BEAM EXTRACTION SYSTEM FOR THE COOLER INJECTOR SYNCHROTRON AT IUCF

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Abstract

The Cooler Injector Synchrotron (CIS) being built at IUCF will serve as an injector for the existing IUCF Cooler Ring. The beam extraction from CIS and injection to the Cooler Ring include the the orbit bump, extraction kicker, septum magnet in the CIS ring, the transport beam line, and injection part to the Cooler ring. After extracted from CIS ring with a traveling wave fast kicker (15 mrad) and a Lambertsen septum, beams are transported by the beam line BL9 to the cooler injection point and injected into the cooler ring by a fast traveling wave injection kicker.

1 INTRODUCTION

A Cooler Injector Synchrotron (CIS)[1], nearing completion at IUCF, is designed to provide polarized light ion beams, such as 200MeV proton beams, for the existing Cooler Ring. The CIS beam extraction system is composed of four orbit bumpers, a traveling wave fast kicker and a 12° Lambertsen septum. After extracted from CIS, beams are transported to the Cooler Ring by the beam line BL9, which consists of a suitable set of quadrupoles and dipoles for beam matching at the injection point and two solenoids for spin manipulation. Beams are injected into the Cooler Ring at an angle of 9.4 $mrad$ by a septum and fast traveling wave injection kicker at the injection point. The beam parameters are matched at the injection point horizontally by adjusting the positions the strength of the quadrupoles and vertically by setting a proper conditions of both CIS and Cooler rf systems.

2 BEAM EXTRACTION FROM CIS

As shown in Figure 1, single-turn method is used for the fast beam extraction from CIS. After deflected by the kicker, the beam passes through the region with deflecting field for extraction while the closed orbit passes through the field-free region in the septum. The beam offset at the location of septum x_s must not be less than the half-width of the circulating beam with an allowance for closed orbit distortions and alignment errors plus the half-width of the extracted beam and the septum width. The kicker is often dictated by technology and economics, so it is advantageous to make betatron phase shift between the kicker and septum $\Delta\mu$ closed to $\pi/2$ and β_k large so that δ_k is reduced. The minimum strength of septum depends on how much more angular deflection is needed to take the beam clear of the next machine magnet. However, the deviation of the beam directly from the central orbit provided by the kicker is not big enough for the structure of the septum.

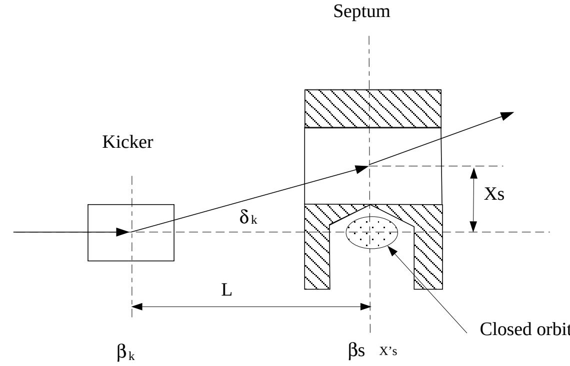

Figure 1: CIS fast extraction structure.

To minimize the cost and strength of the fast kicker, beam bumpers are used to adjust the closed orbit locally closer to the septum. Outside the four bumpers, the closed orbit is still along the CIS central line.

For the CIS extraction, a fast traveling wave kicker[2] is used which can deflect $200MeV$ proton beam at least for an angle of 15 $mrad$ within a cycling time of 90 ns. The deviation of the beam at the septum is only $17mm$ According to the geometry of the septum, totally the beam should have a displacement of $> 40mm$ in order to be extracted from the ring. So before kicking the beam, four bumpers are used to bump the closed-orbit by about 25mm from the central orbit in the vicinities of the septum. Figure 2 shows the closed orbit bump and beam extraction trajectory in the horizontal plane. The beam has a small angle(0.65°) inwards before entering the septum. If the septum is rotated by 3.1°, the field component B_z can correct this angle.

If the traveling wave kicker pulse has some fluctuation before and after the kick, the closed orbit and the extracted beam will be affected slightly near the septum. The simulation results show that the maximum change of the closed orbit due to $\pm5\%$ pre-pulse fluctuation is less than $\pm1mm$ and the changes at kicker and septum are even less. The effect of the $\pm10\%$ kicker top pulse fluctuation(total effect of $\pm5\%$ pre-pulse and $\pm5\%$ top pulse fluctuation) is that the beam trajectory has a change of $\pm1.5mm$ at the first dipole after kicker. The beam positions at kicker and septum change less than $\pm2mm$.

In the vertical plane, the septum deflects the beam upwards by 12° to let the beam avoid the dipole magnet No. 3 and then deflected back to the horizontal direction by another dipole TPES. After the beam is extracted from CIS, it is 0.77m above the CIS ring plane vertically, as shown in Figure 3.

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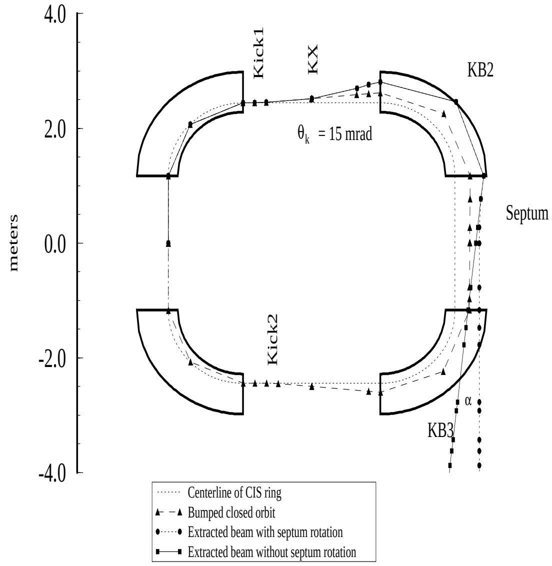

Figure 2: Closed orbit bump and beam extraction from CIS. Note that the orbit deviation are enlarged by 10 times.

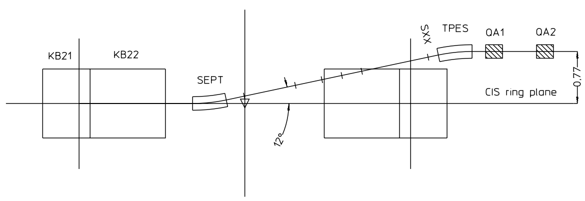

Figure 3: Beam extraction trajectory in the vertical plane.

3 TRANSPORT BEAM LINE BETWEEN CIS AND COOLER

The extracted beam from the CIS ring has emittance of $10\pi mm \cdot mrad$ and momentum spread of 0.15% and is transported from CIS to Cooler by the transport beam line composed of a set of suitable quadrupoles, dipoles and solenoids. Two solenoids SOL1, SOL2 and two dipoles D1, D2 are used for providing proper spin orientation for polarized beam injection for the cooler ring. In order to inject the beam to the cooler properly, both the transversal and longitudinal beam parameters must be matched at the injection point.

The constraints for the transversal beam matching are the field gradients B' of eight quadrupoles from QA1 to QA6, Q99 and Q109, the distance SA12 between the first two quadrupoles Q1 and Q2. After adjusting the above constraints, the beam parameters β functions β_x, β_y, α_x, α_y and dispersion function D_x and D'_x are matched at the injection point of the cooler ring. Table 1 shows the initial and final values of the above constraints. Table 2 shows all the matched parameters. After the matching of the beam parameters, the beam envelope along the beam line must be smaller than the vacuum chamber to avoid beam loss. Figure 4 shows the β functions along the beam line. After the calculation, the horizontal beam envelope is much smaller than the vacuum chamber and the vertical beam envelope is also smaller than the magnet gap, as shown in Figure 5.

Table 1: Constraints for the transversal injection matching.

Parameters	Initial	Final
B'_1	9.9999982	9.9999999
B'_2	-7.2650281	-7.3876488
B'_3	6.6119067	0.9066779
B'_4	-6.5590755	1.1898049
B'_5	2.2938179	6.7237249
B'_6	-2.4567029	-7.1063014
B'_{99}	2.0705442	2.5966974
B'_{109}	-1.2928168	-5.5034685
S_{12}	0.2155292	0.2378493

Table 2: Beam parameters matched at the cooler injection point.

Parameters	Desired	Present	Error
β_x(m)	2.281	3.189	0.908
β_y(m)	1.744	1.599	-0.144
α_x	0.173	-0.486	-0.658
α_y	-0.130	-0.463	-0.333
D_x(m)	-4.180	-5.079	-0.899
D'_x	-0.027	0.053	0.080

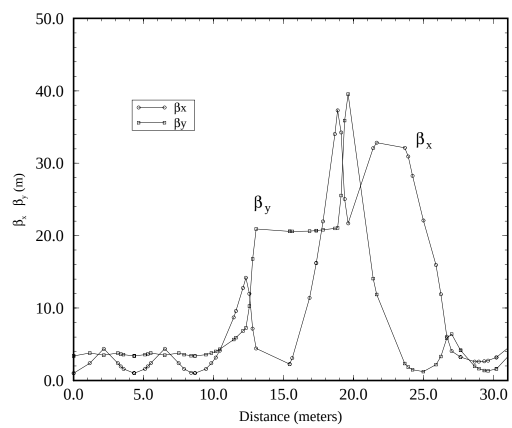

Figure 4: β functions along the extraction beam line.

For the longitudinal beam matching, the ratio of the bucket height and width of the two rings must maintained in order to avoid the bunch dilution during the bucket to bucket transfer from CIS to Cooler,

$$\left|\frac{\hat{\delta}}{\sigma}\right|_{CIS} = \left|\frac{\hat{\delta}}{\sigma}\right|_{Cooler} \quad (1)$$

This condition requires the equilibrium phase space profile

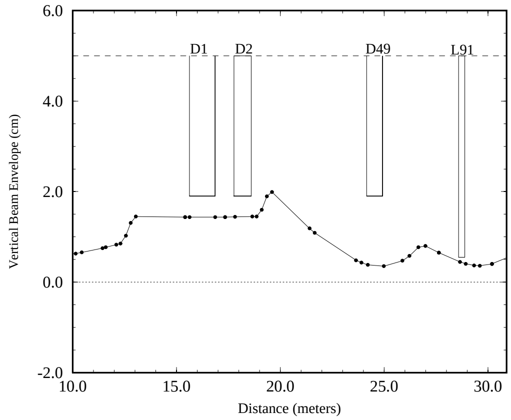

Figure 5: Vertical beam envelope along the beam line.

matching of the rf system

$$\left|\frac{V\cos\phi_s}{h\eta}\right|_{CIS} = \left|\frac{V\cos\phi_s}{h\eta}\right|_{Cooler} \quad (2)$$

which means that the rf system in CIS should reflect a proper longitudinal matching condition.

4 BEAM INJECTION TO THE COOLER

Fast injection method is used for the beam injection into the Cooler upon the modification of the existing beam line BL9. Figure 6 shows the horizontal plane of the injection section.

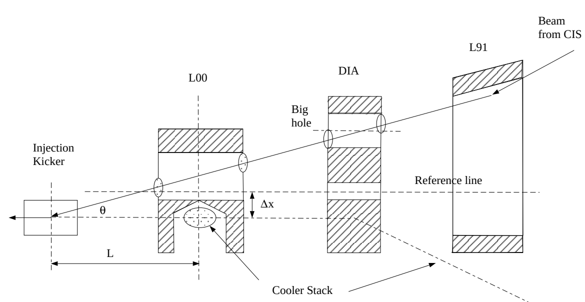

Figure 6: Horizontal plane of the cooler injection section.

In the horizontal direction, Cooler stack is deflected by $3°$ by DIA and DIB respectively and is bumped close to injection beam near L00 by the existing bumpers in the Cooler Ring. Injected beam from L91 enters the kicker with an angle less then 15mrad and then kicked to the Cooler stack direction by the traveling wave kicker. Vertically, the beam is bent down by a dipole SV2 before entering L91 and flatten at Lambertsen magnet L00.

Based on the existing beam element arrangement, the available space for injection kicker is 1.5m and the center of the kicker should be 2.0m away from L00. In order to pass through DIA and L00, the injection beam must have an angle of $> 16mrad$, which is difficult for a 1.5m long injection kicker to deflect. The solution is to merge the two holes in DIA into one big hole. Then, with an angle of $9.4mrad$, the beam is easily injected into Cooler by the fast kicker which is 2.0m away from L00.

Making two existing holes into one big hole, the strength and quality of the DIA dipole maybe affected. However, the calculation results show that the leaking field in the big hole of DIA is only 12Gs which has a deflection angle of 0.1564$mrad$ on the 200MeV beam. This effect is negligible.

For each injection cycle, 5 pulses from CIS are injected to the cooler and accelerated to the desired energy. This requires that the rise and fall time of the injection fast kicker is less than 70 ns. The horizontal gap of the injection kicker must be big enough for the beam and the Cooler stack bump. The acceptance of the cooler is $20\pi mm \cdot mrad$ and the dispersion function at the injection point is 1.5m, which gives a beam size of 11mm. The closed orbit needs to be bumped from 8mm to 14mm for the injection. So the total width of the gap should be bigger than 4.3cm.

5 CONCLUSION

Fast extraction method is used to extract the 200MeV beam from CIS and fast injection method is used to inject the beam into Cooler Ring. The kicker angles required for the extraction and injection kickers are less than $15mrad$. The $\pm5\%$ pre-pulse and $\pm5\%$ top pulse fluctuation of the CIS extraction kicker has small effect on the beam trajectory. Some modifications are needed on the existing beam element arrangement in order to inject the beam into the Cooler properly. Both transversal and longitudinal beam parameters can be matched for the Cooler injection by adjusting parameters of the beam elements and rf systems.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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