METHOD FOR OBTAINING PROPER INJECTION STEERING INTO THE LAMPF DTL*

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Abstract

A portion of the LAMPF tune-up procedure involves properly steering beam from the 750 keV, low energy beam transport (LEBT) into Tank 1 of the 201.25 MHz drift tube linac (DTL). The previous method relied on a lengthy and somewhat arbitrary search over input beam trajectory parameters to obtain the desired result. A new algorithm is presented which produces a well centered beam in Tank 1 while significantly reducing the amount of time spent on this process.

Introduction

Each year during the turn-on phase at LAMPF, effort is expended in an attempt to produce a beam that is properly steered and matched into the DTL from the LEBT. Proper injection steering will minimize betatron oscillations and sensitivities of the transverse trajectories to changes in RF and quadrupole fields within the DTL. To determine if the injection steering is correct, a technique is employed which makes use of the adjustable nature of the electromagnetic quadrupoles in the DTL. The beam position is measured at the exit of tank 1 of the DTL while the upstream drift-tube quadrupole gradients are uniformly varied about their nominal values. With proper injection steering these position data exhibit little or no sensitivity to variations in those quadrupole strengths. Analysis of this "quad unroll" data reveals when the beam is "on-axis" in the tank. However, this procedure does not specify how to modify the injection steering to properly center beam in the tank. Obtaining the desired injection steering has typically been a rather lengthy process involving a grid search over some range of input beam position and angle.

The new method is based upon first-order beam transport theory. The correct injection trajectory is extracted from analysis of a set of linear equations relating the measured input beam trajectory to output beam position.

Theory

Assuming uncoupled motion between the horizontal and vertical planes the first-order relationship between the input beam trajectory and the output beam position of tank 1 can be given for either plane by,

$$x = R_{11}x_0 + R_{12}x'_0 \qquad (1)$$

where x is the output beam position, R_{11} and R_{12} are elements of the transfer matrix, R, and functions of the drift tube quadrupole gradients, and x_0 and x'_0 are the input beam position and angle, respectively. For the ideal case with no misalignments present, the solution is obvious. Realistically, however, misalignments between various beam line and accelerator components produce a different result. Misalignments between drift tube quadrupoles result in an 'effective' central beam trajectory which may not be collinear with the nominal geometric axis. The desired beam trajectory should coincide with this effective central trajectory. Furthermore, misalignments between beam line diagnostics and the DTL may also exist and result in additional differences between this and the ideal case.

The problem, therefore, becomes one of determining the relative offsets between the effective central trajectory of the DTL and the coordinate system of the diagnostics. These offsets can be incorporated into En. 1 to give,

$$x - \tilde{x} = R_{11}(x_0 - \tilde{x}_0) + R_{12}(x'_0 - \tilde{x}'_0) \qquad (2)$$

where $\tilde{x}$, $\tilde{x}_0$ and $\tilde{x}'_0$ are constants which represent the output position, input position and input angle offsets, respectively. Examination of this expression reveals that the correct injection steering values required to obtain the desired beam trajectory are given by these input beam offsets.

The method used here to determine these offsets is to obtain them from a solution to a set of simultaneous linear equations based upon Eq. (2). The first step is to solve for the transfer matrix elements, R_{11} and R_{12}. This can be done if we rewrite Eq. (2) as follows,

$$x = R_{11}x_0 + R_{12}x'_0 + C \qquad (3)$$

where $$C = \tilde{x} - R_{11}\tilde{x}_0 - R_{12}\tilde{x}'_0 \qquad (4)$$

and is constant for a given excitation of the tank 1 quadrupoles. Given at least three independent input beam trajectories and the corresponding output beam positions, the three unknowns can be solved from a system of linear equations constructed from Eq. (3). If this is performed for three or more different tank 1 quadrupole excitations, then these solutions can be combined into a second system of linear equations based upon Eq. (4) and solved for the offsets, $\tilde{x}_0$ and $\tilde{x}'_0$. These offsets will then be used as target values for the input beam trajectory.

Application

A FORTRAN program employing a linear least-squares routine[1] was written to solve the sets of simultaneous linear equations, first for the transfer-matrix elements and then for the input offsets. Measurements were performed using the LAMPF H^- beam and data were obtained for both horizontal

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and vertical planes. The input beam trajectory was extracted from beam profile centroids measured with a multi-wire harp and emittance collector separated by a drift space. These devices are located in the LEBT just upstream of the DTL. The drift space is actually a series of four quadrupoles which were de-energized for the centroid measurements but energized for beam delivery into tank 1. The input beam position and angle were varied by using steering magnets upstream of the multi-wire harp. For each input beam trajectory, the beam position at the exit of tank 1 was measured with a wire scanner at five different DTL quadrupole excitations near the nominal operating value. These data were obtained for three different input beam trajectories. During this procedure, the DTL cavity fields were at their nominal phase and amplitude for normal acceleration. This data set provides an overdetermined set of linear equations which was then solved for the input position and angle offsets. One of the quad unroll data sets (vertical plane) is shown below (see Fig. 1) and is representative of incorrect injection steering. The observed variations in the output beam position result from the beam undergoing betatron oscillations as it moves through the DTL.

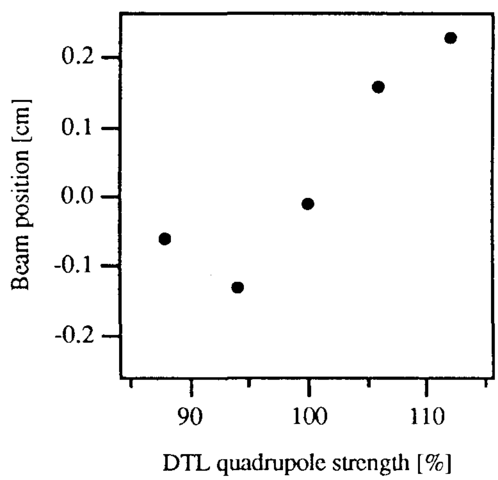

Fig. 1 Vertical beam position at the output of tank 1 versus the DTL quadrupole strength where 100% is the nominal operating value. Typical of poor injection steering.

The above data sets were analyzed and the input beam position and angle offsets were obtained. The injection steering was then modified to obtain this desired trajectory. The beam position at the exit of tank 1 was then remeasured for the same five excitations of the DTL quadrupoles. The results are shown below (see Fig. 2). The overall improvement is substantial. The output beam position is now quite insensitive to changes in the quadrupole strengths. Though not shown here, similar results were obtained for the horizontal plane. Also, on a different occasion, this procedure was performed with H^+ beam and similar results were obtained.

Discussion

This new method has been used quite successfully during the tune-up phase at LAMPF. The amount of time spent on obtaining satisfactory beam injection into the DTL has been reduced considerably. An attempt was made to calculate the transfer matrix elements by using a TRACE-3D [2] model of the DTL, however, the results were unsatisfactory. The R-matrix values obtained with TRACE-3D did not, in general, agree with those obtained with this technique. This discrepancy is most likely due to a combination of misalignments and uncertainty in the actual RF and quadrupole field strengths within the DTL.

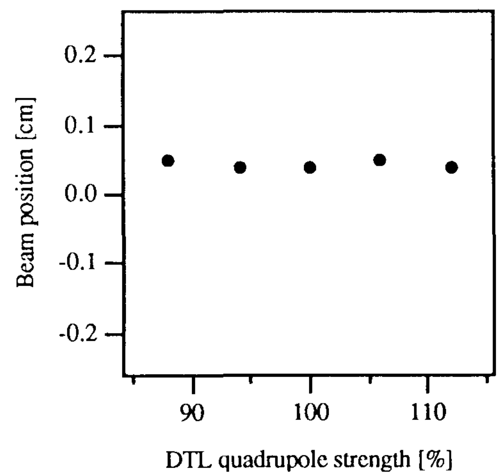

Fig. 2. Vertical beam position at the output of tank 1 versus DTL quadrupole strength where 100% is the nominal operating value. Result after implementation of calculated injection beam trajectory.

Acknowledgments

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References

[1] LLSIA routine, CLAMS library, Los Alamos National Lab, (1981)

[2] K. R. Crandall, "TRACE 3-D Documentation," Los Alamos National Laboratory report LA-11054-MS (August 1987).