PROBLEMS IN DESIGN AND OPERATION OF SUPERHILAC BEAM TRANSPORT SYSTEMS*

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Experimental Area Layout

Experiments are served at the SuperHILAC by a fan-shaped pattern of beam lines radiating from the exit of the linac tank. Fig. 1 shows those beam lines which have been used in the first year of operation. The compact layout of bending magnets was dictated by the need to fit many cave areas into an existing experimental hall. Magnets M2, M3 and M4 are flat field magnets. M2 has normal entry and a curved exit which gives vertical focusing for all lines except 0°. M3 has a circular pole, with normal entry and exit for all lines. M1 and M5 are gradient bending magnets in which the sign of the gradient in the entrance half is vertical focusing and in the exit half vertical defocusing. Quadrupole singlets and doublets have been placed along each beam line in locations where, it is hoped, they are most effective for focusing of the beam.

Design Emittance of Transport Lines

As the lines shown in Fig. 1 were designed before the linac came into operation, certain assumptions had to be made about beam properties. It should be instructive to describe these assumptions, then to review their validity in view of what has been learned of beam properties since the linac came into operation.

The emittance of the linac beam was taken as π cm mrad based upon considerations of injector emittance, damping, and possible dilution in transit through the linac. The crosssection in phase space was assumed elliptical. The specification of the ellipse in each plane, horizontal and vertical, requires two additional parameters. One can be taken as L_x (or L_y), the distance to the waist (or "virtual source") measured from the tank end wall. The other can be taken as x_o' (or y_o'), the maximum angle (see Fig. 3). Positive L_x denotes a virtual source downstream from the end wall, negative L_x upstream.

It seemed reasonable to find the beam envelope in the linac from a consideration of the transverse focusing forces; i.e. the quadrupoles and RF defocusing in the gaps. The quadrupole pattern in the post-stripper is (HD) (HF) (HF) (HD) ..... where HD = horizontal defocusing, HF = horizontal focusing. For this pattern and for $B'\ell$ = const. for the quadrupoles we find the expected beam envelope at the linac exit is as shown schematically in Fig. 2. The linac cell is not quite periodic because of the increasing beam energy at each gap; however this is only a small perturbation and can be neglected in this calculation. There is a waist in each plane 1.6m from the end wall, i.e. $L_x = L_y = -1.6$m. Maximum divergence x_o' is about 2 mrad and varies somewhat with quadrupole excitation.

In order to provide matching to the various beam transport lines the plan was to operate Q74 and Q75 as a doublet, each with its own power supply. Most of the transport systems terminate on at target at which a focused beam is required - usually a small spot. This implies 3 conditions which must be satisfied at the target: a horizontal and a vertical focus and minimum dispersion. Another condition is that the beam fit inside the vacuum chamber, which is 6.4 cm in diameter at the quadrupoles and with magnet gaps typically 4.4 cm.

Operating Experience

When beam was obtained from the linac, measurement showed that the emittance area had approximately the value expected.[1] However the other beam properties were different from those described above for ideal transverse focusing of the periodic structure. This can be seen from Fig. 4 which shows operating points found for x_o', L_x and for y_o', L_y for several of the beam lines, and compared with the values predicted for the periodic structure. These operating points were found as follows: first by a careful tuning procedure all of the machine parameters and the transport line quadrupole currents were varied so as to optimize beam at the target. This was done either by viewing (with a TV camera) a scintillating screen at the target position, or by forcing the beam to pass through a small opening in a collimator before reaching a Faraday cup. Then from the known conditions at the target, together with the known transport line quadrupole excitation, the initial conditions were computed; i.e. the beam ellipse configuration at the tank exit. Fig. 5 shows the result of such a calculation for line E35.

The points in Fig. 4 are scattered throughout the "allowed" regions of the graph (operating points in the upper left and upper right areas of the graph would cause beam intensity losses due to aperture limitations) with no tendency to cluster around the points predicted by the periodic structure calculations.

To understand the reason for this flexibility in the virtual source position it is necessary to look at the effect that the various machine parameters have in focusing the beam. The poststripper quadrupoles are varied in three independent groups - an entrance set of 12, and exit set of 7, and the remainder, 52 quadrupoles, as the third set (Q74 and Q75 are not in fact excited independently). These three sets have some effect on the focusing behavior, as observed on a screen. However the RF gradient level of the 5 independently driven tanks in the post-stripper seem to be much more important. Change in RF gradient level in one of the tanks causes a pronounced change in the beam shape and position observed at the target, in a manner analogous to tuning with a single quadrupole. The other tank gradients and also the relative phase of each tank also change the beam, in a way which is (at least partially) independent.

Similar transverse focusing effects due to RF gradient has been noted in an earlier paper on beam measurement,[1] and here, as there, the results seem to be consistent with a coupling of longitudinal and transverse oscillations of the particles, acting to produce a modulation of the beam envelope in both x_o and x_o' space. The coupling is due to the fact that the energy gained by a particle traversing a gap is

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a function of its radial position.

Steering Effects

As is well known, beam emerging from an Alvarez linac will typically be displaced in position and angle from the axis. This is caused by small random misalignments of the quadrupoles in the linac and from misalignment of the beam entering the linac. For the poststripper, misalignments up to ±5mm, ±10mrad can be expected. All of the parameters which affect focusing (quadrupoles, tank RF gradients and phases) will also affect this misalignment, as seen at the linac exit. Thus tuning to improve the focusing properties of the transport line must also be used to achieve better alignment - the processes are usually inseparable. Small bending magnets are used to achieve a partial separation between steering and focusing. Such magnets will also increase the effective aperture of the transport line. The alignment magnets EAV1, E2AV2,... etc. shown in Fig. 1 are used for this purpose. They are capable of bending the beam vertically up to ±10 mrad. Horizontal alignment magnets have not been necessary because a small trim supply on the bending magnets M1, M2,... etc. performs the same function.

Instrumentation

The beam monitoring instruments which have been used in the experimental area are all time-tested types and certainly are not new. Here it should be sufficient to name the devices which have been found useful. The primary device is the simple Faraday cup. They are usually put into and taken out of the beam with remotely-controlled actuators operated from the control room. Where the beam power is more than a few tens of watts they should be water cooled. Next, the scintillating screen viewed with a TV camera is most useful. This shows beam size, focusing behavior, steering effects, etc. Apertures of various kinds are also very useful. A circular or rectangular opening in a thin plate, placed at the proper place along beam line, can force the tuning process to center the beam and to produce desired focusing effects. The slotted plate emittance apparatus has been previously described.[1] Beam energy is found either by measuring the magnetic field required to bend the beam through a known angle and hence deducing the momentum, or by use of a crystal detector. Features that all of these devices have in common is that they are simple, relatively foolproof, and can easily be produced in quantity.

References

1. F. B. Selph, D. A. Spence, and R. R. Stevenson, Proceedings of the 1972 Proton Linear Accelerator Conference, pp. 67-72.

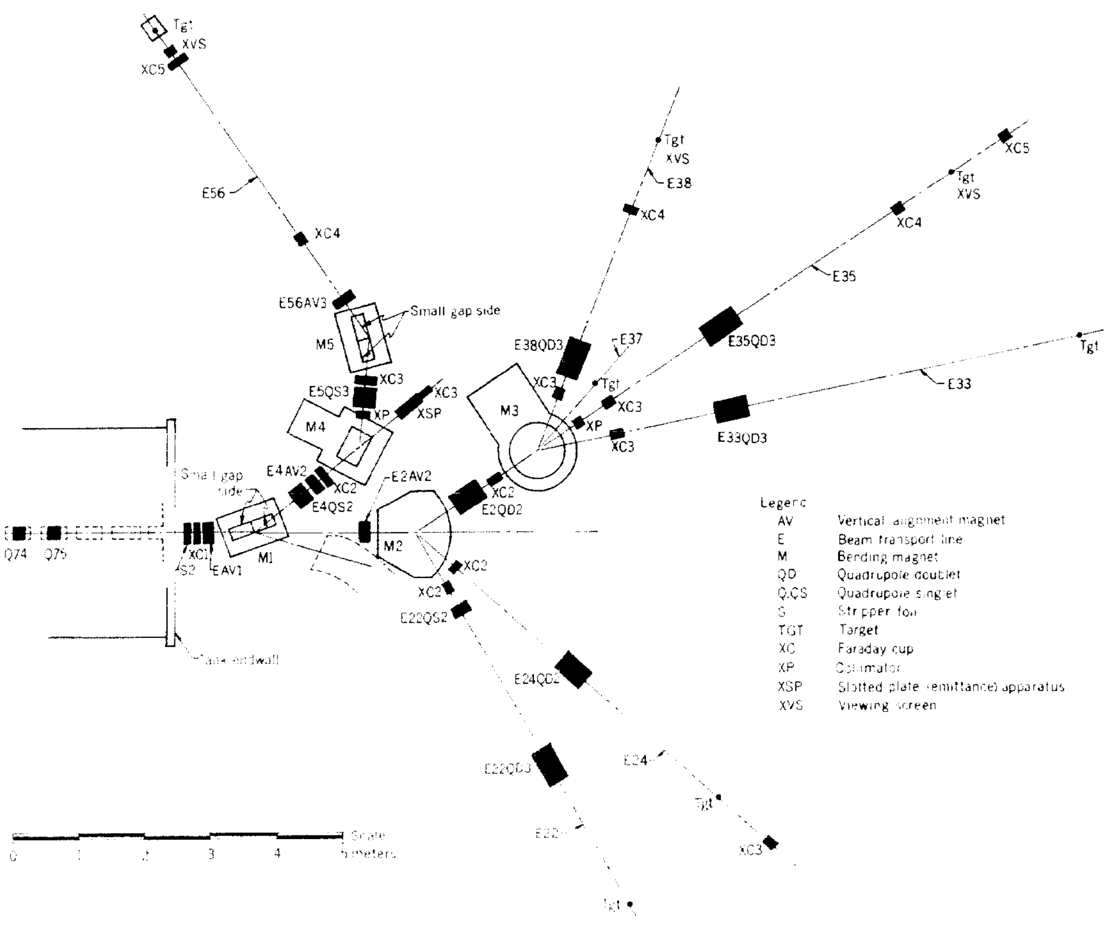

Fig. 1. Plan of SuperHILAC experimental area beam lines as of February 1973.

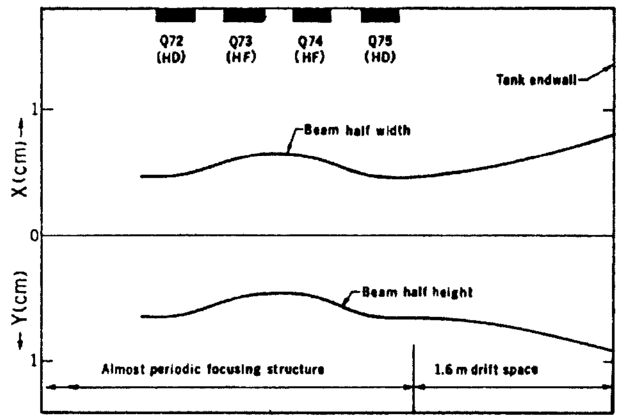

Fig. 2. Beam envelope at poststripper exit, calculated from transverse focusing forces.

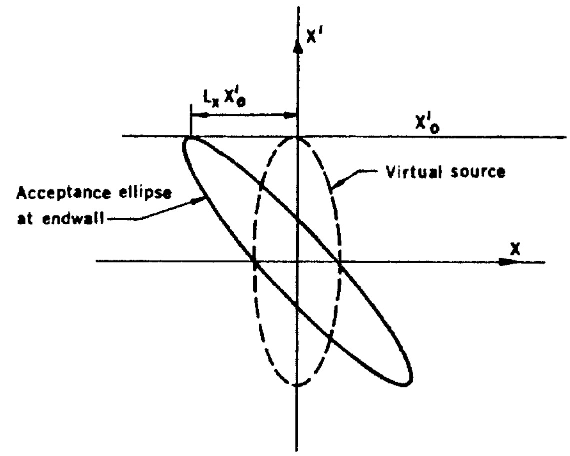

Fig. 3. Relationship of beam ellipse at poststripper end wall and virtual source.

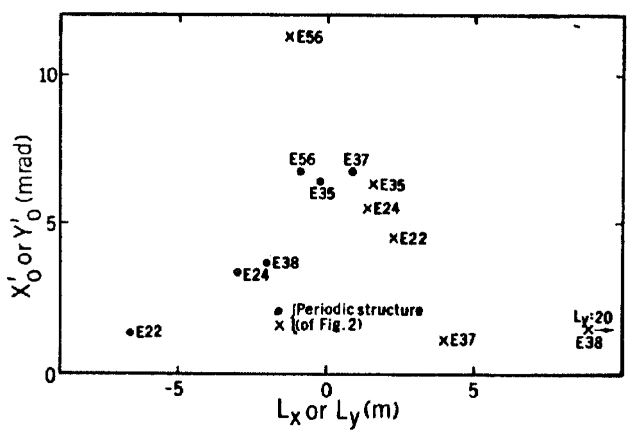

Fig. 4. Virtual source positions found from operation of transport lines.

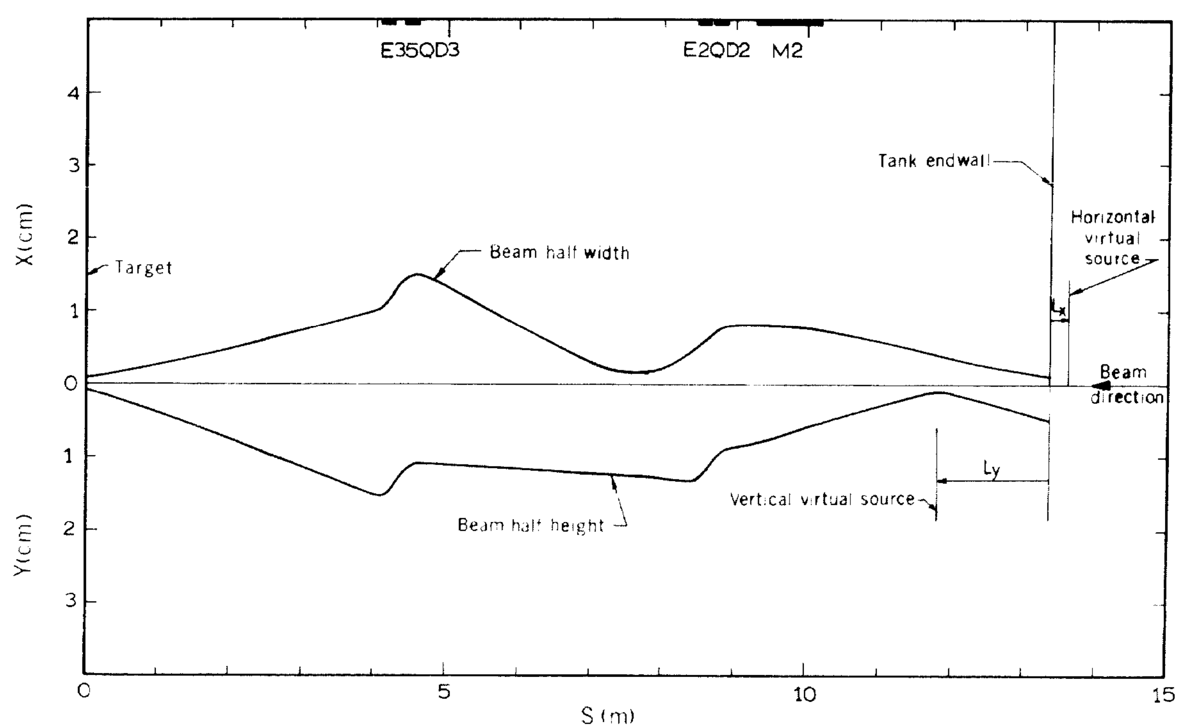

Fig. 5. Beam envelope and virtual source positions for line E35.