MuCOOL-211

Injection and/or Extraction and a Ring Cooler

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Abstract

Injection and extraction for a "ring cooler" or similar structure is discussed. Fast Kicker parameters would be challenging. An alternative "energy-shift" injection/extraction scheme is proposed.

Introduction

The key difficulty in the ring cooler concept[1,2,3] is the problem of injection and extraction into or out of the ring. The initial picture of such a system has been full-aperture fast kickers of the type used for the CERN AA.[4,5] This picture is to obtain a large single turn transverse kick which moves the entire beam from injection to circulating orbit. Fast kickers that can obtain sufficient transverse deflection over the entire beam width are not easy. As an estimate of the required kick we assume a beam at 200 MeV/c with a normalized emittance of 0.01 m-rad and assume $\beta^* = 2$m at extraction. The kick must be greater than the divergence width of the beam (rms width is ~ $(\varepsilon/(\gamma\ \beta^*))^{1/2}$ or ~50 mrad) by a factor of ~4; so a kick of ~200mrad is needed. This means a total kick of $B\rho$*0.2 or 0.133 T-m is needed. Also the rms beam size at the kicker is 10cm; a $\pm 2.5\sigma$ aperture would be 50cm. This can be compared with the parameters of the AA kicker, which was a 2.5m long device provided a kick of 0.088T-m, over an aperture of 25×9 cm. The AA kick is somewhat smaller and the apertures are much smaller. The AA rise time is 88ns, which could be sufficient for a ring cooler, although a faster rise-time is more desirable. Also the kicker must operate at the proton source bunch cycle frequency (15 Hz in the neutrino factory scenarios), while the AA ran at 0.5Hz. A substantial extension from AA parameters would thus be required to obtain ring cooler.

A somewhat different injection/extraction paradigm can be developed by noting that the ring cooler is very much like a recirculating linac (RLA), in that it contains large amounts of rf on each side with return arcs at both ends. Recirculating linacs don't use fast kickers for injection; they inject a lower energy beam which is accelerated within the first turn to an energy which is large enough for recirculation in the following turn. In a ring cooler we have more than sufficient rf to accelerate (or decelerate) the beam to a different circulating orbit after one turn. The trick to obtaining circulating beam is to change the beam rf phase from an accelerating (or decelerating) phase to a storage phase when the bunch returns (on the following turn) to the appropriate cavity. This can be done in two ways: changing the phase (perhaps by perturbing the frequency) of the driving rf cavities, or changing the first–turn path length; possibly with fast kickers. Note the orbit length perturbation should be much less than the orbit difference required for transverse kicker injection/extraction. Note that the complete system requires some sort of RLA-like spreader/recombiner in the arcs where the injected (or extracted) orbit is energy separated (by dispersion) from the circulating beam.

This paradigm can be used for both injection or extraction, with the phase shift occurring in the first half turn and/or last half-turn, respectively. As might be expected, this type of system should work much better for extraction than for injection, since the extracted beam has been cooled longitudinally and would have much smaller momentum spread and bunch lengths than the injected beam.

Description

Figure 2 shows a stylized view of a "ring cooler", drawn as a "race-track" with two long linacs. In "typical" designs each side would be ~10 to 40 m. long. The cooling system in each linac can have accelerating rf of 10 MV/m and energy-loss elements of ~5 MV/m. These could actually be combined to obtain deceleration as high as 15 MV/m, so it is probably more efficient to do the injection (and extraction) by deceleration. An energy difference of 50 MeV should be sufficient for separating initial beams from final beams, since the initial beam full energy width (obtained from upstream phase-rotation and/or cooling)could be less than ~± 20MeV. The phase-shifted rf region could be only a few meters long. For example a beam centered around an injection energy of 200 MeV (kinetic) with a full energy width of ±20MeV could be captured and cooled in the ring cooler at 150 MeV and then extracted at 100MeV. (Extraction could also be obtained through reacceleration.) A schematic view of the system is shown in figure 2.

The cooling rf system is typically run at a stable phase of $\phi_s = 30°$. The injection rf could run at a decelerating phase of $\phi_s = -30°$, which would then have a phase-stable bucket matched to the following cooling bucket. Adding the decelerating rf to the energy losses from absorbers placed in the cooling channel obtains a mean deceleration of ~10 MeV/m, so a 60° phase shift over a ~5m section would be sufficient to obtain the 50 MeV separation. Note that it would be possible to extend this to a 10m segment (for 100 MeV), or even a bit more, if a larger separation between injected and stored beam is needed.

Note that the rf phase must return to the nominal value in this section before the beam returns at the end of the first turn, and then remain at that phase. The time available for reset is simply the particle speed times the difference between the ring circumference and the injected bunch train length (The injected beam could be in a train of bunches rather than a single bunch, although the total length of the train must be less than the circumference.) A typical ring cooler circumference could be ~60m, while the bunch train could be ~30m long (~100ns);the reset time would then be ~30m path length or ~100ns. Ring cooler variations could change these numbers by a factor of ~2, but not much more. (The example of fig.1 has $C \cong 44$m.)

A similar ~5m deceleration in the final linac before the extraction separators would be sufficient.

The spreader/recombiner optics are not trivial, since the two beams must be fully separated in beam size in the beam optics. The layouts must take into consideration that, for medium-energy muons, beam pipes are nearly transparent and septum separators are, at best, helpful suggestions. Since the uncooled beam sizes are of the order of 10cm radius, we need a total separation between the two beams of ~40 cm (or more) at the end of the combiner/separator. Since the beam momentum difference is ~50MeV/c / 250; this would imply a dispersion of 2m, (or 1m if a 100 MeV difference is used), assuming dispersion-matched transports are used. The 2m value is a bit high for ring cooler optics; the ~1m value is more manageable. At extraction the beam is much smaller ($\sigma \cong$ 3cm) and a smaller orbit separation could be sufficient (~20cm?). The optics could be a bit simpler.

The numbers presented here correspond to a ring cooler that is a "first-stage" cooler; that is, one that has had little transverse precooling and has a ~10% rms energy spread, corresponding to the beam from the phase rotation + buncher of the neutrino factory feasibility studies. The aperture requirements could be reduced if the beam is cooled more before injection into this ring cooler. In particular, for a μ^+-μ^- Collider beam source, a sequence of ring coolers could be implemented in a cooling scenario, with injection for a second (or third) ring cooler easier than the first.

Conclusions

We have discussed the fast kicker approach to ring cooler injection/extraction and found the required parameters to be somewhat challenging. An alternative approach in which the injected and extracted beam are separated from the cooling beam energies, obtained by placing the injected (and extracted) beams on a different phase for the first (and last) half-turn. This can be obtained by a 60° phase shift, either in path length or rf. RLA Spreader/combiner – like beam optics are then required at the entrance and exit arcs. This "energy-shift" injection/extraction seems much more suited to the requirements of ring cooler injection/extraction.

References

[1] V. Balbekov & A. van Ginneken, "Ring cooler for muon collider", AIP Conf. Proc. 441:310-3, 1998.
[2] V. Balbekov, "Possibility of using a ring accelerator for ionization cooling of muons", Proc. 1999 Part. Acc. Conf., p. 315-7.
[3] V. Balbekov, "Ring cooler update", NuMu note 189, 2001.
[4] G. H. Schroeder, "Pulsed Magnets", in Handbook of Accelerator Physics and Engineering, A. Chao and M. Tigner, p. 460, World Scientific (1999).
[5]D. Fiander et al. , Proc. 1981 Particle Accel. Conf., p. 2949 (1981).

Figure1: Overview of a Ring Cooler (from ref. [2]).

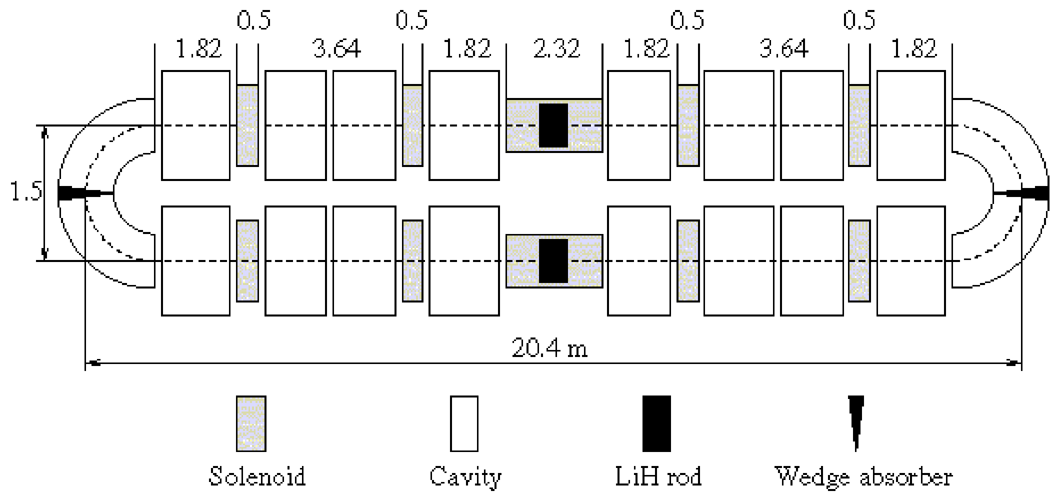
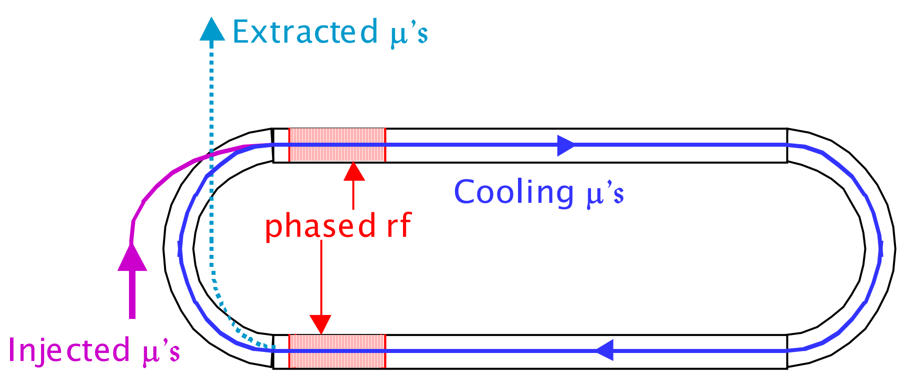


Figure 2: Schematic view of a Ring Cooler injection/extraction, with rephasing for decelerating beam in the beginning of (or throughout) the first half-turn for injection and at the end of the last half–turn for extraction. Injection and extraction paths are only schematically shown; a full design would show spreader-separator magnets for joining and separating the different-energy beams at injection/extraction. Also, the "racetrack" configuration is not essential; the "square" configuration of ref. 3 with injection /extraction phased rf over a quadrant would work as well.



Schematic view of Ring Cooler injection/extraction