DESIGN OF A CURRENT-INDEPENDENT MATCHING SECTION FOR APDF*

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Abstract

We describe the design of a current-independent matching section which could be used to match a 100-MeV, CW beam from a 7-MeV, 350-Mhz RFQ into a 350-Mhz DTL for the proposed Accelerator Performance Demonstration Facility (APDF). This facility is being proposed to demonstrate the performance of a high-current, CW front-end (up to 40-MeV and including a funnel) which would be applicable for the accelerator production of tritium, accelerator transmutation of waste, and accelerator-based conversion of defense waste programs. A detailed description of the APDF is given in another paper presented at this conference [1].

Introduction

We have found from past experience that a matching section or transport line which is very insensitive to beam current can be designed if both the transverse and longitudinal focusing is maintained or varied very adiabatically from one structure to another. Current independence means that the matching section can be set for the full-current match, but it will still propagate lower current beams without significant mismatch or emittance growth. For example, at lower beam currents the match into the DTL changes, however, for a current-independent matching section the output beam of the matching section varies (or tracks) similarly to the match into the DTL.

A nearly current-indepedent matching section design to match a 7 MeV beam from an RFQ to a DTL is shown in Fig. 1. The focusing lattice of the DTL was chosen to give approximately the same transverse zero-current phase advance per unit length, σ_o / L, as in the RFQ. For the RFQ, σ_o / L=28°/βλ. A FOFODODO focusing lattice was chosen for the DTL with a focusing period of 4βλ and σ_o / L=20°/βλ (80°/period). The matching section essentially consists of an extension of the DTL focusing lattice. The quadrupole spacing and number of spaces was chosen so as to allow enough space for flanges, bellows, valves, and diagnostics. Eight electromagnetic quadrupoles will be used for transverse matching and two single-gap bunchers will be used for longitudinal matching. Beam dynamics, error study results, and steering study results will be discussed for this nearly current-independent solution in the following sections. A solution which minimized the number of required matching section components was examined, however, this design was found to be highly current dependent and would require resetting of the quadrupoles and bunchers for each change in beam current during tune-up.

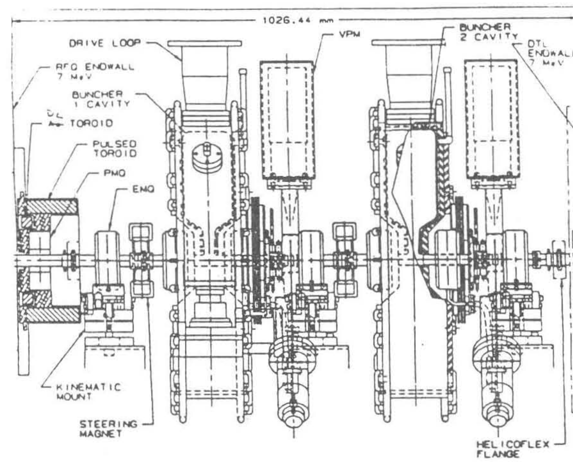

Figure 1 - General Layout of the Matching Section.

Simulation Results

Simulations, using the codes PARMTEQ and PARMILA, were run to verify the current-independence of the matching section and to ascertain the effects of the matching on the beam in the subsequent accelerating structures. In these simulation runs, the beam which consisted of 10,000 macroparticles was transported from the RFQ injection to the output at 40-MeV. Simulations were completed for the linac at three beam currents (I=100-, 25-, and 0-mA). In each case the input beam into the RFQ was matched for the specific beam current which was simulated. Experimentally, this would be required in order to have maximum transmission through the RFQ. The matching section, DTL, Funnel, and Bridge-Coupled Drift-Tube linac, however, were modeled with the nominal full-current, I=100-mA, operating conditions in the simulations. Table 1 shows a comparison of the expected matched input beam Twiss parameters for the DTL for two of the beam currents simulated, as determined by TRACE 3-D, and the matching section output beam Twiss parameters as determined from the simulations.

The transverse input emittance to the RFQ was assumed to be 0.02 π-cm-mrad, rms, normalized at the 75 keV injection energy. The output beam parameters were checked at each major structure transition. These parameters were found to be very similar to the matched, full-current case for the other two beam currents which were simulated. No particle losses were observed for any of the simulations and the overall linac performance was found to be very insensitive to beam current.

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Table 1 - Comparison of the matching section output beam Twiss parameters from PARMILA simulations and those determined to be the matched parameters by TRACE 3-D into the DTL.

Twiss Parameters	I=100 mA PARMILA	I=100 mA TRACE	I=0 mA PARMILA	I=0 mA TRACE
α_x	1.208	2.704	0.302	0.213
$\beta_x(cm/mrad)$	0.0366	0.0462	0.0241	0.0220
α_y	-1.919	-3.702	-1.330	-1.339
$\beta_y(cm/mrad)$	0.0851	0.0742	0.0595	0.0612
α_L	-0.583	-0.752	-0.112	-0.162
$\beta_L(cm/mrad)$	419.55	431.95	130.92	143.40

Figure 2 shows the matching section output phase space and xy plots for beam currents of 0- and 100-mA. The details of the longitudinal phase space distributions are quite different for the two cases however, the size of the beam and the ellipse orientations are all very similar. Because the acceptance of the DTL is large compared to the beam size, the transmission should be nearly 100% for all currents within the range discussed.

Error Study

An error study of the RFQ/DTL matching section was carried out. Three types of error conditions were examined: 1) buncher errors, 2) random quadrupole errors, and 3) input beam errors. The results of this study are discussed below.

Buncher Errors

The matching section contains two single-gap buncher cavities to longitudinally match the beam between the RFQ and the DTL. The individual buncher phases were varied by ± 2° from the nominal operating phase of 90°. The individual buncher amplitudes were varied by ± 10% from the nominal operating amplitudes required to give the I=100 mA longitudinal matched conditions. The matching section output beam Twiss parameters were relatively insensitive to errors of these magnitudes. Variations in the Twiss parameters of 10-20% were observed. Beam emittances were unchanged. Control of buncher phases to within 1° and buncher amplitudes to within 1-2% is typical.

Random Quadrupole Errors

The effects of the following random quadrupole errors on the beam in the matching section and the DTL were studied: 1) quadrupole xy-displacement errors, 2) quadrupole tilt errors, 3) quadrupole roll errors, and 4) quadrupole gradient errors. These random errors were generated as a uniform distribution within some specified range of values. The effects of each of these individual errors were studied. The effects of multiple error conditions were not studied. Random quadrupole errors were generated in both the matching section and DTL.

The PARTRACE simulation code was used to determine the sensitivity and tolerance limits for the various random quadrupole errors. It is possible to simulate both transport lines and drift-tube linacs using the PARTRACE code. This code, however, does not do the multiparticle transport and beam dynamics of PARMILA, rather it transports beam ellipses and uses the beam dynamics of TRACE 3-D.

Transverse phase space ellipses were generated by PARTRACE at the input to the matching section which have Twiss parameters identical to the I=100 mA output beam of the RFQ. The transverse emittance was chosen so as to represent a beam extending out to three times the rms value (3σ) of the RFQ output rms emittance.

As the beam was propagated through the matching section and the DTL, a quantity called FMAX was calculated. The quantity FMAX is defined to be the ratio of the largest radius from the center of the beam pipe of the outer edge of the 3σ beam through the matching section and DTL, and the beam pipe radius (rb). The range of possible values for FMAX is therefore, $3\sigma/rb \leq FMAX \leq 1.0$. The minimum value corresponds to the beam always being on axis and the maximum value corresponds to the outer edge of the beam scraping the beam pipe at some point in the matching section or DTL. FMAX is therefore a measure of how close the beam edge comes to the beampipe and therefore is a measure of the potential for beam loss.

Probability distributions of FMAX were generated by PARTRACE by propagating 1000 beams through the matching section and the DTL for each error condition. For each of the 1000 beams, a different set of initial random error conditions was generated. Probability distributions were then calculated from the tabulated values of FMAX for the set of 1000 beam simulations. Table 2 summarizes the results.

Table 2 - Summary of results of the study of the effect of random quadrupole errors on the matching section and DTL performance. FMAX is as defined above in the text.

Error Condition	Tolerance	Effect on FMAX
XY-Displacement Errors	≤ 2 mils	10% increase
Tilt Errors	≤ 2 deg.	10% increase
Roll Errors	≤ 2 deg	5% increase
Gradient Errors	≤ 2%	5% increase

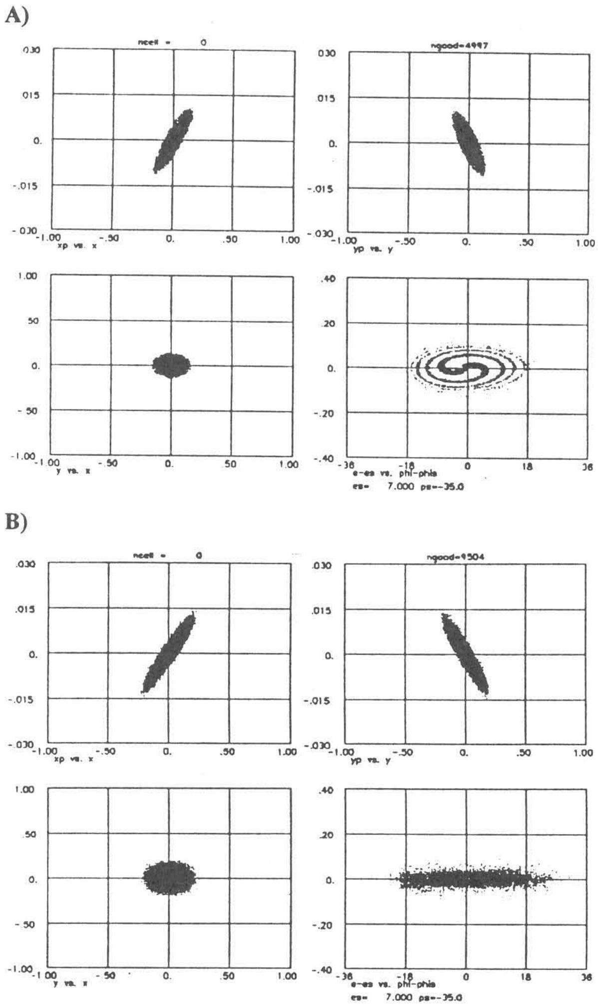

Figure 2 - A) Matching section output phase space and xy-plots for a beam current of I=0-mA. B) The same for I=100-mA.

Input Beam Errors

The effects of input beam xy-displacements and angle misalignments on the propagation of the full-current beam in the matching section and DTL were studied. The effects of these two types of errors were studied independently. The effects of combinations of errors was not studied These studies were done using the multiparticle simulation code, PARMILA. The effects of input beam xy-displacements ranging from 10-40 mil in steps of 10 mil were studied. Significant oscillation of the beam is already visible for a 20 mil input beam displacement.

The effects of input beam angle misalignments of up to 10-mrad were also studied. A 5-mrad input beam angle misalignment causes significant oscillation of the beam in the DTL. The design is essentially insensitive to input beam angle misalignments of less than 3 mrad.

Steering Study

Two dipole steering magnets have been incorporated into the matching section design. Both of these magnets would be capable of doing both x and y steering. The magnet design strengths were chosen to provide a maximum bend angle of 5-mrad for a 7-MeV beam. Simulations were done to study the capability of these magnets to steer misaligned beams back to the beam pipe axis. Only the ability to correct misaligned input beams was examined. Correction of misalignments in the matching section or DTL were not studied. It was determined that the placement of the steering magnets was adequate for correcting up to 5-mrad input beam angle displacements in x, but not in the y-direction.

Summary

A solution for the RFQ/DTL matching section for APDF which satisfies the beam dynamics and engineering requirements and constraints has been found. The sensitivities of the design to operational errors such as magnet gradient errors and buncher cavity field and amplitude errors have been examined. The effects of both quadrupole misalignments and input beam misalignment errors have been examined. For all cases, the tolerances required to assemble and operate this matching section are well within the capabilities of present day alignment and operational techniques and procedures.

We have also demonstrated the current independence of our solution. This feature of our design should greatly simplify the operation of the matching section during turn-on and tune-up where the peak beam currents and accelerator duty factor are varied over large ranges.

The engineering design of the matching section included provisions for beam diagnostics, however, the actual diagnostics requirements and limitations were not evaluated. The evaluation of these requirements and limitations should be completed in the next stage of work for this project.

References

[1] K. C. D. Chan, et al., "Accelerator Performance Demonstration Facility in Los Alamos," ibid.