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**Publication Date**
1983-03-01

LBL-15209 c.2

# Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

## Accelerator & Fusion Research Division

Presented at the Particle Accelerator Conference
on Accelerator, Engineering and Technology,
Sweeney Convention Center, Santa Fe, NM,
March 21-23, 1983

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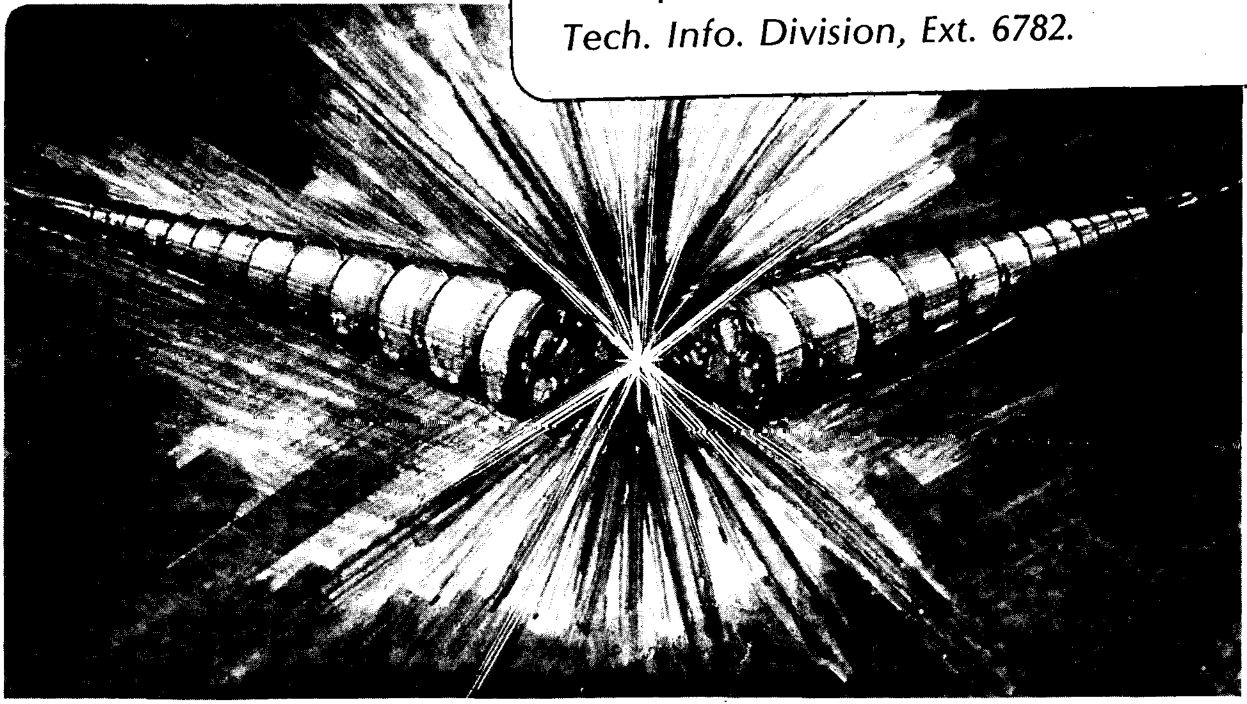

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

# AUTOMATIC TUNING OF THE LBL SUPERHILAC THIRD INJECTOR TRANSPORT LINE*

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## Summary

Testing of a new automatic tuning procedure in an LBL SuperHILAC beam transport line has been conducted with the third injector microcomputer control system. This technique is an advance over the sequential station-by-station automatic tuning method developed for the Bevalac transfer line.[1] The computer now performs steering/focusing adjustments simultaneously on a number of quadrupole and dipole magnets comprising multiple-station sections of the injection line. New magnet currents are computed from equations governing beam optics in a real-time simulation of the beam line. The key to this technique is the calculation of beam transverse emittance utilizing the same control magnets and beam profile monitors used for manual tuning of the line. This emittance calculation requires high resolution beam profile measurements using multi-wire profile monitors recently installed in the third injector line.

## Introduction

The LBL SuperHILAC third injector line transports the 15.8 kev/amu heavy ion beam from the ABEL ion source and the 750 kv Cockcroft Walton pre-injector through the Wideroe linac booster for injection into the Alvarez linac.[2] The MEBT or medium energy section of this line, the subject of this paper, takes the 112.5 kev/amu beam from the exit of the Wideroe, through an oil vapor stripper device and delivers the stripped beam to the Alvarez. The MEBT line is about 14 meters long and it receives from 2 to 36 beam pulses per second from the ABEL source.

The design configuration of the components in the MEBT line, shown in Figure 1, is determined by two primary beam optical constraints:

1) A symmetrical horizontal and vertical focus at the location of the oil vapor stripper to minimize the adverse effects of multiple beam scattering.

2) A 31.5 degree vertical achromatic bend for analysis of the stripped beam and in order to translate it down to the level of the Alvarez linac, a drop in elevation of 1.5 meters.

The theoretical design beam transmission envelope in Figure 2, corresponding to a nominal rigidity of 10.5 kgauss-m and transverse emittance of 4 π-cm-mrad, reflects these design requirements.

## MEBT Tuning Strategies

The MEBT system is tuned by operators interfacing to the hardware through a microcomputer control network. Steering, bending, and focussing of the beam is performed with six dipole and thirteen quadrupole magnets. Beam intensity readings are monitored at four Faraday cup stations and profile information is collected from five wire-monitor stations. For maximum beam transmission through the line, the task of tuning the MEBT is essentially to replicate the longitudinal beam transmission envelope in Fig. 2 through a sequence of station-to-station tuning operations:

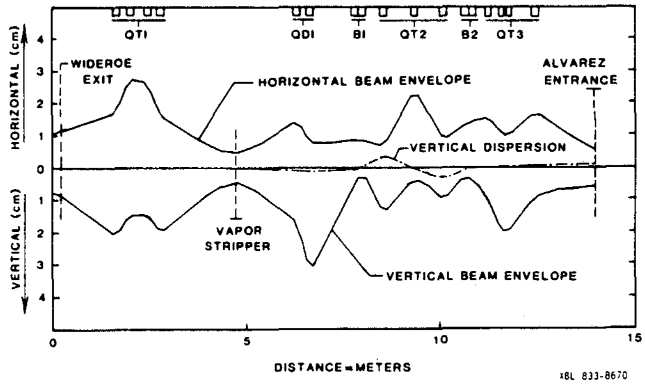

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Fig. 2: Design calculations for the beam transmission evelopes through the MEBT.

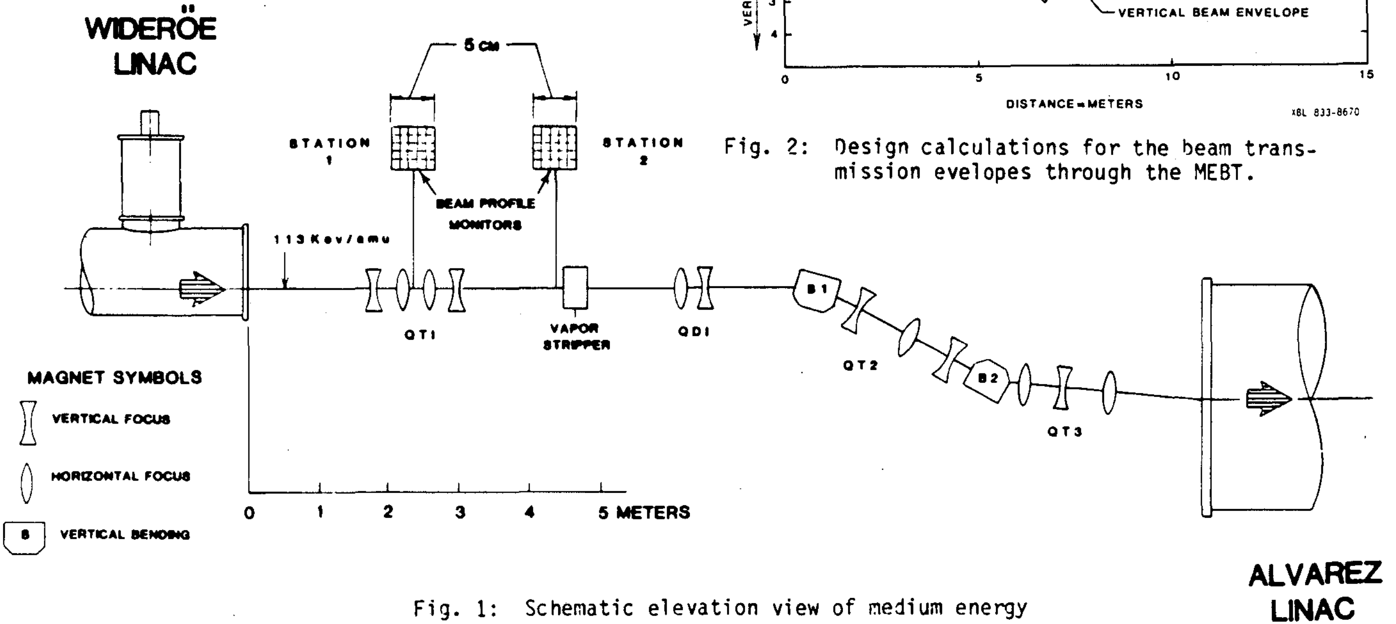

Fig. 1: Schematic elevation view of medium energy section of SuperHILAC Third Injector Transport Line (MEBT).

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A) Synchronized tuning of the quadrupole magnet group QT1 to achieve a horizontal and vertical focus at beam profile monitor station 2 near the stripper, i.e. operate this magnet ensemble as a symmetric triplet.

B) Adjust the quadrupole doublet QD1 to focus the beam through the narrow aperture restriction of the first vertical bending magnet B1.

C) Adjust the symmetric quadrupole triplet QT2 to focus the beam in the narrow aperture of the second bending magnet B2 and simultaneously to minimize the vertical dispersive effects due to beam momentum spread.

D) Adjust the triplet QT3 for the best possible focus of the beam at the entrance of the first drift tube quadrupole magnet inside of the Alvarez linac.

E) Repeat the above steps A-D to improve beam transmission and for better matching to the linac.

Trim magnet corrections are performed concurrently with the above procedure to ensure optimal focussing due to proper beam alignment.

In practice, it is difficult to place beam profile monitors at the preferred locations required for direct observation of the aforementioned tuning objectives. Operators must therefore utilize a combination of direct and inferred empirical operations. For example, an operator will perform task (A) pro forma in focussing the beam using a profile monitor located at the stripper. To tune the remainder of the line, however, he will adjust quadrupole and trim magnet controls to maximize transmitted beam intensity striking a Faraday cup located at the entrance of the Alvarez, irrespective of beam optic considerations. Ideally, the solution thus obtained will converge upon the theoretical optical solution in Figure 2. In reality, a bandwidth of solutions are generated due to time-varying accelerator performance parameters (switching the machine over to a different ion can occur on a daily basis) and a variety of operator tuning preferences.

## Automatic Tuning and Beam Profile Monitors

In order to present the operators with an 'initialized tune' that is consistent with theoretical design objectives, it is desirable to implement a computer-based automatic tuning procedure which utilizes existent control magnets and beam monitors. This procedure could achieve its objectives very rapidly, enabling an operator to concentrate attention on the fine-tuning operations required to peak the beam intensity.

A method for computer automatic tuning of the LBL Bevalac transfer line was described in a prior report[1]. The accuracy in monitoring beam profile parameters in the transfer line is limited by the coarse resolution inherent in the design of segmented Faraday cups. As such, this method only addresses individual particle trajectories which approximately describe station-to-station transport of the total ensemble of particles comprising the beam. This method is therefore restricted to tuning the beam one station at a time. This requires destructive, time-consuming, iterative sampling of beam profiles for each single-station operation.

With the design and installation of a new generation of highly transparent, high-resolution beam profile monitors in the SuperHILAC third injector line, a faster, real-time method for computer automatic tuning becomes feasible. Rapid automatic tuning of beam lines depends upon high accuracy parametric characterization of actual beam performance. This enables beam transport computer programs to accurately simulate real-world tuning problems. The numerous tuning objectives required to tune an entire transport line can be simulated in a short time. New magnet currents are set by the control computer in a single step. The highly accurate measurements derived from the beam profile monitors in the MEBT transport line make possible the calculation of the requisite beam parameters utilizing the same control magnets and monitors used for manual tuning of the beam.

As depicted in Figure 3, each monitor is assembled as a mesh of 10 mil diameter gold-plated tungsten wires. Each monitor is composed of two mesh planes, rotated by 90 degrees, each containing 16 wires for sampling the beam in both horizontal and vertical transverse planes. Beam striking the wires induces an electrical current proportional to the beam current density at that location. As shown, up to 16 wire signals are combined to yield 8 beam current density samples. These samples are digitized and sent

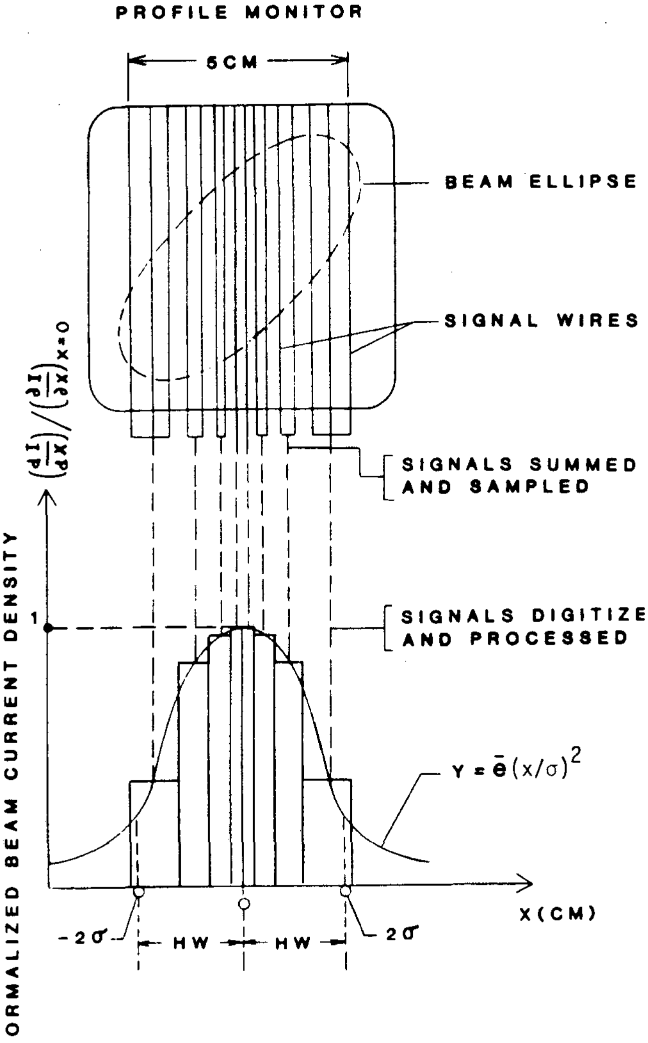

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Fig. 3: Derivation of profile measurements from the raw data generated when beam is intercepted by multi-wire monitors.

to the ABEL control computer where a processor program generates profile measurements from a least-squares fit of the data to a Gaussian (or Normal) distribution curve. The horizontal and vertical half-widths are defined to span a distance of 2 standard deviations from the beam centroid, i.e., these half-widths contain 95% of the integral beam intensity. This method allows for accurate profile measurements in the event that the beam 'spills off' beyond the bounds of the sampling mesh.

## Calculation of the Ellipse Parameters

The amplitudes and trajectories of all particles comprising the beam are geometrically represented in position-momentum phase space by an ellipse which contains all the particles. The parameters which characterize the ellipse are related in the following way: $\beta_n*\gamma_n - \alpha_n^2 = 1$, and $\beta_n*\varepsilon = X^2_n$. These parameters, $\beta$, $\alpha$, $\gamma$ and $\varepsilon$ are measures of beam amplitude, tilt, angular divergence, and emittance, respectively, in phase space as shown in Figure 4. $X_n$ is the beam amplitude as measured directly by a beam profile monitor at station 'n'. The transport of beam ellipse parameters between profile monitor stations 1 and 2 in the MEBT line is depicted in Figure 4. The relevant equations governing beam transport are:

1) $\beta_2 = T11*\beta_1 + T12*\alpha_1 + T13*\gamma_1$
2) $\bar{\beta}_2 = T11*\beta_1 + \bar{T}12*\alpha_1 + \bar{T}13*\gamma_1$
3) $\alpha_2 = T21*\beta_1 + T22*\alpha_1 + T23*\gamma_1$

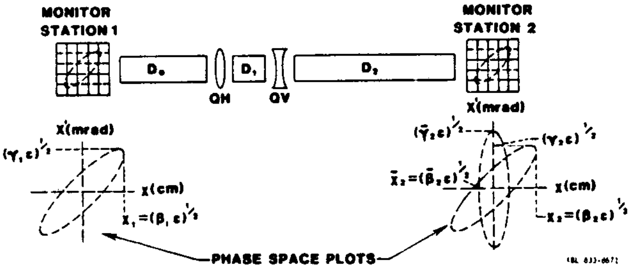

Fig. 4: Station-to-station transport of beam ellipse parameters in position-momentum phase space.

The Tij elements are known linear combinations of the transfer matrices which describe the beam optical properties of magnets $Q_H$, $Q_V$ and drift spaces $D_0$, $D_1$, $D_2$ in Figure 4. Equations 1) and 2) are generated by measuring the beam profiles $X_n$ at stations 1 and 2 for each of two different current settings of the last quadrupole magnet in the QT1 group. This operation yields the known parameters $\beta_1$, $\beta_2$, $\bar{\beta}_2$. Equations 1) and 2) are solved in closed form for the unknown parameters $\alpha_1$, $\gamma_1$. Since the horizontal and vertical properties of the beam are essentially uncorrelated, the horizontal and vertical ellipse parameters are solved independently by applying the above procedure to each dimension.

## Tuning the Line

Having determined the horizontal and vertical ellipse parameters at station monitor 1, these ellipses are mathematically 'transported' back to the Wideroe exit, upstream of all control magnets. Beam sampling is no longer required. The global tuning objectives are achieved, in simulation, by solving for the quadrupole magnet currents required to properly transport these ellipses to match the theoretical solution in Figure 2. This requires simultaneous solution of two versions of equation 1), one each for the horizontal and vertical cases,

4) $\beta_x(n+1) = T11x*\beta_x(n) + T12x*\alpha_x(n) + T13x*\gamma_x(n)$
5) $\beta_y(n+1) = T11y*\beta_y(n) + T12y*\alpha_y(n) + T13y*\gamma_y(n)$

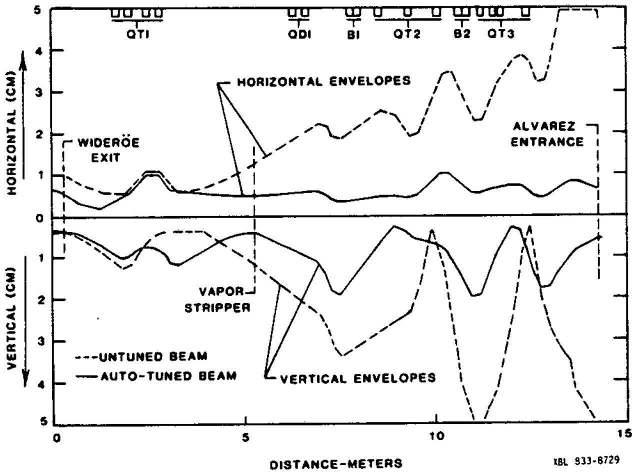

Fig. 5: Beam transmission envelopes through the MEBT both before and after a test of the auto-tuning program for $^{93}Nb^{3+/6+}$.

These equations are solved for the unique set of quadrupole magnet currents at station n to achieve the desired focussing $\beta_x(n+1)$, $\beta_y(n+1)$ downstream at station (n+1). These equations are solved numerically by a non-linear least-squares gradient optimization program.

The complete sequence of MEBT tuning operations previously outlined is equivalent to solving a sequence of two-parameter or three-parameter optimization problems in a numerical simulation of the transport line. The entire line can be optimized in the simulation mode within a short time. To the extent that the initial ellipse measurements are subject to error, i.e., due to resolution limits of the profile monitors or deviations of transport simulation from actual beamline performance, the ellipse measurement is repeated until the beam is maximally focussed at station 2. This condition ensures that $\alpha_2$ vanishes in equation 3) above, corresponding to the upright ellipse at station 2 in Figure 4, and providing another independent check of the precision of these measurements.

## Results

The tuning algorithm has been successfully tested on the MEBT transport line. Figure 5 compares the beam transport for the cases both before and after the automatic procedure was exercised. The entire operation was completed in less than one minute. CRT graphical displays of beam transmission similar to Figure 5 permit the operators to monitor the progress of the automatic procedure. After the calculation of the ellipse parameters, these plots can also be generated and refreshed once per second to display the progress of operator tuning in the manual mode.

## References

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*This work supported by the Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Sci. Div., U.S. Dept. of Energy Under Contract Number DE-AC03-76SF00098

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