TRANSVERSE MATCH OF HIGH PEAK-CURRENT BEAM INTO THE LANSCE DTL USING PARMILA

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Abstract

A new algorithm that uses a multiparticle PARMILA-based code to match high peak-current H^+ beam (~21mA) into the Los Alamos Neutron Science Center (LANSCE) drift-tube-linac (DTL) has been developed. Two single-cell RF bunchers in the low energy beam transport (LEBT) prepare the initially unbunched beam for DTL capture. The transverse distribution at the entrance to the DTL is set with four quadrupoles in the 1.26m between the last transverse emittance measuring station and the DTL entrance. Previous matching algorithms used TRACE and TRACE 3-D to determine these quadrupole strengths. PARMILA simulations show this procedure produces non-zero mismatch and additional emittance growth through the DTL for high current beams. Because of strong space-charge forces and a rapidly forming longitudinal bunch, simple envelope calculations do not model the beam evolution in the LEBT well. A PARMILA model of this region was combined with an iterative search routine to set the LEBT quadrupole strengths to achieve a better transverse match into the DTL. Simulations predict a significant reduction in transverse emittance at the exit of the DTL over the typical TRACE 3-D result.

Introduction

The LANSCE accelerator begins with two Cockroft-Waltons (CW) injectors which accelerate H^+ and H^- beam to 750keV. Each beam is transported in a separate LEBT to a common LEBT which transports both beams to the DTL. The DTL operates at 201.25MHz and accelerates the beams from 0.75 to 100MeV. The transition region (TR) transports the beam from the DTL to the side-coupled linac (SCL) which operates at 805MHz and accelerates the beams to 800MeV.

The H^+ beam is prepared for injection into the DTL with two 201.25MHz single-cell buncher cavities and a series of quadrupole magnets in the LEBT. The two bunchers prepare the initially unbunched beam for DTL capture and the LEBT quadrupoles prepare the beam for injection into the magnetic lattice of the DTL. The last transverse emittance measurement diagnostic, a slit and collector separated by 89.1cm, is located in the LEBT downstream of the second buncher and upstream of the last four quadrupole magnets in the LEBT. To match the beam, the measured emittance is used with a model of the LEBT and DTL to determine the final four quadrupole strengths.

Previous studies have shown that space-charge dominated beams which are RMS mismatched when injected into a linear accelerator undergo emittance growth [1] and halo formation [2]. At LANSCE the 750keV H^+ beam, with a typical peak current of 21mA and a normalized transverse RMS emittance of ~0.008π-cm-mr, is injected into the 201.25MHz DTL. At this energy, emittance and peak-current the tune depression in the first few periods of the DTL is ~0.5 ($\sigma/\sigma_0 \cong 26^o/49^o$). Thus, the beam is close to space-charge dominated. Achieving a good match into the DTL can therefore minimize emittance growth resulting from transverse mismatch. Excess emittance growth and halo formation due to mismatch at the front of the DTL can result in the loss of high energy particles in the TR and SCL, which in turn can result in the activation of beam line elements and the accelerator structure.

Figure 1 (a) shows the measured horizontal distribution of beam with 21mA peak current at the last LEBT emittance station and the estimated longitudinal phase space distribution. Figure 1 (b) shows the PARMILA prediction of the horizontal and longitudinal distributions at the exit of the tenth drift tube in the DTL. The longitudinal phase space evolution in this region of the LEBT and the first DTL tank is complex. Through space-charge forces this longitudinal evolution couples to the transverse phase space dynamics and complicates the process of matching the beam into the DTL. The use of an accurate model of this region of the LEBT and DTL is critical in determining the parameters of the matched

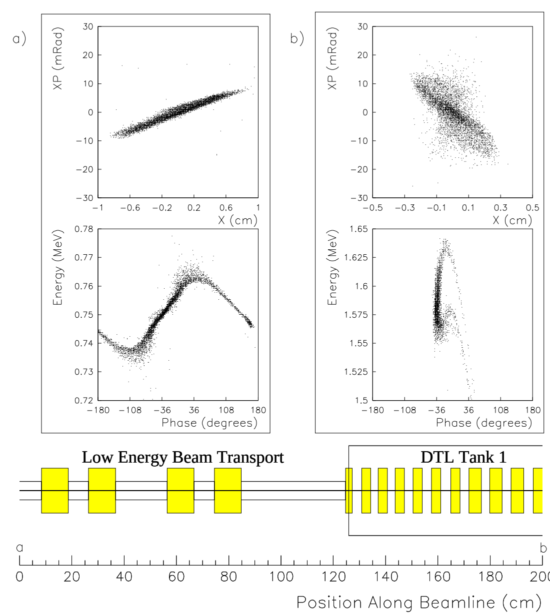

Fig. 1: (a) The horizontal and longitudinal phase-space distributions at the last emittance measuring station and (b) at the exit of the tenth drift tube for the standard quad and buncher settings. The bottom schematic diagram shows the end of the LEBT and the entrance to the DTL (shaded blocks are quadrupole magnets).

beam and setting the quadrupole strengths to achieve that match.

Beam Dynamics Models

Various models have been used in an attempt to determine and achieve matched beam into the DTL. Two-dimensional models such as TRACE and a two-dimensional version of PARMILA have been used. These models can not, however, properly model the rapidly increasing transverse space-charge forces due to longitudinal bunching. TRACE 3-D has also been used with limited success. The longitudinal phase space distribution used with TRACE 3-D must be described by an ellipse. Typically, the ellipse is chosen to have the same RMS parameters as the true longitudinal distribution assuming near longitudinal elliptical symmetry. Since longitudinal elliptical symmetry is not present, this model is not expected to properly represent the complicated longitudinal beam dynamics occurring over the long distances in the LEBT and through the many RF gaps of the DTL. Of the models presently used the three-dimensional version of PARMILA should be successful because of the accurate calculations of space-charge forces and emittance growth. However, the structure and speed of PARMILA has limited its use to the modeling of existing setups rather than the determination of match parameters and quadrupole strengths.

Figure 2 shows a comparison of the ratios of modeled space-charge forces in TRACE, 2-D PARMILA and TRACE 3-D to the space-charge forces calculated by the three-dimensional version of PARMILA. The ratios of the space-charge forces are calculated for a particle at one RMS distance from the center of the beam. As can be seen from this graph both 2-D PARMILA and TRACE 3-D underestimate the space-charge forces by a factor of two initially and by a factor of five when the longitudinal bunch is well established at the exit of the tenth drift tube. In both cases this discrepancy of space-charge forces is due to inaccurate representation of the initial longitudinal phase-space distribution and its subsequent evolution. The spike in the ratio using the TRACE 3-D model is a result of injecting a mismatched longitudinal ellipse into the DTL. The longitudinal beam envelope oscillates and the phase width for the beam becomes very small soon after entering the DTL.

Matching Algorithms

The matching algorithm which is presently being used is a hybrid model combining TRACE and the two dimensional version of PARMILA. In the mid 1970's a two dimensional version of PARMILA was used to determine the Twiss parameters for matched low-current beam at the entrance to the DTL. To incorporate the effect of longitudinal bunching an effective current of four times the measured current was used for the simulations. The Twiss parameters resulting from this study have become known as "magic numbers" and an iterative

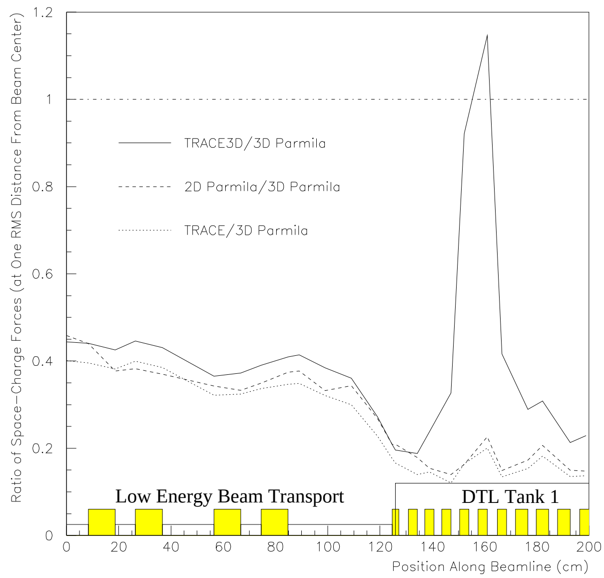

Fig. 2: The ratio of space-charge forces experienced by a particle at an RMS distance from the center of the bunch between TRACE, 2D PARMILA, TRACE 3-D and PARMILA.

TRACE routine is used to adjust the LEBT quadrupoles to achieve these "magic numbers" at the DTL entrance.

TRACE 3-D has also been used to determine the Twiss parameters at the entrance to the DTL and to iteratively search for LEBT quadrupole strengths to achieve these matched parameters. For these simulations the RMS quantities of an estimated PARMILA distribution were used to determine the ellipse parameters of the TRACE 3-D longitudinal distribution. This procedure resulted in more emittance growth and halo formation than measured from the matching routine previously developed.

A new matching algorithm based on the PARMILA model of the LEBT and DTL has been developed. This new algorithm combines realistic initial phase-space distributions with the extensively tested three-dimensional space-charge calculations of PARMILA and first order corrections for space-charge neutralization.

To accurately model the beam transport through the LEBT into the DTL a large effort was expended to create realistic initial phase-space distributions. Initial particle distributions in transverse phase-space were created from measured distributions and all simulations began at the measurement position. The longitudinal distribution was estimated by tracking particles from the DC injection into the first buncher, through the second buncher, to the emittance station used to measure the input transverse distributions. The buncher phases and amplitudes used in the simulation had been estimated from previous phase-scan measurements while amplitudes were also checked through power and Q measurements for SUPERFISH simulations. To create the input particle distribution the estimated longitudinal distribution was randomly combined with the transverse distributions created from the measured phase-space distributions.

Because space-charge forces play a dominant role in the beam dynamics in this region, a measurement was made to estimate neutralization in the LEBT. Both horizontal and vertical phase-space distributions were measured at the last emittance station in the LEBT along with beam profiles obtained 89.1cm downstream of the emittance slit. These measured transverse distributions were combined with the estimated longitudinal distribution and used as the starting distribution in a PARMILA simulation. An iterative PARMILA simulation tracked the initial distribution of particles through this drift region with various effective current values and compared the resulting horizontal and vertical profiles to the measured profiles. The effective current which resulted in the best agreement between PARMILA and the measured profiles was 17mA for a measured peak current of 21mA. This value of effective peak current was used for all subsequent modeling of the beam transport in the LEBT. It was assumed that the beam in the DTL is not neutralized and thus the effective current was set to the measured current of 21mA when in the DTL.

The PARMILA program was converted into a subroutine and combined with a non-linear system solving routine employing the Regula Falsi technique (modeled after the fitting routine used in TRACE 3-D [3]). Various minimization criteria were studied for the minimization routine. Since a mismatched beam results in emittance growth, it was found that the minimization of emittance growth in the first two DTL tanks resulted in a good average match along the DTL. The non-linear system solving routine adjusted the LEBT quadrupole gradients to minimize emittance growth in the first two tanks of the DTL.

The results of the three matching algorithms discussed above were simulated with PARMILA and the results are shown in figure 3. The top graph displays horizontal mismatch (M_H as defined by the TRACE 3-D code [3]) versus drift-tube number and the second graph shows normalized horizontal emittance (ε_H) as a function of drift-tube number in the first two tanks of the DTL. The third and fourth graphs are the mismatch (M_V) and emittance (ε_V) versus cell number for the vertical plane, respectively.

Because the beam is small in the horizontal plane and large vertically, the horizontal space-charge forces are large as the beam enters the DTL. It is thus most difficult to achieve a horizontally matched beam distribution. The horizontal emittance is thus reduced more than the vertical emittance when the space-charge forces are properly calculated in the PARMILA matching algorithm.

Conclusions

Two-dimensional models and three-dimensional envelope models of the beam in the LEBT and the entrance to the DTL do not properly account for the changing space-charge forces due to the rapidly bunching beam at LANSCE. Because of this inability to properly represent the longitudinal beam distributions, these models do not lead to a satisfactory match of the beam into the DTL. Matching with these models can result in mismatched beam, emittance growth and halo formation.

PARMILA has been combined with a non-linear system solving routine for matching beam into the LANSCE DTL. This new matching tool more accurately models the changing space-charge forces due to the rapidly changing longitudinal distribution. PARMILA simulations have shown that this new matching technique results in less mismatch in the DTL and lower emittance growth. The results of this new matching algorithm, presented here, will be tested before the end of the 1996 run cycle.

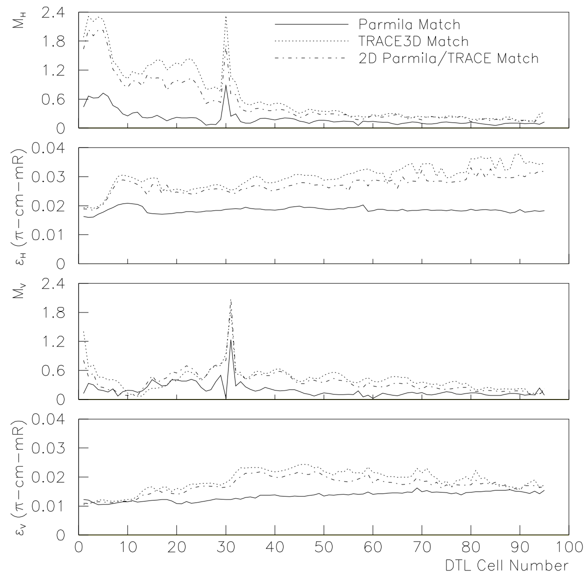

Fig. 3: Horizontal and vertical mismatch (M) and normalized emittance (ε) versus drift tube number in the first two tanks of the DTL.

Acknowledgments

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