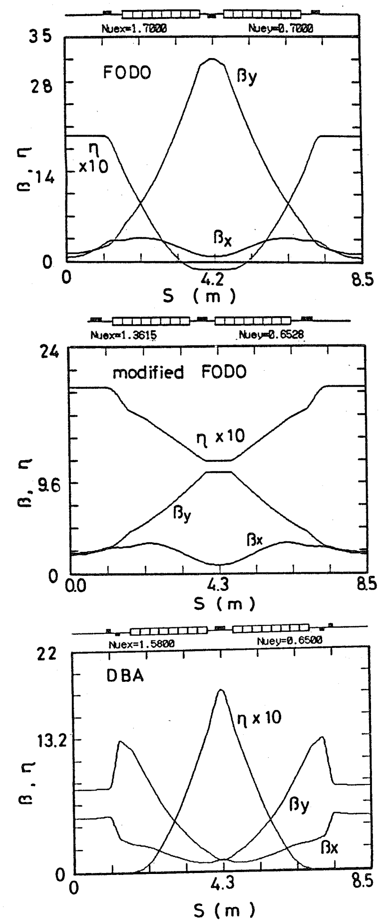

Fig.5 Beta and dispersion function for the three kind of latteces

The tune diagrams of the three type of lattice are shown in Fig. 4. FODO lattice structure in this compact ring has a small stability region and, consequently, has a problem in the control of betatron tune.

Figure 5 shows the lattice functions of the types of FODO, modified FODO, and DBA. In the case of DBA lattice, the dispersion function is controlled by a focusing quadrupole magnet located at the center of two bending magnets. The betatron tune is controlled by the doublet of the quadrupole magnets independently of the dispersion function. We have dispersion-free straight sections in the lattice structure of DBA. On the contrary, the dispersion is not small in the FODO and modified FODO lattice. FODO and modified FODO lattice structure may be not suitable for the compact storage ring for FEL.

Figure 6 shows the tune diagram with keeping the dispersion function zero in the type of DBA. It is found that the type of DBA has the non-dispersive sections without decreasing the stability region in the tune diagram.

Figure 7 is plots of the beam emittance of the type of DBA as functions of the betatron tune, νx and νy. This figure describes that, in this lattice structure, the beam emittance strongly depends on the horizontal betatron tune, νx, and that the low beam emittance is able to be obtained by the use of the doublet of quadruple magnet with strong focusing.

Table 2 describes the storage ring parameters of the FODO, the modified FODO lattice and the DBA lattice obtained by optimizing the lattice functions and the beam emittances.

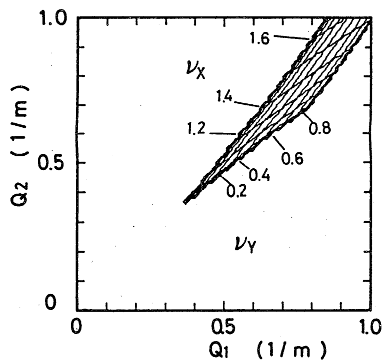

Fig.6 Tune diagram of the dispersion free operation of DBA

Discussion and Conclusion

The lattice structure of DBA is suitable for the compact storage ring for FEL studies. It needs the doublet of quadrupole magnets with large focusing strength to get the low beam emittance. It is considered that the strong focusing causes a high sensitivity to energy spread of electron beam and field errors in magnets. As a result, beam injection is difficult.

On the contrary, the long dispersion-free straight sections are not easily obtained in the FODO and the modified FODO lattice. It is , however, expected that the FODO and the modified FODO lattice provides large acceptance. These two lattice structures are appropriate to the storage ring required for a high storage beam current of more than 500 mA and a long life time longer than 10 hours . The SR rings for lithography and SR-CVD experiments should be compact, operated easily, and capable of large area exposure to soft X-rays. In this respect, we consider that the choice of lattice for these purposes should be experimentally made from three kinds of lattices; the FODO, the modified FODO, and the DBA operated at low tune.

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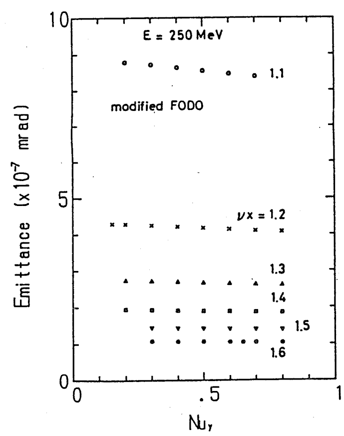

Fig.7 A plot of the beam emittance as a function of betatron tune for DBA

Table 2
The lattice parameters of three types considered at 250 MeV

Type		FODO	modified FODO	DBA high tune	DBA low tune
Betatron tune	νx	1.70	1.362	1.58	1.15
	νz	0.60	0.653	0.65	0.3
Momentum Compaction		0.148	0.544	0.187	0.187
Natural emittance		1.63 x 10^{-7} m-rad	2.35 x 10^{-7} m-rad	1.11 x 10^{-7} m-rad	5.75 x 10^{-7} m-rad
Beam dimensions at the straight sections					
	σx	0.518 mm	0.573 mm	0.476 mm	2.01 mm
	σy	0.888 mm	0.499 mm	0.739 mm	2.06 mm
Energy spread		0.0174 %	0.0167 %	0.0174 %	0.0174 %
Chromaticity	ξx	-1.381	-0.860	-1.290	-2.330
	ξy	2.127	1.264	-0.046	1.549
Natural bunch length		1.54 cm	2.62 cm	1.71 cm	1.70 cm
Radiation damping time					
	τx	132 msec	353 msec	141 msec	141 msec
	τz	115 msec	115 msec	115 msec	115 msec
	τe	54 msec	42 msec	53 msec	53 msec
rf voltage		25 keV	25 keV	25 keV	25 keV