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A Modest Proposal for ERL Injection Merges: "Don't"

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Abstract

Merging an injected beam onto a linac axis has been identified as a critical performance issue for ERLs, especially for systems intended to accelerate and recover high beam currents. In this note, we propose an alternative to merge geometries ("don't merge") that may be particularly applicable to lower frequency systems.

The Issue

Merging an injected beam onto a linac axis involves bending the beam, which can lead to space-charge-induced beam quality degradation and which, further, may require significant and space-intensive compensatory steering of the recirculated beam. Alternatives however involve either not injecting the beam – also bad from a performance viewpoint – or use of some RF deflection system to combine the spatial trajectories of the various beam passes. The latter solution also engenders problems: RF separation/combination tends to be space intensive and can introduce transverse emittance degradation due to variations in the (time-varying) deflecting field across the bunch length. If there is a desire to avoid bending the low energy beam entirely, the required fields/power required to deflect the high energy beam (particularly at high currents) can be excessive. Such systems also often require the use of septum magnets, a dicey proposition in machines involving high current beams with attendant halo effects.

A Possible Resolution

In the case of low-ish frequency SRF accelerators (say, below 1 GHz), it may be possible to avoid either bending the injected/recirculated beams or invoking RF separation. Simply note that a) an ERL does not have a closed orbit, and is not necessarily betatron or phase stable; b) the linac for the ERL under consideration is (low frequency and therefore) alleged to have large acceptance, and c) the sow's ear of RF focusing can be used – if an appropriate conspiracy is properly engineered – to provide silk-purse steering of the low energy beam independently of the high energy beam. So, *don't* merge. Just get the two beams "close" and stuff them both into the linac, and see where they end up.

Figure 1 presents orbits relative to the axis of a 750 MHz cryomodule for the acceleration to 100 MeV of a 7 MeV beam offset by 1" to the outside of the machine and the recovery to 7 MeV of a 100 MeV beam displaced 2" to the inside. (In memory of the victims of the French Revolution, the computation was in fact done in MKSA and the results are presented in meters…). Note that the beams are moved around by the RF focusing in a manner consistent with operational needs: the up-going pass moves over to a parallel orbit on the inside of the machine; the beam recovered is – at the end – angled away (as if toward a dump) from the linac axis toward the outside (okay, okay, you might

want the dump on the inside, whatever. Do it all vertically and then it's going down, or up, or whatever. It's getting out.)

Figure 2 shows a concept for such a "not a merge" system. The beams are separated by 3" – well within the 6" bore of a low frequency linac (if you want more aperture you can simply go to 500 MHz). It also introduces some very interesting design options, which will be discussed below.

Figure 1: Orbits for steered injected (7 MeV) and reinjected (100 MeV) beams in 93 MeV 750 MHz linac

Figure 1a: Low energy beam injected to outside of machine.

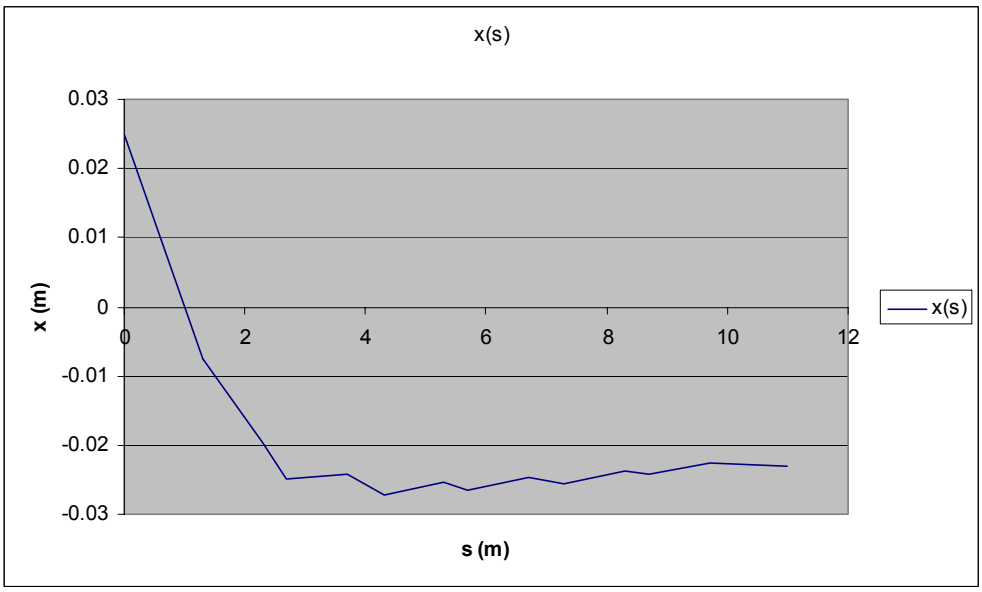


Figure 1b: Reinjected beam biased to inside of machine.

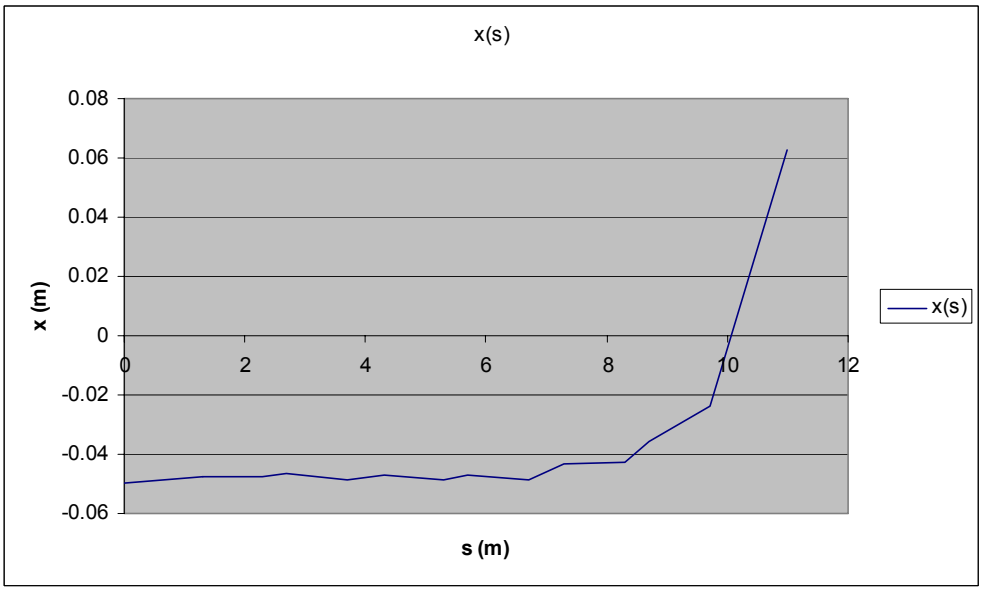
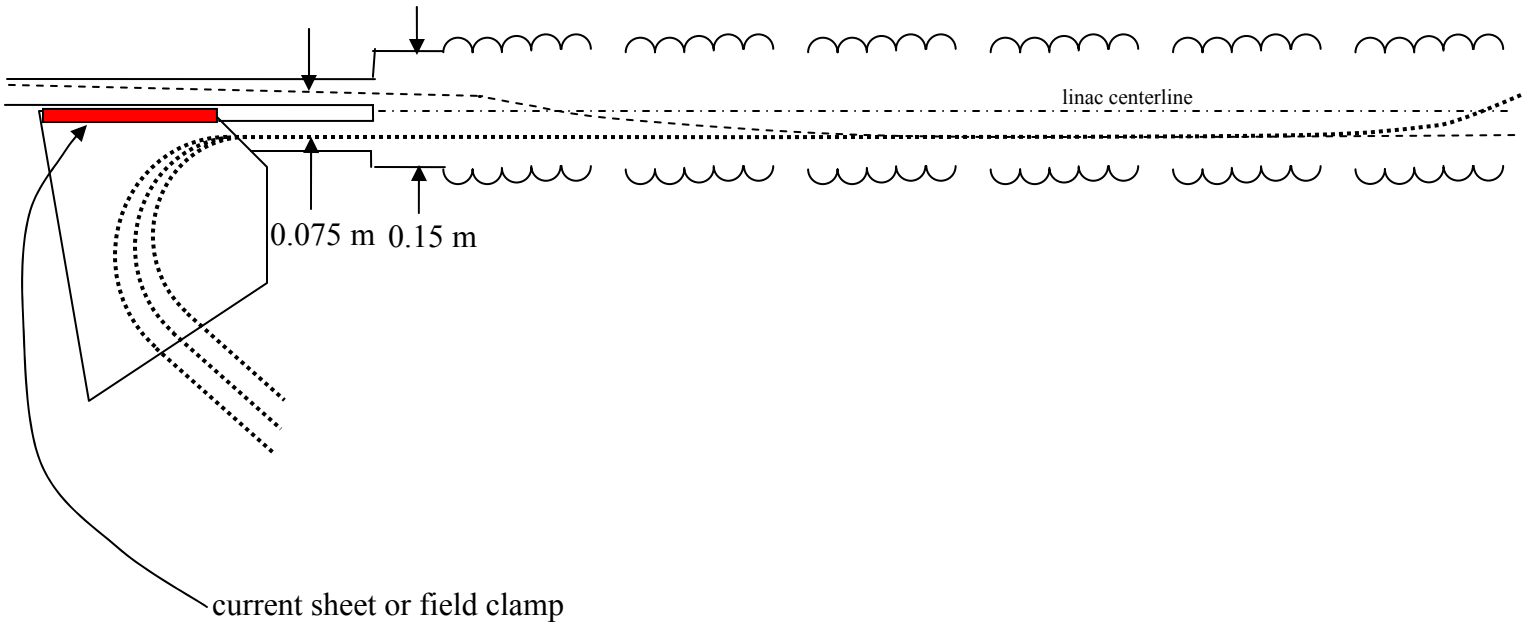


Figure 2: A-mergal injection/reinjection geometry. Something like this works (or so Figure 1 seems to allege) for extraction as well.



Note that even larger separations could be used in lower frequency systems. The 3" separation considered here is likely adequate to manage the geometry of the two beams (that is, you have a chance at building the dipoles and clamping the fields well enough) and may be adequate to get focusing on either beam separate from that on the other (through the use of Collins or septum quadrupoles). Alternatively, the injected beam could be matched to the linac acceptance by a telescope upstream of the final recirculator dipole, and the final recirculation arc could be designed to deliver an appropriately matched beam for energy recovery using only matching telescopes upstream of the arc. This would be determines as a result of a detailed optimization of the beam optics solution in a specific design.

Nice Things About This Idea

Use of a non-merge avoids bending the injected beam, with all the bad ju-ju [1] that such bending entails. It also provides considerable injector design and acceleration operational flexibility. One could, for example, generate multiple bunch trains with differing properties (a la the CEBAF injector) and use the associated timing or energy differentials so created to select the destination of the bunch train later in the acceleration cycle. This was, for example, the process used in the old CEBAF-based FEL proposal, wherein an "FEL drive beam" was generated in the injector and accelerated out of phase with the nuclear physics beams. The resulting energy separation was then used to direct the FEL beam out of the CEBAF recirculator and to the FEL itself.

Similarly, the absence of bending would allow variation in the injector energy without significant impact on the ERL as a whole. This may be advantageous in machine operation or diagnosis.

And, it's likely to be really, really compact.

Bad Things About This Idea

As noted above, there is not a great deal of space to introduce quadrupoles to work on either the injected or the reinjected beam in the region between the recirculation arc and the linac. Focusing solutions may therefore be rather constrained in this configuration.

The first response I got when I described it (independently) to Claus Rode and George Neil was "it'll drive HOMs". Proper module and recirculator design may (or may not) be able to address this concern.

Acknowledgments

Thanks to Claus Rode, George Neil, and Steve Benson for discussing this rather than just laughing, shaking their heads, and walking away while muttering that "someone needs to be sedated..."

Notes and References

[1] J. Coleman (informal – but by acclamation official – JLab FEL lifestyle, fashion, and personal growth consultant), private communication.