

Design of the Compact Storage Ring, NIJI-IV.

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Abstract

Recently, there are some plans for the development of the ultra-violet Free Electron Laser (UV FEL). The usage of the storage ring has a large advantage for investigations of the UV FEL because of its low emittance, low energy spread and high current. We have tried to design a compact storage ring, NIJI-IV, which has a long dispersion free drift space (L_s). The circumference (C_f) of NIJI-IV is 29.6 m and the beam energy is up to 500 MeV. The long drift space is 7 m long, where the beam momentum dispersion is suppressed to be 0.

Introduction

Free electron laser (FEL) can generate tunable, very intense monochromatic photons which conventional laser devices cannot emit. However, the FEL needs a high energy, small energy spread, high density, low emittance electron beam. Such a high quality beam can be utilized in an electron storage ring. Therefore, a compact storage ring dedicated to UV FELs with a long optical klystron should be developed. The requirements for the stored beam in the compact ring are
:several hundred milliamperes of the current on average and peak current of 10 A,
:low emittance of the order of 10^{-8} m-rad,
:low energy spread of the order of 10^{-4} ,
:beam momentum dispersion is 0 at a long drift space.

To obtain effective interactions between the undulating electron beam and emitted photons, the length of the optical klystron is desired to be longer than several meters. Consequently, the storage ring used must have a long drift space.

In this paper, we describe a design of the compact storage ring, NIJI-IV, satisfying the requirements above mentioned. The NIJI-IV will be constructed in 1990 as an UV FEL machine.

General Ring Design

To obtain a high gain FEL system, the emittance of the stored electron beam must be fulfilled the above requirements. The natural emittance is written as^{1,2},

$$\epsilon = C_q \cdot \frac{r^2}{\rho J_x} \cdot \frac{1}{2\pi\rho} \int \text{Dipole } H ds$$

$$= F \cdot \frac{E^2}{J_x N_0^3}$$

$$C_q = 3.84 \times 10^{-13} \text{ m-rad}$$

Table 1
Approximate minimum values of F.

Lattice Type	F_{min}	Nd/cell	Example
FODO	7.282×10^{-4}	2	PEP
Triple Achromat	3.86×10^{-4}	2	ETL TERAS
Chasman-Green	2.36×10^{-5}	2	NSLS VUV
Triple Bend Achromat	6.76×10^{-5}	3	SRRC

where ρ is the dipole bending radius, γ is the beam energy (E/mc^2), J_x is the horizontal damping partition number, H is the Courant-Snyder invariant N_d is the number of dipole magnets and F is a constant for a given lattice (Table 1). For a low emittance ring, it is desirable to increase N_d . Therefore, we choose the triple bend achromat type lattice. The bending angle is set to be 60° and edge focusing (edge angle of 16.1°) is adopted. The bending radius is determined by the maximum energy of the stored beam and by the geometric condition of the ring. In our case, the circumference is limited to be 29.6 m because of the room space and of the RF system. The maximum energy is required to be 500 MeV. Using a standard operation of the bending field, the maximum field is about 1 T and 1.7 m radius

Table 2
Parameters of NIJI-IV

Fundamental Parameters			
Beam Energy	250 MeV	(Max. 500 MeV)	
Circumference	29.6 m		
Lattice Type	Triple Bend Achromat		
Periodicity	2		
L_s/C_f	0.49		
Bending Angle	60°		
Bending Radius	1.2 m		
Max. Bending Field	1.5 T		
Field Index	0		
Edge Angle	16.1°		
Harmonic Number	16		
Radio Frequency	162 MHz		
Max. RF Power	2.5 kW		
Machine parameters			
Momentum Compaction Factor	0.088		
Betatron Number	Low- ν	High- ν	
	ν_x	2.3	2.85
	ν_y	0.6	1.45
Quadrupole Magnet (Length 0.2 m)	QF1	0.453 /m	0.606 /m
	QF2	0.712 /m	0.712 /m
	QD	-0.391 /m	-0.518 /m
Natural Emittance	250 MeV	3.373×10^{-8} m-rad	3.373×10^{-8} m-rad
	500 MeV	1.349×10^{-7} m-rad	1.349×10^{-7} m-rad
Beam Size	σ_x 250 MeV	0.391 mm	0.127 mm
	500 MeV	0.782 mm	0.254 mm
	σ_y 250 MeV	0.407 mm	0.196 mm
	500 MeV	0.815 mm	0.392 mm
Energy Spread	250 MeV	0.190%	0.190%
	500 MeV	0.380%	0.380%
Bunch Length	250 MeV	16.7 mm	
	500 MeV	47.6 mm	
Radiation Loss	250 MeV	0.3 keV	
	500 MeV	4.6 keV	
Natural Chromaticity	ξ_x	-2.806	-4.045
	ξ_y	1.394	-1.726
Taushek Life Time	250 MeV	11.1 sec/A/bunch	4.38 sec/A/bunch
	500 MeV	154 sec/A/bunch	85.1 sec/A/bunch
Damping Time	τ_x 250 MeV	195 msec	
	500 MeV	24 msec	
	τ_y 250 MeV	172 msec	
	500 MeV	21 msec	
	τ_E 250 MeV	81 msec	
	500 MeV	10 msec	

is needed. However, a long drift space is the main goal of our ring design. We determine the bending radius to be 1.2 m and the maximum bending field is 1.5 T. Figure 1 displays the general layout and Table 2 lists the fundamental parameters of the NIJI-IV. It should be noted that the long dispersion free drift space obtained is about 7 m for the circumference of 29.6m.

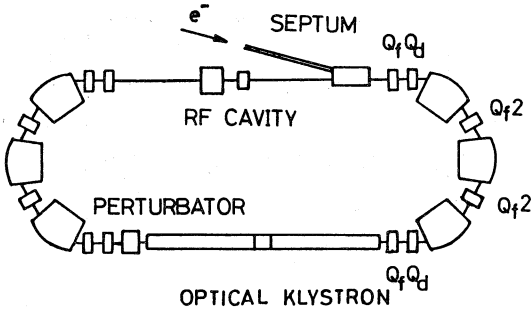


Fig.1 Schematic layout of the NIJI-IV.

Lattice Design

To obtain a long dispersion free drift space, we have tried to design several types of lattice. In these calculations, we use the computer code MAGIC³ and several tiny codes which are developed in our laboratory. Figure 2 displays several trial designs. Figure 3 shows stable region diagrams for each trial design. We find a few types of the lattice which have the dispersion free drift space. Finally, we choose the lattice-(c), Triple Bend Acromat lattice (TBA), because the length of the long dispersion free drift space is suitable for our purpose, the natural emittance is relatively low and the stable region is comparatively large. The ratio of the long drift space to the ring circumference, L_g/C_f , is about 0.49. Furthermore, we have found that a proper field strength of the QF2, middle quadrupole magnets, can achieve the long dispersion free space. Figure 4 displays the tune diagram of the dispersion free system for the lattice-(c). Hence, we can use a very wide range of the betatron frequency.

We have calculated lattice parameters to obtain a lower emittance. Figure 5 shows the emittance as a function of the betatron frequency. As is shown in this figure, we have obtained two operational points in the condition of the minimum emittance. Table 2 lists the machine parameters of the NIJI-IV in these two operational conditions. Obtained beta and dispersion functions for each operational condition are shown in Fig.6.

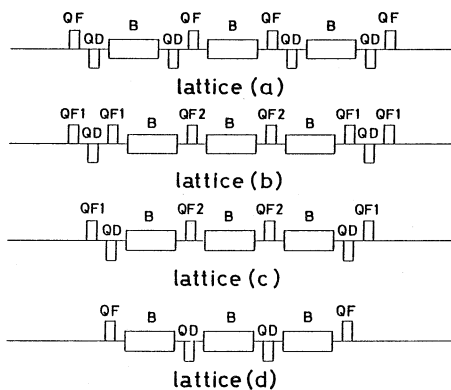


Fig.2 Trial lattice types.

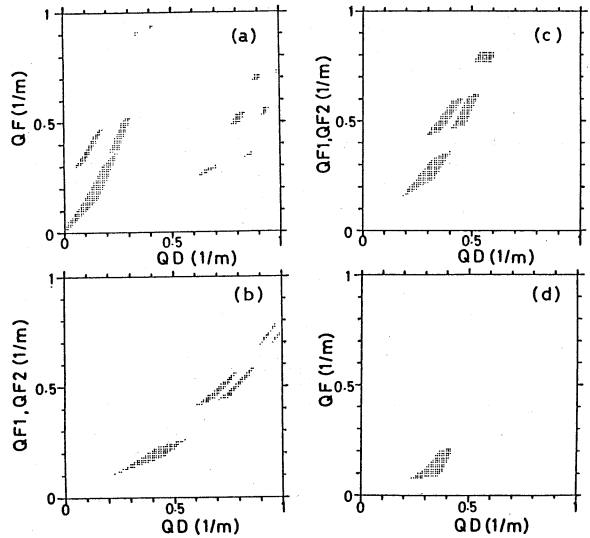


Fig.3 Stable region diagram for 4 types of lattices.

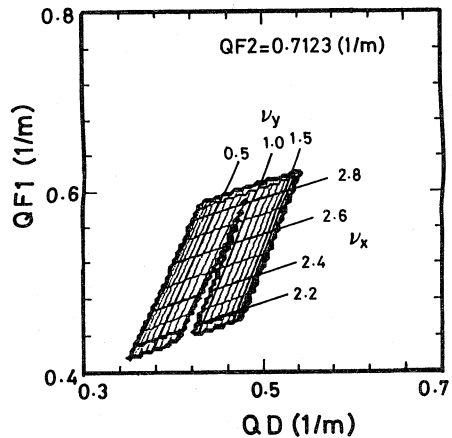


Fig.4 Tune diagram of the dispersion free system for the lattice-(c).

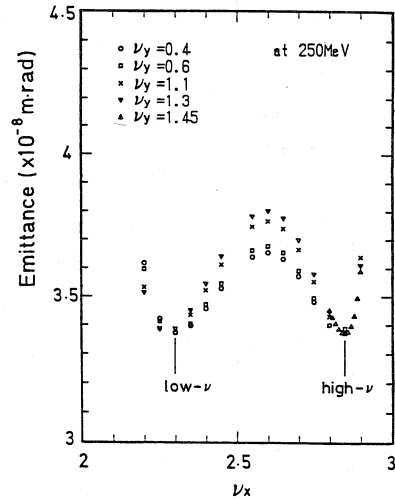


Fig.5 Emittances as a function of betatron frequency.

The tune shift due to the off momentum particle, $\Delta p/p=1\%$, is calculated and displayed in Fig.7 for each operational condition. Figure 7 also represents the regular resonances up to order 4. It is noted that the high ν condition crosses the 2nd resonance. The linear tracking calculations are also investigated. Figure 8 shows the result of the investigation for 100-turn track. The initial condition of this calculation is 4 mm x-, y-displacement and 0.1% dx/ds, dy/ds. It is clear that the high ν condition shows the larger beam envelope. Therefore, we consider that the low ν condition is a better candidate for the NIJI-IV.

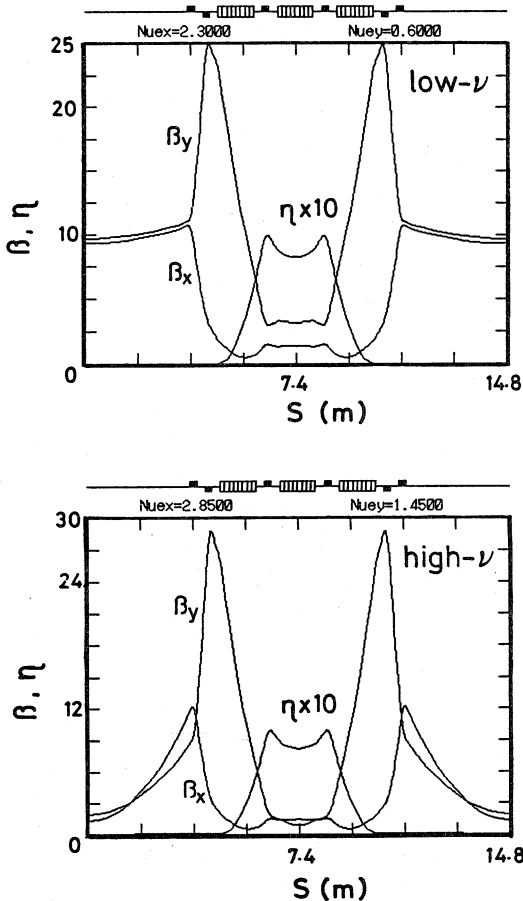


Fig.6 Beta and dispersion functions for the two operational conditions.

Conclusion

Design of the compact storage ring, NIJI-IV, has been performed. A dispersion free drift space with the largest L_S/C_F ratio has been obtained. The adopted lattice is the TBA type. The natural emittance is 3.4×10^{-8} m-rad and the energy spread is 1.9×10^{-4} at the beam energy of 250 MeV. These conditions satisfies the requirements for the UV FEL experiment.

References

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- [3] A. S. King, M. J. Lee and W. W. Lee, "MAGIC, A Computer Code for Design Studies of Insertions and Storage Rings", SLAC-183 Report(1975).

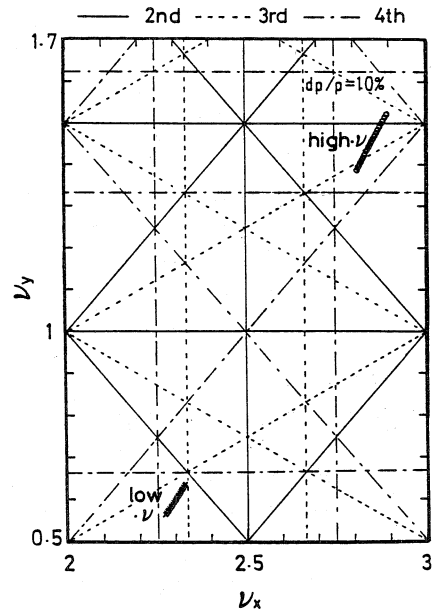


Fig.7 Tune shift diagram for $\Delta p/p=1\%$ particles.

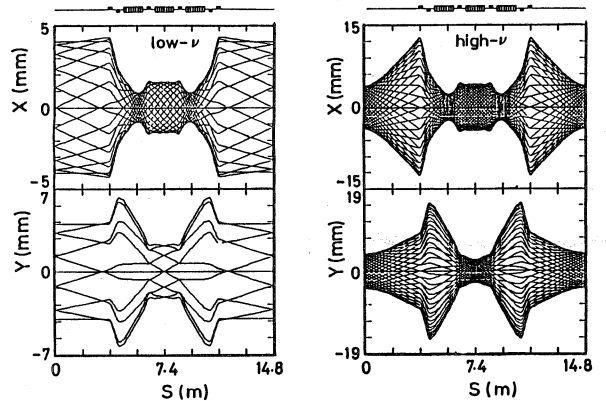


Fig.8 Beam envelopes for 4 mm x-,y-displacement and dx/ds, dy/ds=0.1% condition.