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RFOFO Cooling Ring: Simulation Results

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Brookhaven National Laboratory

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Physics Department, Brookhaven National Laboratory, Upton, NY 11973

Abstract. Practical cooling rings could lead to lower cost or improved performance in neutrino factory or muon collider designs. The ring modeled here uses realistic 3-dimensional fields and includes such "real-world" effects as windows on the absorbers and RF cavities and leaving empty lattice cells for injection and extraction. The ring increases the density of muons in a fixed acceptance volume by a factor of 4.2.

INTRODUCTION

Designs for neutrino factories [1] and muon colliders [2] use ionization cooling to reduce the emittance of the muon beam prior to acceleration. Current baseline designs make use of linear channels that only cool the beam in transverse phase space. However, there has been considerable progress over the past two years in achieving 6-dimensional ionization cooling in cooling rings [3]. At present the most realistic modeling has been done for the RFOFO ring [4-7]. Alternating polarity solenoids provide transverse focusing. The bending field is provided by alternately tipping the axis of the solenoids above and below the orbital midplane. A short cell length is used to obtain a small beta function with a reasonable value of the solenoid field strength. Wedge-shaped absorbers are placed in the beam path at locations where the solenoidal field changes direction. Most of the lattice cell is filled by RF cavities to restore the energy lost in the absorbers.

MODELING THE RING

The RFOFO ring was modeled using the simulation code ICOOL [8]. A layout of three cells of the ring is shown in Fig. 1 and a summary of ring properties are given in Table 1.

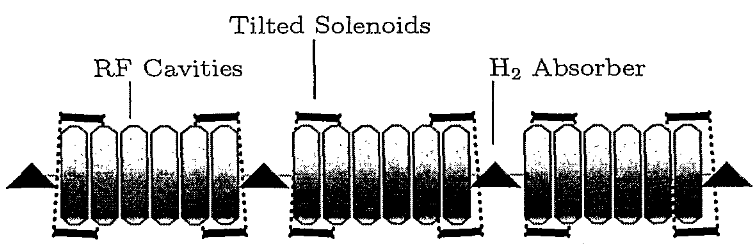

FIGURE 1. Vertical view of three cells of the RFOFO lattice.

The particle motion is centered on a 33 m circumference circle. The centers of the solenoids are displaced radially outwards from this circle by 10 cm to reduce the on-axis radial field. The 3-dimensional magnetic field from the ring of tipped solenoids was calculated in an independent code by summing the fields from a system of current sheets [9,10]. The resultant field components were shown to satisfy Maxwell's equations to a high level of accuracy and agreed well with independent calculations [11,12]. The RF cavities were modeled using cylindrical pillboxes running in the TM010 mode. The liquid hydrogen absorbers have a wedge shape and are located in dispersive regions in order to decrease the momentum spread in the beam.

TABLE 1. RFOFO ring parameters.

circumference	33	m
cells	12	
coil tilt angle	3	degrees
min. transverse beta function	38	cm
max. dispersion function	8	cm
wedge opening angle	100	degrees
RF frequency	201.25	MHz
peak RF gradient	12	MV/m
RF phase from 0-crossing	25	degrees

SIMULATION RESULTS

We first examine the performance of an "ideal" ring, ignoring the effects due to windows on the absorbers and RF cavities and leaving empty space for injection. Since the magnetic field has a small radial component on-axis, the closed orbits are non-planar. Fig. 2 shows the transverse motion of the closed orbit for a 200 MeV/c muon.

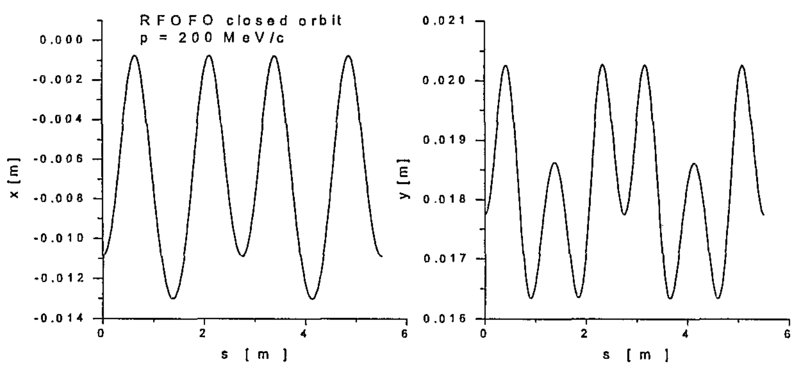

FIGURE 2. Transverse position of a closed orbit along two cells of the system axis. y: vertical, x: radial position.

Note that the closed orbit is offset by 11 mm in x and by 18 mm in y at the beginning of the cell. Along the cell x varies by ±6 mm and y varies by ±2 mm. For the simulations we use a Gaussian input beam with normalized transverse emittance of 12 mm and normalized longitudinal emittance of 18 mm. The initial beam had a correlation between the axial momentum and the transverse amplitude to minimize the tendency for the particles in the bunch to spread out longitudinally in the solenoidal field. The correlation causes the average axial momentum to be larger than the reference momentum of 203 MeV/c. The ring has a momentum acceptance from 160 to 260 MeV/c. Fig. 3 shows the radial and longitudinal phase space after 1 and 15 turns.

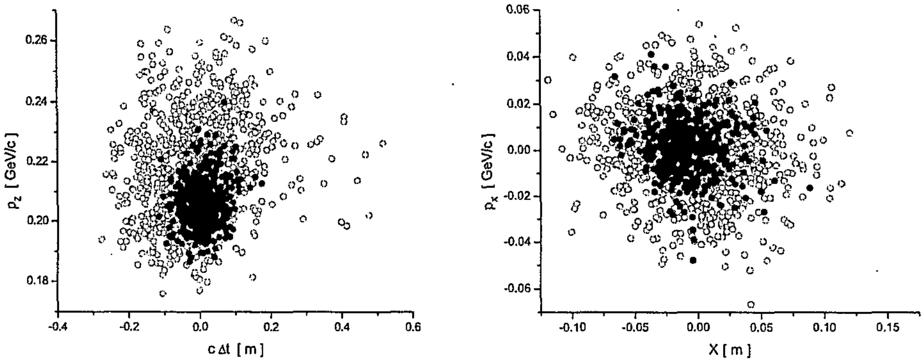

FIGURE 3. Longitudinal phase space (left) and radial phase space (right) after 1 turn (open circles) and 15 turns (closed circles).

The reduction of phase space area can be seen clearly in both distributions. The vertical transverse distribution is similar to the radial one because of the solenoids.

We now consider the effects on performance of including windows for the absorbers and RF cavities and leaving empty cells for injection. We refer to this as the "practical" ring design. We enclose the liquid hydrogen absorbers with 360 μm aluminum windows. The RF cavities have tapered 20 μm thick beryllium windows on the two ends and tapered 70 μm thick beryllium windows between the interior cells. Two adjacent cells have the absorber and RF cavities removed in order to leave space for the injection kicker, but the magnetic periodicity is maintained. Fig. 4 shows the evolution of the emittances and transmission for the practical ring design.

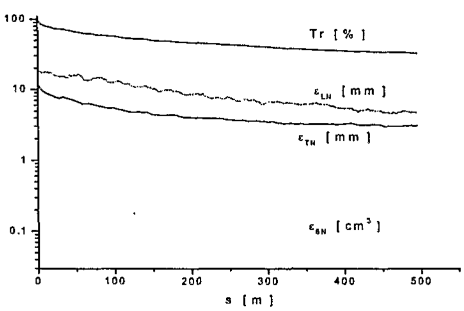

FIGURE 4. Normalized emittances and transmission with decay as a function of accumulated distance in the practical cooling ring. One turn is 33 m.

The performance of the practical ring is summarized in Table 2.

TABLE 2. Performance of the practical RFOFO cooling ring.

ε_{TN}	3.1	mm
ε_{LN}	4.8	mm
ε_{6N}	0.05	cm^3
Tr	33	%
M	18	
D	4.2	

Two common merit factors for cooling rings listed in Table 2 are

$$M = \frac{\varepsilon_{6N}(initial)}{\varepsilon_{6N}(final)} Tr, D = \frac{N(s)/V}{N(0)/V}$$

where N is the number of muons and V is a fixed 6-dimensional acceptance volume. The corresponding factors for the ideal ring are M=112 and D=8.9.

ACKNOWLEDGMENTS

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