STATUS OF STUDIES OF ACHROMAT-BASED 6D IONIZATION COOLING RINGS FOR MUONS

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Abstract

Six dimensional ionization cooling of muons is needed to achieve the necessary luminosity for a muon collider. If that cooling could occur over multiple turns in a closed ring, there would be significant cost savings over a single-pass cooling channel. We report on the status of a cooling ring with achromatic arcs. The achromatic design permits the design to easily switch between a closed ring and a snaking geometry on injection or extraction from the ring. The ring is designed with sufficient space in each superperiod for injection and extraction magnets. We describe the ring's lattice design, performance, and injection/extraction requirements.

INTRODUCTION

A substantial cooling in the full six dimensional phase space of the beam is required to lead ultimately to a useful luminosity in the Muon Collider [1]. It was realized that a collected muon beam could be cooled by a process utilizing energy losses during the beam passage through an appropriate material [2]. In this technique, referred as ionization cooling, if muons alternately pass through a material absorber, and are then re-accelerated, and if there is sufficient focusing at the absorber, then the transverse phase space is reduced, i.e. the muons are cooled in the transverse dimension. A consequence of the transverse cooling is an increase of the longitudinal phase space caused by the unfavourable slope of the dE/dx curve for momenta below the ionization minimum and by energy straggling in the material [3]. In order to realize longitudinal cooling via the energy loss process, it is necessary for the beam to have dispersion. This is because dispersion gives the beam a correlation between energy and tranverse displacement. The placement of absorbing wedges in the beam creates a favourable correlation between particle energy and energy loss, and this allows longitudinal cooling.

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 [4]. 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.

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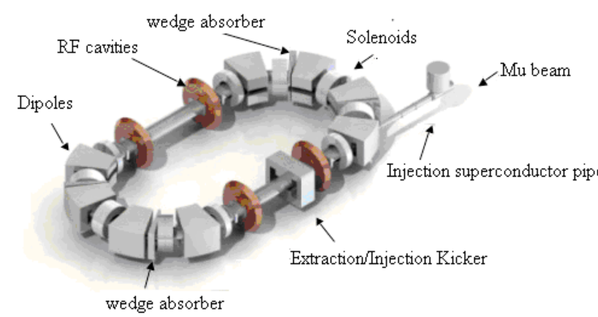

Figure 1. Schematic drawing of an achromatic 6D ring cooler with superconducting flux pipe injection system.

In this paper, we report on the status of a cooling ring and a snake with achromatic arcs. The ring is designed with sufficient space in each superperiod for injection and extraction magnets. We describe the ring's lattice design, performance, and injection/extraction requirements.

THE ACHROMATIC SOLENOID-DIPOLE RING COOLER AND SNAKE

We have studied the lattice and 6D cooling performance in detail in Ref. [5] for an achromatic four-sided ring cooler. As shown in Fig. 2, we also recently design a snake-like shape lattice. This four-sided and snake lattice had a significantly improved dynamic aperture, and a significantly improved momentum passband arising from the reduced chromaticity of the lattice. In addition, this four-sided and snake lattice improved the sum of the damping partition numbers and the resulting cooling performance was a significant improvement over that of the original lattice of two-sided "racetrack" shape shown in Fig. 1. 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, which allows the cell to be used in a closed ring or in an open single-pass configuration, and even to switch between the two. 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. We envision a series of rings connected by snakes for cooling from large to small emittances.

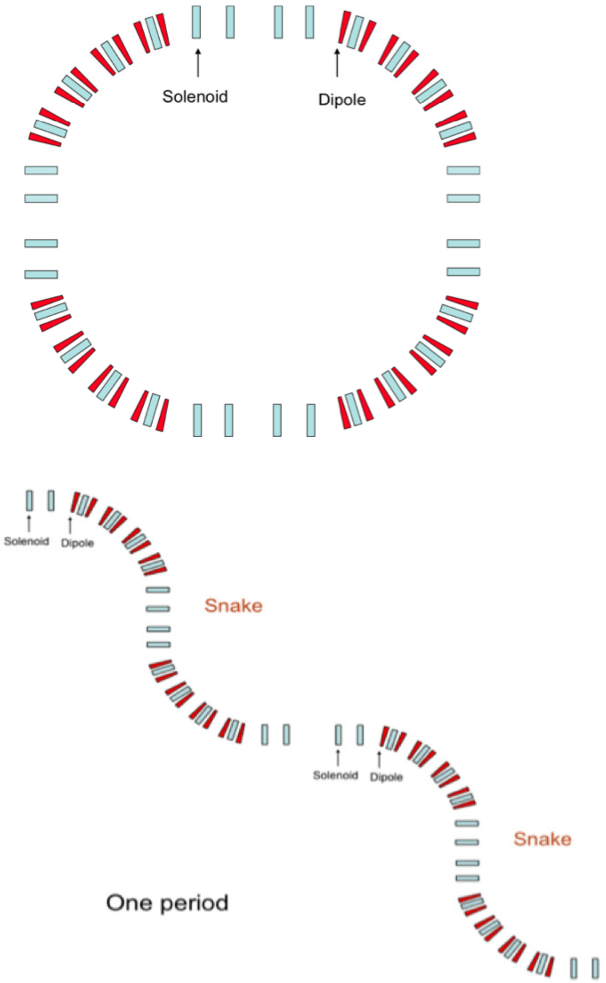

Figure 2. Schematic drawing of the four-sided ring (top) and snake (bottom) utilizing dipoles and solenoids.

As shown in Fig. 3, liquid hydrogen (LH_2) wedge absorbers are inserted into a region with low β and high dispersion for cooling the beam. Each LH_2 wedge absorber has a length of 19.5 cm along the closed orbit of the working momentum at 220 MeV/c. The energy loss rate at the absorber is 0.303 MeV/cm and the total angle of each wedge is 23^{O}. Four 201.25 MHz accelerating cavities (RF) are placed in the superperiod. Each cavity has a maximal axial accelerating gradient of 15 MV/m and the RF phase is set at 30^{O}. The RF cavities will restore the energy of the muon beam as it is lost in the LH_2 absorbers. Evolution of the beam parameters in the cooling process during 30 turns of the four-sided ring cooler is presented in Fig. 4. The initial input beam is selected by first generating a beam with large spreads in all 6 dimensions and following the passage of each particle through 15 full turns of the ring with stochastic processes (multiple Coulomb scattering and energy straggling) turned off. We then identify the beam particles which successfully traverse the complete 15 turns of the ring and recover their initial starting values. We then re-launch these recovered particles with the stochastic processes turned on. Note that the emittance reduction is confined mainly to the first 15 full-turns of the ring at which point the emittances are approaching an equilibrium value for each of the three dimensions.

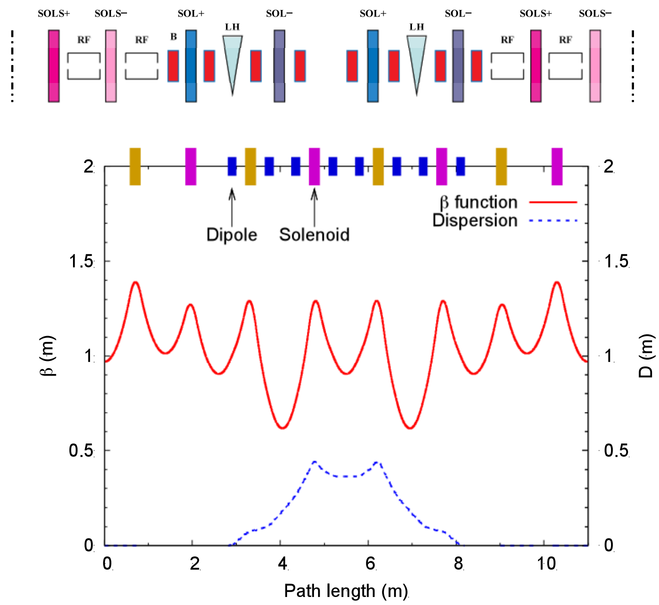

Figure 3. Schematic drawing of the ring quadrant (top) and beta function and dispersion (bottom) in the four-sided and achromatic ring cooler.

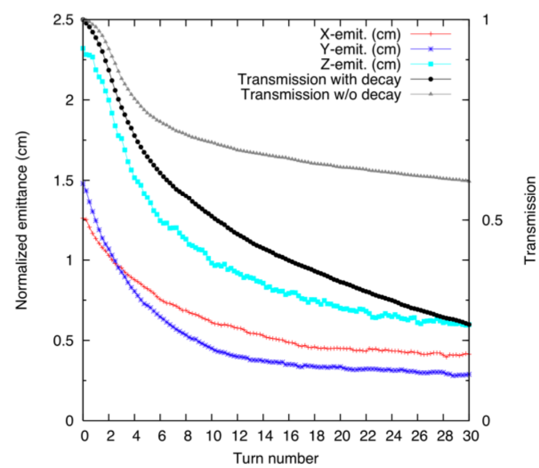

Figure 4. Beam emittance and transmission as a function of full ring turns.

We also compute the merit factor as defined in [3]. This factor is the ratio of the initial product of the horizontal, vertical, and longitudinal emittances to the final value of that product, multiplied by the fraction of the muons that survive. This merit factor vs. the number of turns or periods is shown in Fig. 5.

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

The biggest challenges in a compact ring cooler have been injection and extraction [3]. Because of little space in the basic lattice cell, an extremely powerful kicker is expected. Our proposed ring has a long straight section of 0.9 m in its cell structure, it is still not enough to separate the injected beam away from the cooling orbit in single straight section that a kicker of K1 is located (see Fig. 6 with length of solenoids in straight section 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 the cooling orbit just before the second solenoid for insertion of a superconducting flux pipe. This tube will shield the magnetic field from the Sol2 and create a field-free path through the magnetice field of Sol2. We envision the beam can be injected from the right to left inside this flux exclusion tube and then merged into the cooling orbit utilizing two kickers. In table 1, 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. We also estimate the current, flux in the kicker and the voltage required to change the field in one revolution based on our studies of 6D cooling [6].

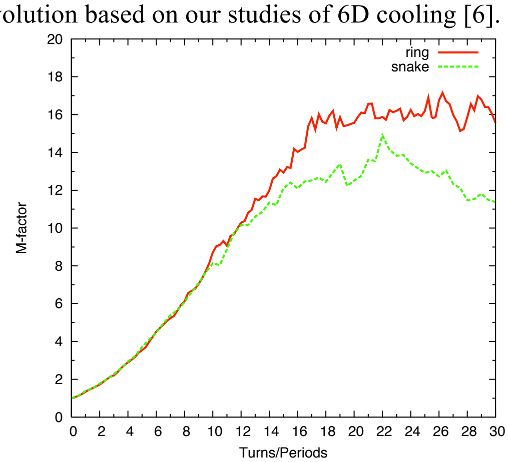

Figure 5. Merit factor [3] with muon decay considered for the four-sided ring and snake.

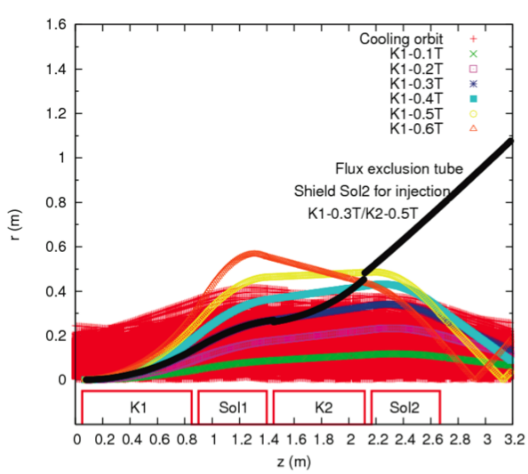

Figure 6. The injection system (K1, K2 and flux exclusion tube are required for injection).

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

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. Preliminary simulation of single particle shows that we need 2 kickers and a superconducting flux pipe to satisfy the injection/extraction requirements.

ACKNOWLEDGMENTS

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