ENVELOPE MATCHING FOR AN 8 GEV MULTI-SPECIES SUPERCONDUCTING LINAC

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Abstract

Fermilab is investigating the feasibility of an economical 8 GeV superconducting linac for H^- and electrons using existing cavity and cryostat designs from diverse sources. Only four geometrical $\bar{\beta}$ values are used in spanning the velocity range β = 0.40 – 0.99; therefore beam phase and rf focusing vary widely over short distances. Because only four distinct cryostat layouts are planned, the transverse envelopes are not easily matched with a simple quad excitation rule. Irregular spacing of the gaps and substantial drifts at cryostat ends give rise to appreciable bunch shape oscillation. This paper describes to what degree it has been possible to regulate the envelopes and phase advances. The result is what could be called a fine-tuned or continual rematching pattern of quad strengths.

The motivation for design choices as well as current layouts and parameters may be found at

`http://tdserver1.fnal.gov/project/8gevlinac`

1 INTRODUCTION

Faced with a green field site or a blank sheet of paper, the linac designer looks for a simple quad law and scaling according to kinematic parameters. In the present case, however, disparate fragments are selected from existing machines and designs to be pasted together to produce an economical high energy, multi-species linac. The process is somewhat lacking aesthetically, but economics trumps aesthetics. The proposed scheme is a superconducting linac from 87 MeV to 8 Gev consisting of four segments, where a segment consists of identical modules with the same geometrical β. Table 1 lays out the design goals; Table 2 provides a brief summary of the constituents. A more comprehensive discussion of the proposal is given in the paper of Foster and MacLachlan.[1]

Simple propositions have been used to guide a largely empirical design process.

1. The FODO scheme is the most tolerant of changes in beam parameters.
2. Fixed length periods with fixed quad strength give (approximately) constant maximum widths and dropping phase advance with increasing energy.
3. Large ratio of maximum to minimum Twiss β means the phase advance is high and the lattice critically tuned.
4. Magnetic field at maximum beam width is constrained by H^- stripping.
5. No special matching sections are to be introduced between segments.
6. All modules of a given segment should be mechanically identical.
7. The practical objective is a non-specific matching technique emphasizing primarily acceptable maximum envelope extent.

The TRACE3D code[2] has been used for all of the calculations; the dynamics treated are fully adequate to this and a rather wide range of preliminary design. However, ray tracking calculations will also be needed.

2 FOCUSING DESIGN STEPS

The rf structures and the cryostat lengths are givens. The number and strength of quads is to be adjusted to maintain an acceptable envelope. The quad positioning should be the same throughout a given module type. Naturally the number of quads is to be minimized as much as allowed by the performance requirements. The initial calculation consists of determining for each of the four module types the matched beam with good envelope widths and less than $90°$ zero-beam-current phase advance. This serves to indicate the generally appropriate quad strengths. The entrance and exit phases for the multicell cavities are calculated with a spread sheet which tracks a particle at the central energy. Then all of the modules are concatenated; the initial beam is taken from the SNS[3] normal-conducting design at 87 MeV. From here on there follows a quad-by-quad matching that trys in the first instance to place a double waist in the center of each quad. In general this is a far too restrictive criterion, and to produce suitable envelope widths farther downstream it is necessary to adjust slightly, essentially by hand, one or two upstream quads. One need not care precisely where a waist is so long as (for a FODO arrangement) it is within or very close to a quad. The number of quads per module is determined by attempting a crude approximation to a momentum scaled FODO channel.

3 MATCHING THROUGH THE 805 MHZ SEGMENTS

The focusing conditions vary the most in the three 805 MHz segments. Two modules at $\bar{\beta}$ = 0.47 cover the energy range 87 – 173 MeV; three modules at $\bar{\beta}$ = 0.61 cover 173 – 386 MeV; seven modules at $\bar{\beta}$ = 0.81 cover 386 – 1305 MeV. A beam envelope is obtained that nowhere exceeds 1 cm and is generally considerably smaller, but the match is not tolerant of big changes in beam current.

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This may complicate plans for multimode operation on interleaved pulses. Reduced sensitivity to beam parameters might be obtained at the cost of a larger beam envelope with weaker focusing. Because the cavity iris radii are 38 mm and greater, this option appears viable.

Figure 1 displays the transverse envelopes. Figure 2 gives the excitation of quads of 15 cm effective length. The stripping probability for H^- at four times the calculated envelope is infinitesimal according to the formulation of Furman.[4] These results support the credibility of the initial concept; however, the envelopes do not *look* fully optimized. The experience with the calculations to this stage suggests that an enhancement of the TRACE3D code to allow under-constrained fits in the general manner of TRANSPORT[5] would very useful. Given the common underlying beam matrix approach, effort required for a TRACEPORT hack could have high return. In addition to optimization of the envelope matching, the validation of a baseline design needs ray tracking calculations to establish acceptances (especially longitudinal) and parameter sensitivity.

4 MATCHING FOR THE 1.2 GHZ, $\bar{\beta} = 1$

There is no special matching between the 805 MHz and 1.2 GHz segments, but it is a computational convenience to separate them. The matching has been carried only to 2.2 GeV, since the greater regularity of this segment implies that the matching will be qualitatively similar all the way. The cryo-feed break at 208 m is an exception to the regularity; the quad strengths in this neighborhood will require adjustment. The quadrupoles in this segment have a magnetic length of 1 m to avoid all stripping. The length could in fact be cut some; the safety margin is somewhat greater than for the lower energy segments — very conservative, in any case.

Figure 3 displays the transverse envelopes [mm] and the bunch length [deg]. The asymmetry between horizontal and vertical envelopes reflects the initial beam condition presented by the 805 MHz segments, and it will persist to higher energy. Figure 4 shows the quad strengths [T/m]; it is evident that they are appreciably more regular than those for the lower energy segments.

5 IN FINE

The envelope matching for a proposed 8 GeV superconducting linac establishes that the segmentation is reasonable, the quad strengths are practical, and the envelopes can be constrained to maximum extent of 1 cm or less. The calculations leading to these conclusions were routine but very tedious; the possibility of some software development has been mooted with the thought that it should have general appeal.

The 8 GeV linac concept is highly attractive; generating a credible design will require far more effort than has been available to date. However, many of the details have been taken over directly from the work on SNS. By the time a project such as this can get started, SNS should have large amounts of relevant practical experience. Further effort on the TESLA[6] design will also contribute to understanding of the 1.2 GHz segment. The commonality of ideas and hardware is a cardinal element of the proposal; *viz.*, make the 8 GeV linac economic by detailed copying and borrowing. “Not invented here” is the aim, not a problem.

Table 1: General design goals for an H^-, e^- linac

initial energy	87	MeV
final energy	8000	MeV
macropulse beam current	26	mA
repetition rate	10	Hz
macropulse length	1	ms

Table 2: Segment properties

$\bar{\beta}$	l [m]	KE [MeV]	# mod	# $\frac{\text{cav}}{\text{mod}}$	# $\frac{\text{quad}}{\text{mod}}$
0.47	21.7	87-173	2	8	9
0.61	36.6	173-386	3	8	5
0.81	89.5	386-1305	7	8	3
1.0	506.2	1305-8000	36	8	2

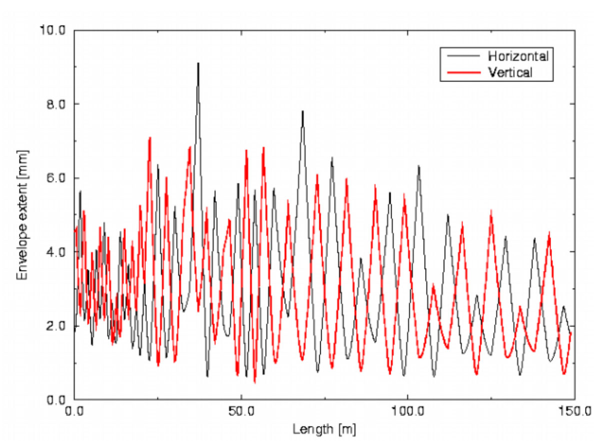

Figure 1. Transverse envelopes [mm] for entire 805 MHz linac to 1.3 GeV

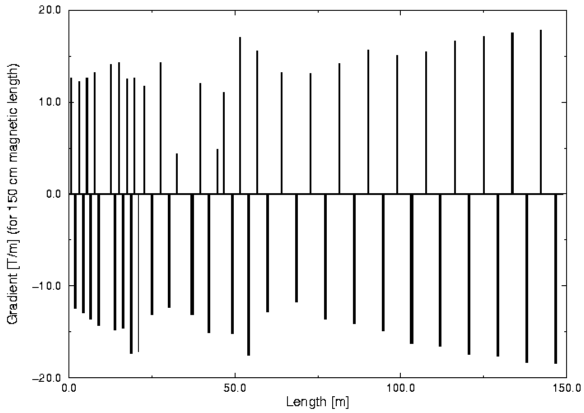

Figure 2. The strength of quads of 15 cm magnetic length [T/m] in the 805 MHz segments

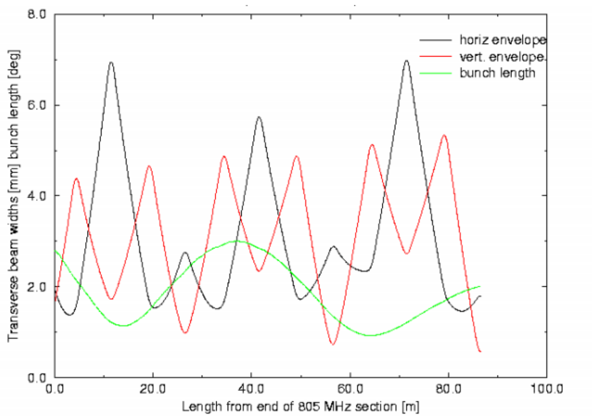

Figure 3. Transverse envelopes [mm] and bunch length [deg] for 1.3 to 2.2 GeV of the 1.2 GHz segment

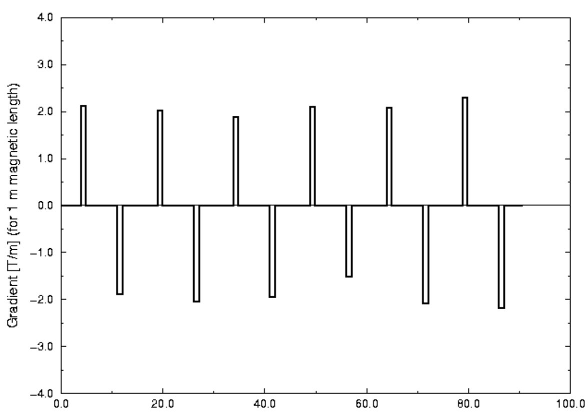

Figure 4. The strength of 1 m magnetic length quads in the first four and one half modules of the 1.2 GHz segment (to 2.2 GeV)

6 REFERENCES

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