The Lattice Design of Indiana University Cyclotron Facility Cooler Injector Synchrotron

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Abstract

This paper reports lattice design studies of a low energy booster at Indiana University Cyclotron Facility (IUCF). This booster will be used as an injector, which is named as Cooler Injector Synchrotron (CIS), for the existing IUCF Cooler ring. The IUCF CIS will be able to accelerate high-intensity polarized protons or deutrons coming from a RFQ linac from 7 MeV (6 MeV) to 200 MeV (105 MeV). The beam bunch then will be extracted and injected into the Cooler ring for further acceleration. The finalized lattice design for the CIS has four superperiods. Each period is composed of a drift space and a dipole magnet which has 90° bending angle and 12° edge angle at both ends. The circumference of the CIS is 17.364 meters, one fifth of that of the Cooler ring. The designed horizontal and vertical tunes are 1.463 and 0.779, respectively. Possible effects from the employment of trim quadrupoles, which will be located between dipoles, are also discussed.

I. Introduction

The Cooler Injector Synchrotron (CIS) at Indiana University Cyclotron Facility (IUCF) was jointly found by National Science Foundation (NSF) and Indiana University in 1994 [3]. The CIS will be replacing the currently running cyclotrons, which are used to fill the Cooler at IUCF, to increase the beam intensity of the Cooler ring. The CIS is designed to accelerate 7 MeV high-intensity polarized protons (or 6 MeV for deutrons) exited from a RFQ linac to 200 MeV (105 MeV). The beam bunch is then injected to the Cooler storage ring for further acceleration [2]. The CIS will be a zero gradient synchrotron with a superperiod of four. Each period consists of a draft space and a dipole magnet. In order to find the best lattice design for the CIS, namely, to locate a good working point in tune diagram, i.e. the tunes are not too close to any possible linear, nonlinear and spin resonance lines, and at the same time to enhance the injection efficiency at a tolerable emittance, and to limit the construction costs of the machine without losing the proposed beam performance, a number of lattice designs have been considered, discussed and compared. Finally a compromised lattice design is reached with the circumference as one fifth of the Cooler ring. The lattice parameters are listed in Table I. The general layout of the CIS is shown in Figure 1.

II. CIS Lattice Design

For such a simple lattice without any quadrupoles, only a limited parameters θ_e, the edge angle, and L, the length of the dipoles can be adjusted. Scanning over θ_e and L of the dipoles,

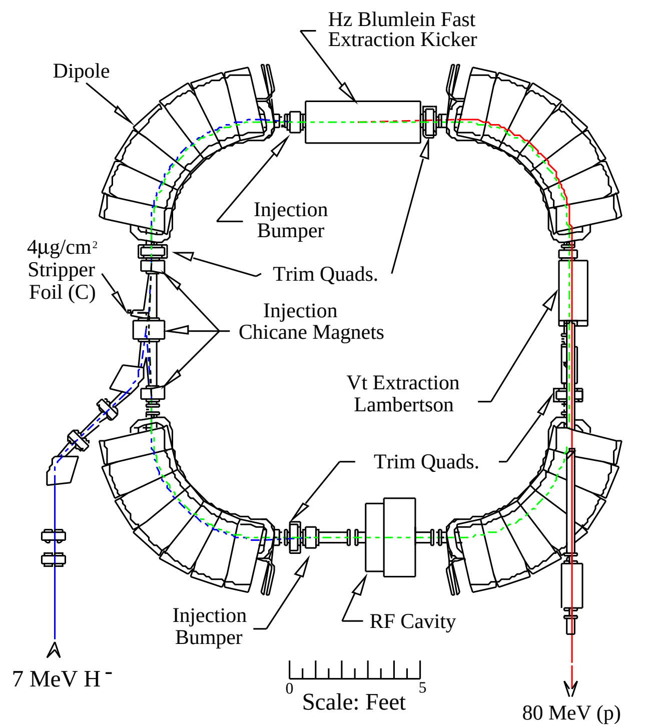

Figure. 1. The general layout of the Indiana University Cyclotron Facility Cooler Injector Synchrotron at IUCF

Table I
IUCF CIS lattice parameters

Parameters	Symbol	Values
Circumference(m)		17.364
Horizontal tune	Q_x	1.4633
Vertical tune	Q_z	0.7788
Dipoles:		
Length(m)	L	2.0
Edge angle	θ_e	12°
Bending radius(m)	ρ	1.273
Transition Energy	γ_T	1.271
Beta x: Maximum(m)	β_x	4.373
Minimum(m)		0.996
Beta y: Maximum(m)	β_y	3.786
Minimum(m)		3.380
Dispersion	D_x	
Maximum(m)		1.759
Minimum(m)		1.617
Chromaticity(x)	C_x	-0.529
Chromaticity(z)	C_z	-0.156

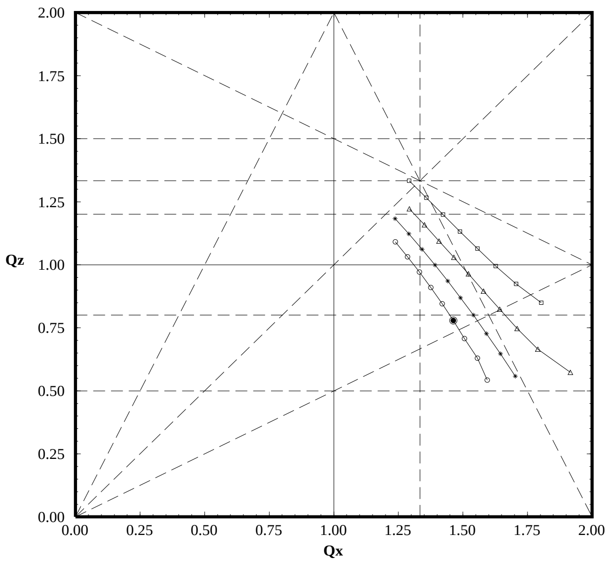

Figure. 2. Tune Diagram of the Cooler Injector Synchrotron of IUCF. Where □ stands for θ_e changing from $12°$ to $26°$ for $L = 1.7$m, △ for θ_e from $6°$ to $24°$ for $L = 1.8$m, $*$ for θ_e from $6°$ to $22°$ for $L = 1.9$ m and ◯ for θ_e from $12°$ to $26°$ for $L = 2.0$ m. Step between two points is $2°$

a number of possible lattice designs were obtained using MAD program [1].

A. Tune diagram

Tune changes due to the variations of edge angle θ_e and dipole length L are plotted in tune diagram as shown in Figure 2, where betatron resonances and the spin tune at injection energy are also shown. In particular, the working point is marked by a symbol •, where the horizontal and the vertical tunes are 1.463 and 0.779, respectively.

B. Betatron Function

When scanning over the edge angle and the length of dipoles, lattice functions are also changed due to the variations of the effective focusing forces in both planes. Figure 3 shows the lattice function distributions of β_x, β_z and D_x (horizontal dispersion function) at the working point. We note that $\beta_z \approx 3.5$ m and $\beta_x \approx 1.0$ m at the injection stripper location.

C. Dispersion Function and Chromaticity

Momentum spread could result in closed orbit changes through the dispersion so as to cause emittance growth during the injection. At a $D_x \approx 1.5$ m, the emittance growth due to energy loss at the stripper thickness of 4μg/cm^2 is tolerable. The final momentum spread of the injected beam is about 2×10^{-3}. Thus the chromaticity of the machine dose not cause large tune spread. The effects of the dispersion and the chromaticities on the variations of θ_e and L are also studied. It becomes clear that the chromaticities of the CIS lattice are small, we do not need to worry them.

D. Momentum Compaction Factor α

To avoid passing transition energy problem, we also need to keep tracking the changes of the momentum compaction factor α

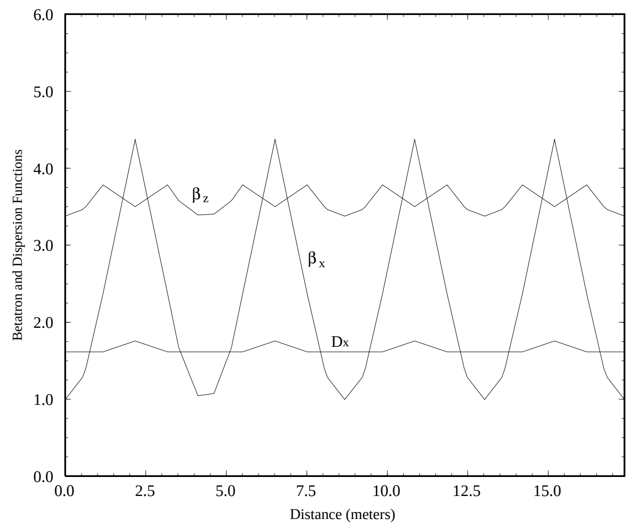

Figure. 3. The CIS lattice function distributions for $L = 2.0$ m, $\theta_e = 12°$

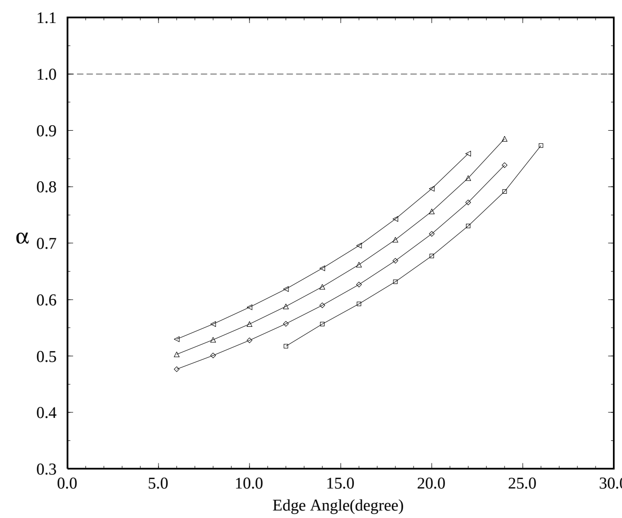

Figure. 4. Momentum Compaction Factor α variation with respect to L and θ_e with the same parameters used in Figure 2

($\alpha = 1/\gamma_T^2$) when other parameters are adjusted. Figure 4 shows the change of α with θ_e and L.

III. The CIS Lattice With Trim Quadrupoles

In order to have the flexibility of adjusting betatron tunes, four trim quadrupoles will be used. However, we do have the options of using two or four trim quads. with their positions adjustable.

A. Tune Diagram

Figure 5 shows the tuning range of the CIS with these trim quads.. In the case of two trim quads., machine is stable for the vertical tune below 1.0, which shows in Figure 5 as △s below the line of $Q_z = 1$. In the case of four asymmetrical quads. with superperiod of two, there is a vertical tune gap due to the integer resonance. Within this gap, the vertical motion is unstable as shown in Figure 6. The corresponding lattice function distributions are shown in Figure 7.

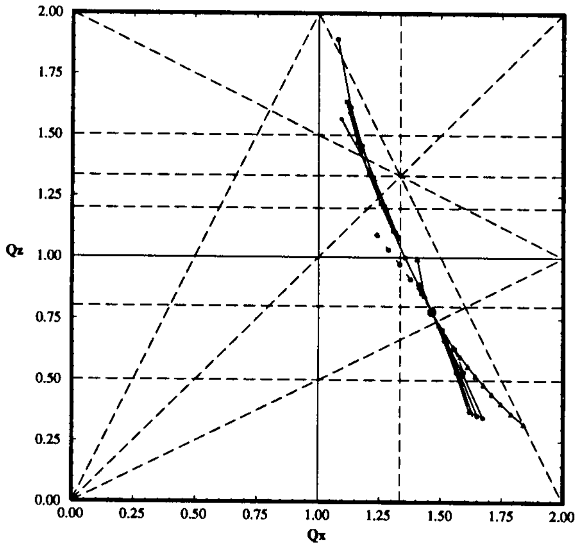

Figure. 5. Tune diagram for the CIS with trim quads.. Where ◯ stands for the lattice without trim quads., △ for the lattice with two trim quads. and all others having four trim quads. with their locations adjusted with respect to the the dipoles

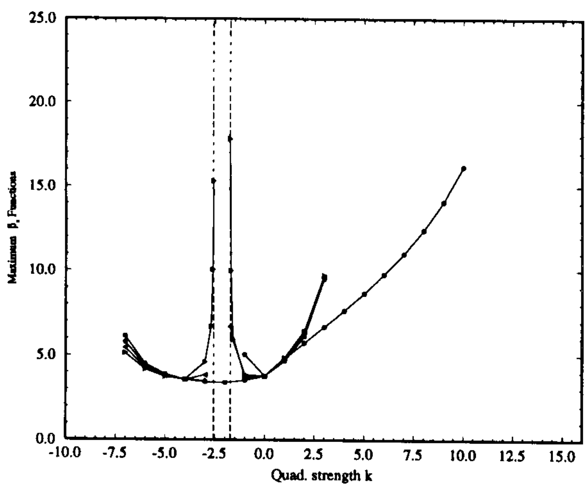

Figure. 6. Maximum vertical betatron functions for the CIS with trim quads. Where the notations and conditions are as same as that we used for Figure 5

B. *Momentum compaction factor* α

Figure 8 displays the variation of momentum compaction factor α. It turns out that α does not change very much for different strengths of the quadrupoles. It, however, offers possibilities of transition crossing lattices. In the case of two trim quads., momentum compaction α changes sign at the quadrupole strength between 7.68 and 7.8. This leads to a possible imaginary γ_T lattice ($\alpha = 1/\gamma_T^2$).

IV. Conclusion

In conclusion, we have studied the CIS lattice by varying parameters, such as circumference, the dipole length, the edge angle, the trim quads. position and strength. We found that the CIS lattice parameters, which are listed in Table I, will meet our proposed requirements for the beam performance. With the employment of trim quadrupoles, the machine possesses flexibility for

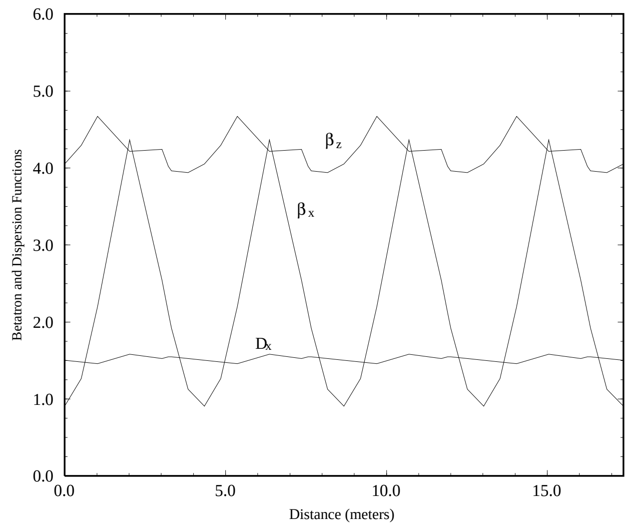

Figure. 7. Lattice functions for the CIS with trim quads. for four trim quads and each quadrupole is 20 cm away from the dipole.

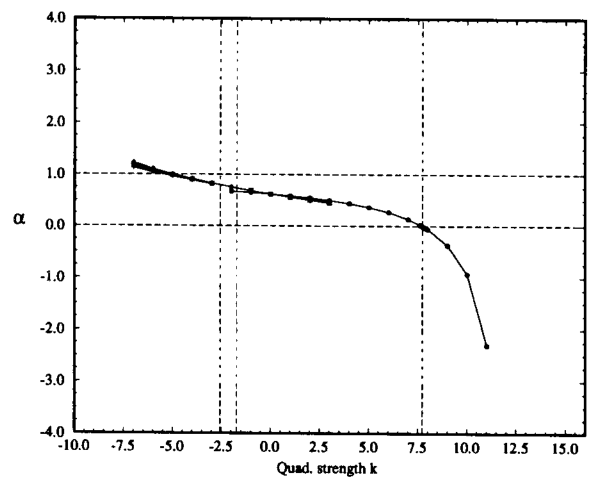

Figure. 8. Momentum compaction factor α for the CIS with Where the notations and conditions are as same as that we used for Figure 5

betatron tune adjustments. Furthermore, γ_T can be also varied by the trim quadrupoles. Thus, the CIS will become an interesting machine for accelerator physics studies such as transition energy crossing and imaginary γ_T lattice in longitudinal beam dynamics studies.

References

[1] H. Grote *et al.*, The MAD Program, User,s Reference Manual.

[2] D. Friesel *et al.*, News Letter, IUCF, April, 1995.

[3] Conceptual Design Manual For CIS, IUCF Internal Report (January 1995).