RFOFO Ring Cooler

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Abstract. This note describes the design of an ionization cooling ring that uses an alternating polarity solenoid lattice. The ring is approximately 33 m in circumference and has 12 cells. Each cell has two opposing focusing solenoids placed either side of a hydrogen wedge absorber. The solenoid coils are located outside pillbox rf cavities. Bending is provided by tipping the solenoid coils. The simulated merit factor (≈ the increase in 6D phase space density) is 81.

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1. Design

There has been considerable recent progress in the design of cooling rings for neutrino factories[1]. The ring discussed here uses hydrogen wedge absorbers in a solenoidal lattice to cool transverse and longitudinal phase space simultaneously. The focusing is done with solenoids for large angular and momentum acceptances. Each cell includes dispersion, acceleration, and energy loss in a thick hydrogen wedge. The lattice has dispersion at the rf cavities, which introduces synchro-betatron mixing. Performing the transverse cooling with an absorber where there is dispersion also introduces additional emittance growth. However, we find that these disadvantages are compensated by the greater acceptance from the use of a single repeating cell with no integer or half-integer betatron resonances in the momentum acceptance. In addition the longitudinal cooling provided by the wedge-shaped absorber minimizes losses from particles falling out of the rf bucket.

The basic ring is made up of 12 identical 2.75 m long cells[3], shown schematically in Fig. 1 without the bends. This symmetry will have to be broken for injection and extraction, but the intention is to make such changes as small as possible. The type of lattice used has been described as a Reverse FOFO (RFOFO) to distinguish it from the Super FOFO (SFOFO) used in the Second U.S. Feasibility Study of a muon-based Neutrino Factory[2].

The minimum value of the beta function at the central momentum (40 cm) occurs in the center of the hydrogen wedges. Bending is provided by tipping the solenoid coils, giving an average dipole field of 0.125 T. The dispersion at the absorber of -7 cm is in the y direction, perpendicular to the bend. This is a result of the Larmor rotation generated by the axial fields. The dispersion at the rf has the opposite sign, and is still mostly in the y direction. The dynamic acceptance was determined by studying the lattice with no rf or absorber[3].

The liquid hydrogen wedge had an opening angle of 76.93^o, a radius of 18 cm and a central thickness of 28.6 cm. No absorber windows were included in this simulation.

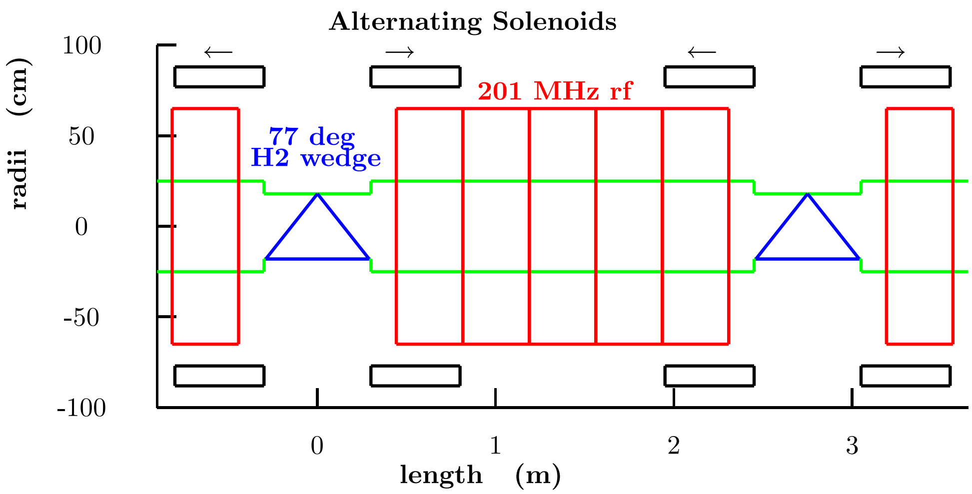

Figure 1. Schematic representation of two cells of the RFOFO ring lattice.

There were six 201.25 MHz rf cavities in each cell. No rf windows were included and the aperture of 25 cm radius is somewhat larger than the windows in Study 2 (21 cm). The gradient of 12 MV/m is smaller than the 16 MV/m used in Study 2.

2. ICOOL Simulations

We have simulated the performance of the RFOFO ring with 76.93^o wedges. Cooling ring performance is frequently summarized by a merit factor[1], which is defined as the ratio of initial to final 6-dimensional emittance multiplied by the transmission. For constant shape distributions, this would equal the increase in central 6D phase space density. The merit factor obtained here is 81. Larger merit factors (≈160) have been obtained[1]in RFOFO rings using bigger wedge angles.

The ICOOL simulations used Fourier representations of on-axis solenoidal and transverse magnetic fields. The simulation uses Maxwellian fields accurate to 5th order in the distance from the central orbit. The actual coils to generate the axial fields, in the presence of the bending fields, would have to be slightly different from those given. But since the 3D fields used are consistent with Maxwell's equations, we are confident that suitable coil positions can be found. It does mean, however, that a full 3D field calculation will have to be done before a fully realistic design is defined. The rf is represented as the fields from a perfect rectangular pillbox cavity located in a region with superimposed dipole fields.

The input tracks are taken from a Study 2[2] simulation, using beam distributions from just before the start of transverse cooling. The use of Study 2 simulated distributions is intended to allow a more realistic estimate of the ring's performance.

In Fig. 2 we show the number of particles accepted in the predefined 6 dimensional acceptance of the following acceleration system. The plot shows the total muon transmission and the muon density for two different accelerator acceptances. The total transmission drops very sharply in the first few turns, indicating losses from scraping at the transverse apertures due to mismatches between the initial beam distributions and the ring acceptance. Some of these transverse losses originate from particle which initially slip out of the rf bucket, although this is a much more serious problem for Study 2. Following this there is a steady loss due to decays. The muon densities into the accelerator acceptances peak after about 8 turns (≈250 m). The increase in density in the volume 2 accelerator acceptance is 6.5, significantly better than that of the linear cooling channel of Study 2 (4.1). Some of this improvement is coming from the emittance exchange, but some performance is lost because the focusing beta function in the ring cannot be tapered down as the emittance falls, as was done in the Study 2 case. The improvement of the ring over the Study 2 lattice would be even larger if the accelerator longitudinal acceptance was smaller than the value used here because the final rms normalized longitudinal emittance achieved here is 7.3 mm, while the corresponding value for Study 2 is 28 mm.

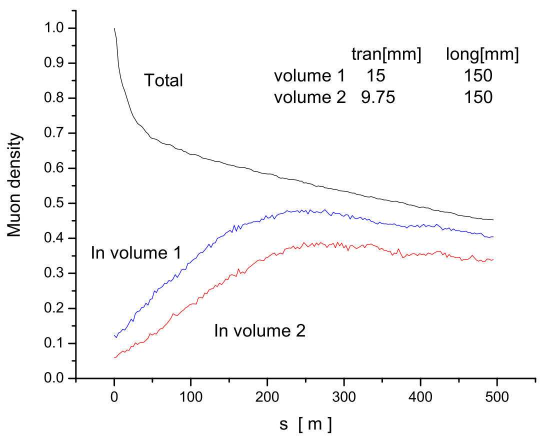

Figure 2. RFOFO ring cooling performance.

It must be understood that this ring could not be used, as is, to replace the Study 2 cooling channel because the bunch train in this case is far too long to fit in the ring. However, if instead a spiral 3D cooling channel were used to replace the linear Study 2 channel, then an even greater performance gain could be expected if the spiral were also tapered. Thus this approach seems very attractive, but it is still far from being fully explored, so much more additional work needs to be done[3].

References

[1] R B Palmer, Ring coolers, these proceedings.

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[3] J S Berg, R C Fernow and R B Palmer, An alternating solenoid focused ionization cooling ring, Muon Collaboration technical note MUC-NOTE-COOL-THEORY-239, March 2002.