

INJECTION/EXTRACTION OF ACHROMAT-BASED 6D IONIZATION COOLING RINGS FOR MUONS

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Abstract

An achromat-based cooling ring using dipoles and solenoids is introduced and it can cool muons by large factors in six dimensions to achieve the necessary luminosity for a muon collider. The ring is designed with sufficient space in each superperiod for injection and extraction magnets. We estimate the parameters for the injection system into the solenoid-dipole ring cooler. We also present some simulations for injection/extraction system and discuss the injection/extraction requirements.

INTRODUCTION

Six dimensional cooling of large emittance μ^+ and μ^- beams is required in order to obtain the desired luminosity for a muon collider [1]. In recent years, we have developed a lattice concept for muon cooling called the achromatic ring cooler. We show a schematic of the ring cooler with an injection system in Figure 1, using a superconducting flux pipe [2]. The magnet system of such a ring uses solenoids and dipoles. The ring is composed of two or more modules (or superperiods), each consisting of an arc and a straight section. The arc provides dispersion in spaces for the wedge absorbers needed for 6D cooling. The straight sections are dispersion-free and provide spaces for injection and extraction and RF cavities. This achromatic ring lattice design can be converted to one for a single-pass snake-like device by alternating the polarity of the dipole fields from one arc to the next [3]. We have previously published our results of a four-sided ring cooler at NIMA journal [4]. We demonstrate that this ring cooler can give substantial cooling in all 6 phase space dimensions.

It is known that the biggest challenges in our compact Dipole/Solenoid ring cooler and the similar RFOFO cooling ring [5] have been injection and extraction. Because of little space in the basic lattice cell, a powerful kicker is expected. As an estimate of the required kicker [6] we assume a beam at 220 MeV/c with a normalized emittance of 0.012 m-rad and assume $\beta^* = 1\text{ m}$ at injection/extraction. The kicker must be great than the divergence width of the beam (the rms width is $\sim(\epsilon/(\gamma\beta^*))^{1/2}$ or $\sim 75\text{ mrad}$) by a fact of 4; so a kick of $\sim 300\text{ mrad}$ is needed. This means a total kick of $B\rho \times 0.3$ or 0.22 T-m is needed. Also the rms beam size at the kicker is $\sim(\epsilon\beta^*/\gamma)^{1/2}$ or $\sim 7.5\text{ cm}$; a $\pm 3\sigma$ aperture would be 45 cm.

In our proposed four-sided ring cooler [4], our simulation shows that the injected beam has to go through one or more solenoids before it can be merged into the

circulating orbit and we must insert a device to create a field-free path inside those solenoids that the beam will go through. In the 1970s SLAC built a superconducting flux exclusion pipe, which is being used to create a field-free path through a transverse magnetic field of 1.5 T in an experiment at SLAC [2]. In our injection system, we can use this idea with a superconducting flux exclusion pipe and two or more induction kickers [7] to merge the beam into the cooling orbit.

In this paper, we give an overview of our four-sided ring cooler with the lattice and 6D cooling performance included. We then estimate the parameters for the injection system into the solenoid-dipole ring cooler. Finally, we will present some simulations for injection/extraction system and discuss the injection/extraction requirements.

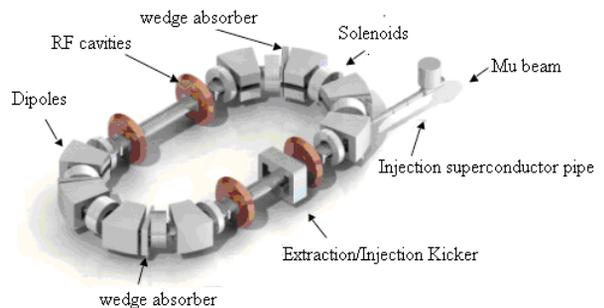


Figure 1: Schematic drawing of an achromatic 6D ring cooler with superconducting flux pipe injection system.

THE ACHROMATIC SOLENOID-DIPOLE RING COOLER

We have studied the lattice and 6D cooling performance in detail in Ref. [4] for an achromatic four-sided ring cooler, as shown in Fig. 2. In Fig. 3, we show the ring quadrant for the four-sided solenoid-dipole ring cooler. We see each quadrant or basic cell of our ring cooler consists of an arc and a straight section and has an internal eight-fold symmetry. The arc is achromatic at a particular reference energy. To generate dispersion primarily in one of the two transverse phase space planes, thereby simplifying the task of making the arc achromatic, we alternate the field directions of successive solenoids. Transverse focusing is primarily provided by solenoids, and bending is provided by the dipoles in the arcs.

Evolution of the beam parameters in the cooling process during 30 turns of the four-sided ring cooler is presented in Fig. 4.

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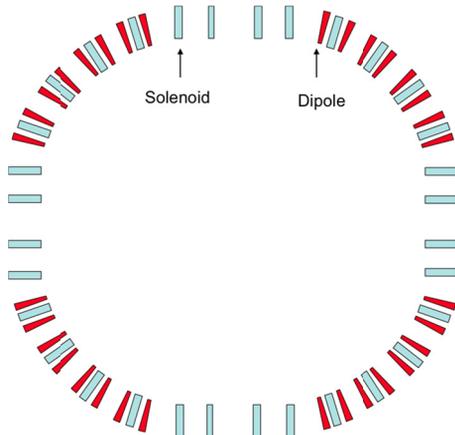


Figure 2: Schematic drawing of the four-sided ring utilizing dipoles and solenoids.

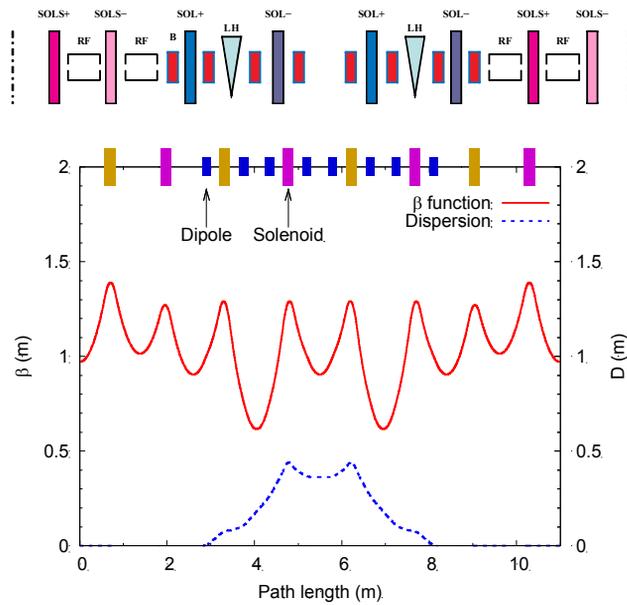


Figure 3: Schematic drawing of the ring quadrant (top) and beta function and dispersion (bottom) in the four-sided and achromatic ring cooler.

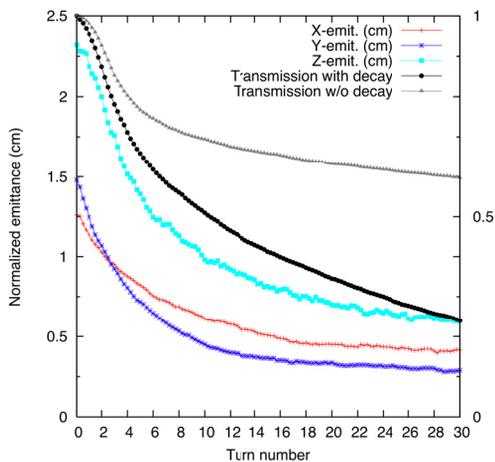


Figure 4: Beam emittance and transmission as a function of full ring turns.

ESTIMATE OF THE PARAMETERS FOR THE INJECTION INTO THE FOUR-SIDED RING COOLER

As shown in Fig. 5, we calculate the offset of the injected beam and the kick angle needed 90 degrees away in betatron phase to make the beam follow the central orbit. In Table 1 we list the estimated field, current, and flux in the kicker and the voltage required to change the field in one revolution, etc. for 3 sigma acceptance.

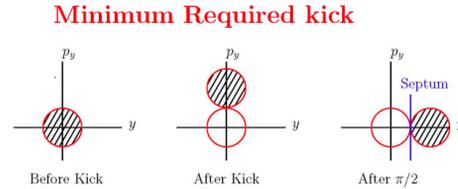


Figure 5: Schematic diagram for estimation of the kicker system.

Table 1: The Parameters of the Kicker System (Based on 3 Sigma Acceptance)

Name	Unit	Value
Brho	Tm	7.3384E-01
Emit	m	5.9553E-03
Ampl	m	2.5361E-01
Offset	m	5.0721E-01
Kicker	Tm	3.1001E-01
Length	m	8.0000E-01
Kick	T	3.8751E-01
Flux	W	6.1057E-01
Current	Amp	5.2166E+04
Voltage	Volt	4.0263E+05

SIMULATION OF INJECTION THROUGH THE FLUX PIPE

First, we study the behavior of a single muon in the long straight section of our four-sided ring for extraction [3]. As shown in Fig. 6, it is not enough to separate the injected beam away from the cooling orbit in single straight section that a kicker of K1 is located (length of solenoids in straight section is modified from 0.25 m to 0.5 m for less hard edge focusing). We could add a second kicker of K2 between the solenoids to obtain necessary separation between injected beam and cooling orbit just before the second solenoid for insertion of a superconducting flux pipe. This tube will shield the magnetic field from Sol2 and create a field-free path through the Sol2 magnetic field. We envision injection from the right to left inside this flux exclusion tube and then merged into the cooling orbit using two kickers.

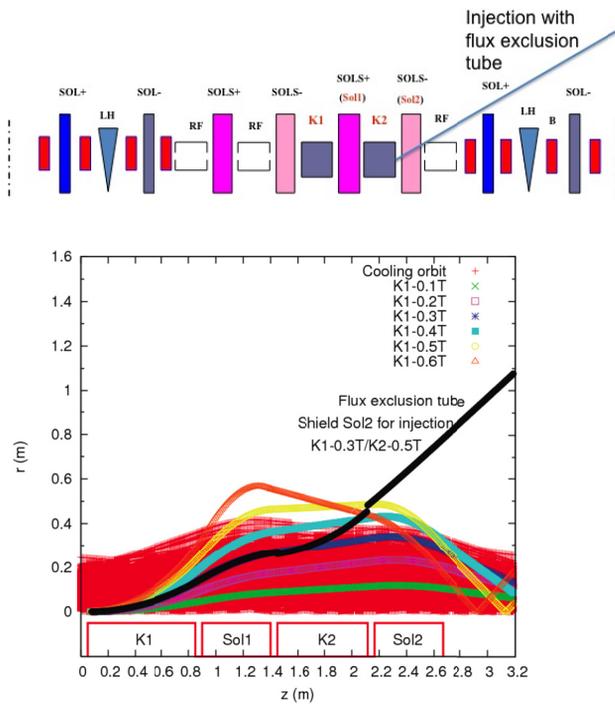


Figure 6: Layout of the injection system (K1, K2 and flux exclusion tube are required for injection) (top) and single particle simulation (bottom).

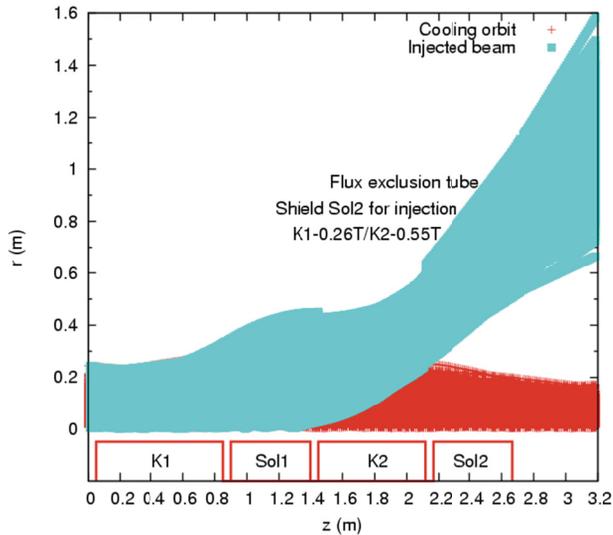


Figure 7: Simulation of 85% of the initial entire beam for injection/extraction (r-z plot).

Second, we simulate the real beam for extraction. This beam comes from our previous 6D cooling study with normalized horizontal emittance of 1.26 cm and vertical emittance of 1.48 cm. Our simulation shows we can't obtain necessary separation in front of the Sol2 if this entire initial beam is launched. By adding aperture to impose a rectangular or elliptical constraint on all particles transverse coordinates at this location, we can limit the P_x to 0.03 GeV/c and pick out the remaining 85% from the entire initial beam, we found a clear separation between this beam and the circulating orbit in

Fig. 7 shows the simulating results. We see the beam has enough separation for inserting the flux tube using 0.26 T for K1 and 0.55T for K2.

CONCLUSIONS

We have described an achromatic ring cooler and snake using solenoids and dipoles as lattice elements. We demonstrate that the lattice gives substantial cooling in all 6 phase dimensions. In addition, we have also estimated the kicker parameters for the injection system needed 90 degrees away in betatron phase to make the injected beam follow the central orbit of the four-sided ring cooler. Furthermore, we have simulated the extraction process with both single particle and the beam. We find two kickers and a superconducting flux exclusion tube are required in our extraction system. At this stage, our simulation shows a clear separation can be created in front of the Sol2 between the extracted beam from 85% of the entire initial beam for 6D cooling and the circulating orbit. The injection is exactly a reverse of extraction process. So we can envision the beam can be injected from the right to left inside this flux exclusion tube, go through the Sol2 with field-free path and then merged into the cooling orbit utilizing two kickers.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy in part under award numbers DE-FG02-92ER40695 (UCLA), DE-AC02-98CH10886 (BNL) and DE-FG02-07ER84855 (Particle Beam Lasers, Inc.)

REFERENCES

- [1] M. Yu, Ado, V.I. Balbekov, Sov. At. Energy 31 (1971) 731.
- [2] F. Martin, S.J. St. Lorant, W.T. Toner, "A four-meter long superconducting magnetic flux exclusion tube for particle physics experiments", Nuclear Instruments and Methods, Volume 103, Issue3, 1972, p. 503.
- [3] X. Ding, et al., "Status of studies of achromat-based 6D ionization cooling rings for muons", IPAC11, MOPZ030, San Sebastian, Spain, 2011.
- [4] A.Garren, J.S. Berg, D. Cline, X. Ding, H.G. Kirk, "6D μ^\pm cooling using a solenoid-dipole ring cooler for a muon collider", Nucl. Instr. And Meth. A 654 (2011) 40-44.
- [5] R. Palmer, et al., Phys. Rev. Spec. Top. Accel. Beams 8 (2005) 061003.
- [6] D. Neuffer, "Injection and/or extraction and a ring cooler", Nucl. Instr. And Meth. A 503 (2003) 374-376.
- [7] R.B. Palmer, L. Reginato, D. Summers, An Induction Kicker for Muon Cooling Rings, MUC-NOTE-COOL-THEORY-256 (2002).