JLAB-TN-00-005
1 February, 2000

Injector Linac Optics for a High Current SRF Driven Electron Accelerator

D. Douglas

Abstract

We describe linac optics in a 1 GeV injector for an energy-recovering high-current electron linac. Such an injector could be used as a source for a high luminosity e^- – ion collider [1] or as the front end of a driver linac for a coherent light source [2]. The following results were developed to support BBU estimates for such a machine.

Machine Concept and Parameters

The machine under consideration is assumed to be an intermediate step in a larger, multi-stage high-power SRF-driven electron linac. It could, for example, be the injector for a 10 GeV collider or coherent light source driver. As the required currents are large (~200 mA) energy recovery is assumed as a means of RF drive system cost control and to avoid the need to dump the very high power full energy beam.

Conceptually, a low energy, high current electron beam of 100 MeV energy is injected into 900 MeV of TESLA-style accelerating structure. In this case, five eight-cavity modules are used. Each cavity is operated on crest and provides 22.5 MeV energy gain. The resulting 1 GeV beam is taken “elsewhere”, used, and returned to the injector linac for energy recovery. This multi-stage acceleration scenario is invoked to reduce the ratio of the injection to final energy, thereby providing improved focussing, and thus beam performance, throughout the system [3].

In the following, it is assumed that the RF design of TESLA structures, like that of CEBAF modules, will not support counter-rotating acceleration or energy recovery. Even if this constraint is relaxed, a preliminary estimate of beam-beam interaction effects in such systems suggests that a counter-rotating architecture will provide poor performance [4]. Therefore, acceleration and energy recovery will in this study proceed in the same sense along the linac.

Machine parameters are given in Table 1; Figure 1 illustrates the machine configuration.

Table 1: Machine Parameters

Injection/Recovered Energy	100 MeV
Extracted/Reinjected Energy	1 GeV
Energy Gain	900 MeV
Linac Structure	5 Eight-Cell TESLA Cryomodules
Energy Gain/Cavity	22.5 MeV
Current [5]	170 mA

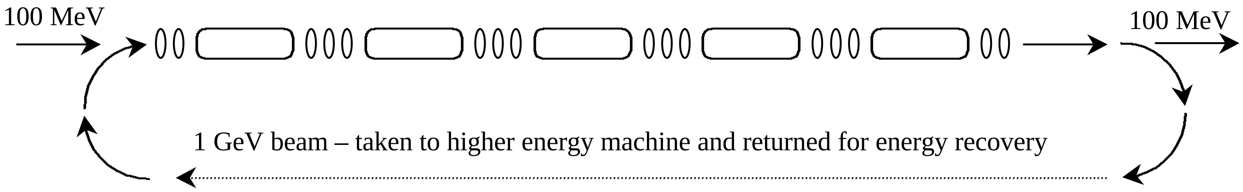

Figure 1: Machine Concept

Linac Optical Design

Inasmuch as the linac is rather short (5 modules each ~11 m long), a reflectively symmetric, essentially constant gradient focussing structure is nominally called for [6]. Such focussing can be provided by quadrupole triplets between modules and quadrupole doublets at the ends of the linacs. Optical effects of SRF modules have been estimated by using a CEBAF module model in EXCEL [7]; given the relativistic injection energy of 100 MeV, this is probably an adequate approximation.

Observations on BBU control by Ilan Ben-Zvi [8] have influenced the particular optical solution under consideration. Ben-Zvi noted that insofar as the transport through a linac can be given a high degree of symmetry, it is possible to strongly suppress turn-to-turn beam response to steering and consequently impede BBU. Specifically, in a recirculating lattice with $M_{11} = M_{22}$ (and, for the vertical plane, $M_{33} = M_{44}$), if the turn-to-turn matrix element M_{12} (M_{34}) = 0 at one point of the linac, then it will remain zero throughout. The general conditions on this suppression are actually more relaxed, as may be realized by considering a ring with integer tune – a system in which the full turn M_{12} is zero everywhere.

The practical application of this observation is impeded by the fact that a linac is an inherently anisotropic (and thus asymmetric) system. In particular, a parameterization of the matrix elements in terms of a beam envelope solution reveals an exact suppression is possible only if

1. the pass-to-pass envelopes (βs) are everywhere equal, while either
2. a) the pass-to-pass phase advance (not tune!) is an integer or b) the envelope slopes (αs) are equal in magnitude and opposite in sign.

These conditions are not, in practice, achievable. For example, the pass-to-pass beam envelopes cannot be made equal in magnitude because of unavoidable focussing mismatch between beams at different energies. However, these constraints give guidance as to how to proceed. We have determined that the best suppression of M_{12} and M_{34} occurs when

1. pass to pass beam envelopes are “smooth” with small slopes, not highly modulated, and
2. the overall pass-to-pass phase advance is “appropriately” selected (this was done empirically using a design model).

The amusing thing about this result is that suppression seems best when the beam envelopes are moderately large and weakly focussed, so they are slowly varying. This is contrary to intuition, which implies BBU control is best achieved through the use of very strong focussing and small beta functions.

A “unit cell” of the five-period linac lattice is shown in Figure 2. The “best effort” beam envelope solution [9] is given in Figure 3, and the resulting M_{12} and M_{34} results are given in Figure 4. In this system, the matrix elements vary by ± 2 m through most of the linac with the variation growing to ± 6 m at the end, where energy-induced mismatch and adiabatic antidamping are most dramatic. This is to be contrasted to the beam envelopes, which are ~25 m in the linac front and back end and grow to over 40 m at extraction and reinjection. We note that the matrix element results must (and do) include the effects of adiabatic damping and antidamping to properly model the pass-to-pass beam response to steering.

We observe that RF focussing effects [10] are noticeable in the front and back end of the linac. These can in principle be alleviated by altering the energy profile to lower gradients (and focussing) at the ends, and raise gradients in the middle (where energies are higher and focussing weaker). However, a brief effort to do so produced no obvious improvement in performance. Similarly, the large reinjection beam envelopes can in principle be rematched to smaller values using appropriate upstream optics. A brief effort to do so produced, as in the previous case, no obvious improvement in performance.

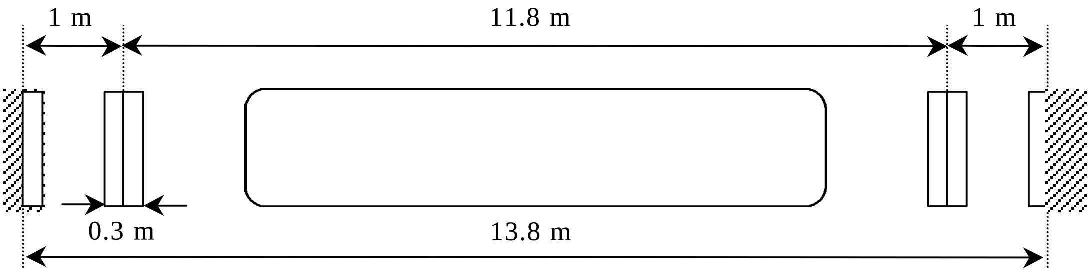

Figure 2: Unit Cell

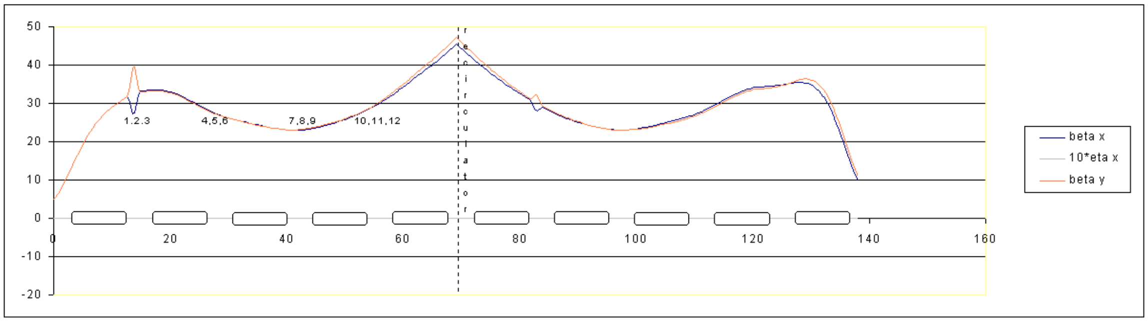

Figure 3: Beam envelopes (m).

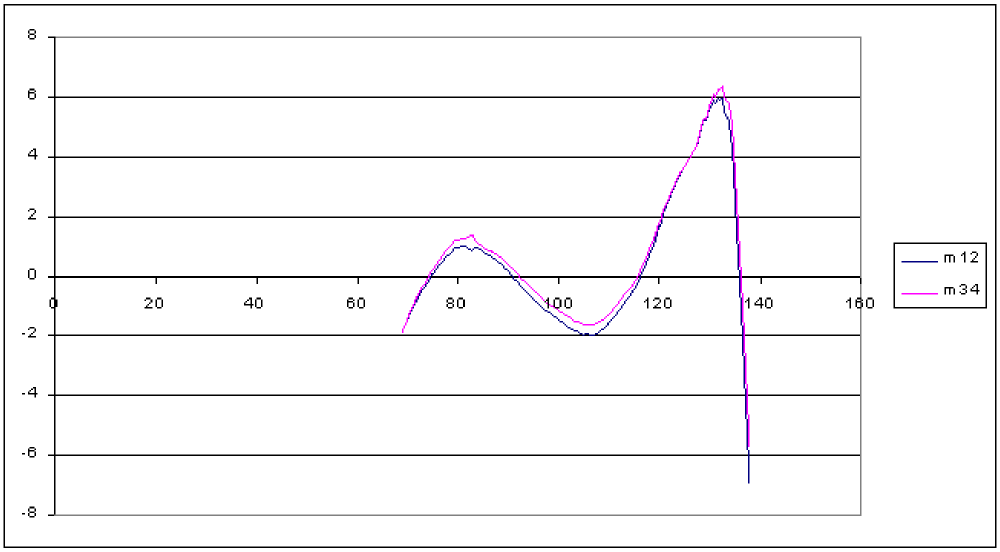

Figure 4: Pass-to-pass M_{12} and M_{34} (m).

An Excel spreadsheet modeling these optics is available online at http://www.jlab.org/~douglas/ULTRAFEL/injectorbbu.xls.

Acknowledgments

I would like to thank Lia Merminga for calling my attention to this problem and Yu Chao for his effort providing an initial solution. Ilan Ben-Zvi is the prime motivator for this study and suggested the method used to develop the optics. All three provided significant useful input; I appreciate their help. In addition, Lia Merminga performed a thoughtful review of the manuscript and greatly improved its quality by providing a number of useful comments.

References

[1] I. Ben-Zvi, private communication

[2] D. Douglas, “Incoherent Thoughts About Coherent Light Sources”, JLAB-TN-98-040, 13 October 1998.

[3] D. Douglas, “Lattice Design Principles for a Recirculated, High Energy SRF Electron Accelerator”, Proc. 1993 I. E. E. E. Part. Accel. Conf., Washington, D. C., May 1993.

[4] D. Douglas, “Incoherent Thoughts About Coherent Light Sources”, *op. cit.*

[5] Design current requirement for e^- – ion collider application, from Ilan Ben-Zvi via Lia Merminga (private communication).

[6] D. Douglas, “Lattice Design Principles for a Recirculated, High Energy SRF Electron Accelerator”, *op. cit.*

[7] D. Douglas, “An Alternate Paradigm for High-Level Application Development”, JLAB-TN-97-047, 12 December 1997.

[8] I. Ben-Zvi, private communication.

[9] “Best effort” in the sense of minimizing the average pass-to-pass M_{12} and M_{34}, not the beam size. It is possible to reduce the envelopes significantly through much of the linac, but at the cost of increased focussing, additional phase advance, and consequentially larger turn-to-turn matrix elements.

[10] G. Krafft, J. Jackson, and D. Douglas, “First Order Focussing and Steering of Misaligned Cavities”, CEBAF-TN-90-0287, 14 December 1990.