60 keV BEAM TRANSPORT LINE AND SWITCH-YARD FOR ISAC

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Abstract

The ISAC project under construction at TRIUMF[1] is to consist of radioactive ion sources, a high resolution mass separator, a low-energy (60 keV) experimental area, RFQ and DTL linacs to reach 1.5 MeV per atomic mass unit (amu), and a high-energy experimental area. Additionally, there will be a stable off-line source primarily for commissioning the linacs but also for use by the low-energy experimental program. The transport line which connects these elements therefore includes a switch which allows either the radioactive beam to supply the low energy area simultaneously with the off-line source supplying the RFQ, or the radioactive beam supplying beam to the RFQ simultaneously with the off-line source supplying beam to the low-energy experiments. The maximum ion source voltage is 60 kV. The RFQ accepts particles with 2 keV per amu, so masses less than 30 must have lower energy and masses larger than 30 can only be accelerated if they are multiply-charged. All optics is electrostatic; the bends have spherical electrodes. Alignment tolerances are given. Aberrations are kept sufficiently small that the maximum beam emittance of 50 πmm-mrad is transported with negligible distortion. Of particular interest are the achromatic bend sections, the sawtooth buncher insertion, and the matching section to the RFQ.

1 BEAM PROPERTIES

For acceleration in the RFQ, particles must have a velocity corresponding to 2 keV per amu. The lightest mass considered will be 6 amu; therefore the smallest momentum is $B\rho = 386$ gauss-m.

After considering variously reported emittances for radioactive ion sources, we have chosen 50 πmm-mrad as the upper limit nominal emittance. This means we desire to be able to transport this emittance easily with negligible degradation. In practical terms, this means that the acceptance of the transport system should be at least 200 πmm-mrad.

In some cases, the beam after the separator may have a much smaller emittance in the bend plane than in the non-bend plane. Somewhat arbitrarily, we impose the condition that for an emittance ratio of 25, the smaller emittance be allowed to increase by no more than 20%.

The intensity of the radioactive beam is not envisaged to exceed 1 μA, so space charge is not important.

2 OPTICS ELEMENTS

All optics will be electrostatic. This is cheaper than magnetic, but also simpler to tune since the settings depend only upon beam energy, and not on mass. One can go from one mass to another by simply changing the separator dipole, without retuning the quadrupoles and electrostatic bends in LEBT. The voltages are not high, since the highest beam energy is only 60 keV.

At TRIUMF, we have been using electrostatic optics since 1974 in our 20 m long, 300 keV, H^- injection line for the cyclotron (ISIS)[2].

The ISAC LEBT quadrupoles will be similar to the ISIS quads, with a bore radius of 25 mm. Typical lengths will be 50 mm as opposed to the ISIS standard length of 100 mm. For the typical focal length $f = 0.3$ m, the required electrode voltage is 2.5 kV at the maximum beam energy of 60 keV. The electrodes are cylindrical in section, with radius 1.145 times the bore radius. They are cut from an aluminum extrusion: the ends are not shaped in any special way[3], but slightly rounded to remove the sharp edge.

The bends are similar to the ISIS bends with an aperture of 38 mm, except that the radius is 254 mm instead of 381 mm, and the shape is spherical instead of cylindrical. Spherical electrodes give equal focusing in the bend and non-bend directions. The electrode potentials are ± 9 kV at the full energy of 60 keV. The outer electrode can swing open on a pivot to allow switching between straight-through (bend off) and 45° bend. See Fig. 1. Special care is taken in alignment: the tolerance on positioning the electrodes is ± 0.4 mm and on the roll angle is ± 1.4 mrad.

A first order transport code was used for designing the optics. However, $3^{\rm rd}$ order aberrations were calculated for individual quads using the formula[3] $\frac{\Delta f_x}{f} = \frac{1}{fL}\left(\frac{7}{6}x^2 - \frac{1}{2}y^2\right)$ for x, and similarly for y. Fractional increases in emittance for individual quads were added in quadrature as well as the emittance increase incurred from an inexact match. This was minimized using a simulated annealing optimization engine. Optimization parameters were quadrupole strengths and positions: the optimization algorithm works efficiently for any number of optimization parameters.

`GIOS` was used in a final check of the transport from buncher to RFQ. It confirmed that an emittance of 200 πmm-mrad was transported with only slight distortion.

3 OPTICS MODULES

Besides special sections for matching from the separator, from the Off-Line Ion Source, and to the RFQ, there are only 3 different modules; the periodic cell, 90° bend, and an insertion for creating small waists e.g. for the buncher.

The backbone of the transport is FODO periodic with a phase advance of 90° degrees per cell. Each cell is

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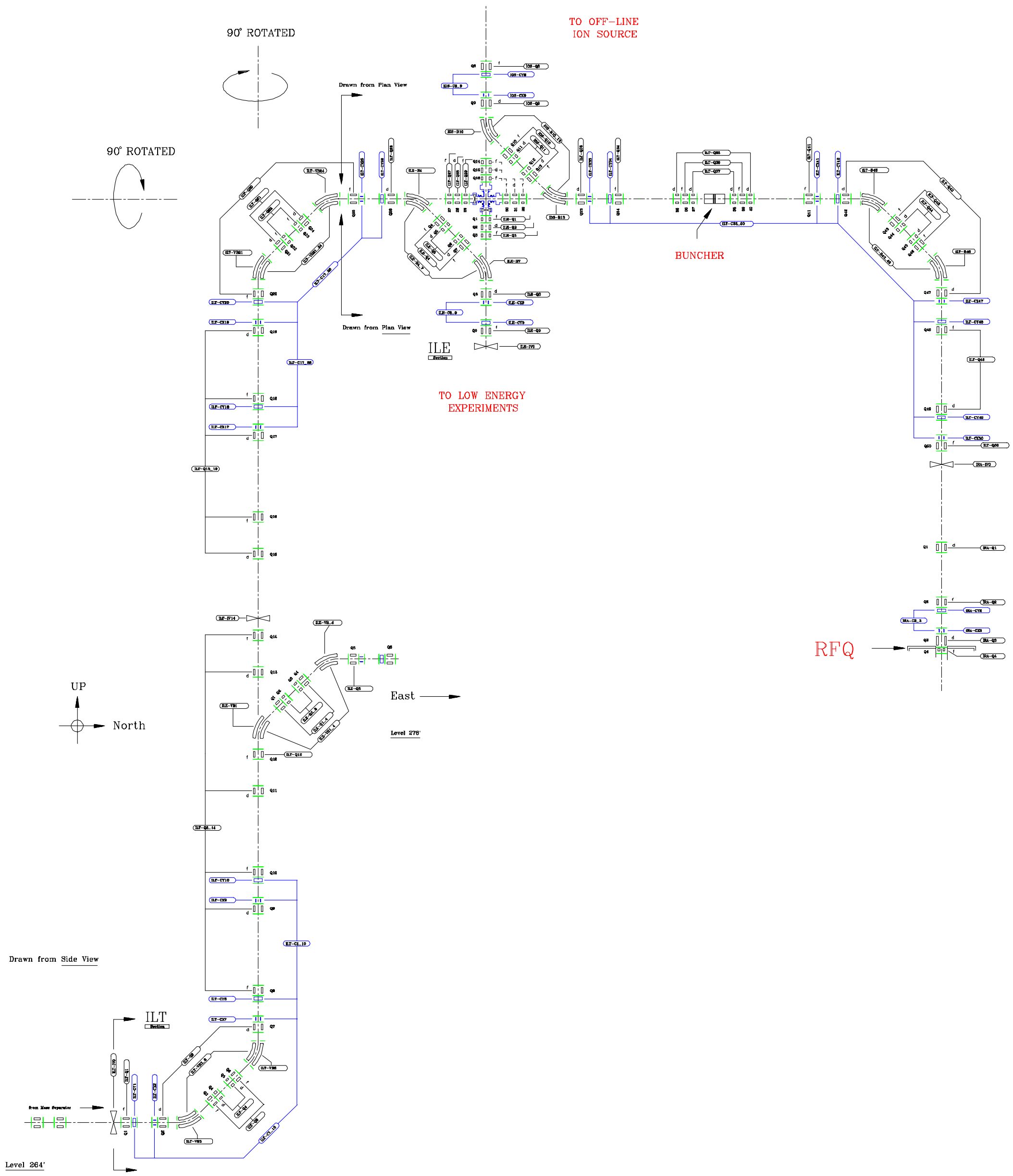

Figure 1: Layout of LEBT

$L_c = 1$ metre in length, and the quads are arranged in doublets, 0.31 m between quad centres. The quadrupoles themselves are only 5 cm in length. (See, for example, Fig. 2, which shows a periodic section cell on either side of a bend section.) These parameters are of course a compromise between good optical properties and minimum cost.

The main optical condition was that the beam not be easily perturbed by outside influence. A fairly good approximation for motion in the periodic section under the influence of a stray magnetic field is $x'' + k^2 x = 1/\rho$, where k is the focusing strength ($= \pi/2/L_c$ for 90° per cell) and ρ is the radius of curvature in the stray field. This shows that the average beam deflection is $\Delta x = (k^2\rho)^{-1}$, and we wish this to be small compared with the quadrupole aperture. Stray field from the earth and the TRIUMF cyclotron combined is approximately 1 gauss. This yields $\Delta x = 1$ mm for the 6 amu case, which is tolerably small compared with the quadrupole aperture radius of 25 mm. Since $\Delta x \propto L_c^2$, it would be 4 mm for a 2 m cell length, and this would have required magnetic shielding.

Monte Carlo calculations were made for periodic section quads with random roll angles. It was found that to meet the above condition for maintaining emittances of non-round beams, the rms roll angle be no more than 5 mrad.

The bend module (Fig. 2) consists of two 45° bends with a symmetric triplet between. The triplet is tuned to make the module achromatic. Since it is symmetric as well, this also zeroes the transfer matrix elements M_{51} and M_{52}. This is essential for the bend module between the buncher and the RFQ.

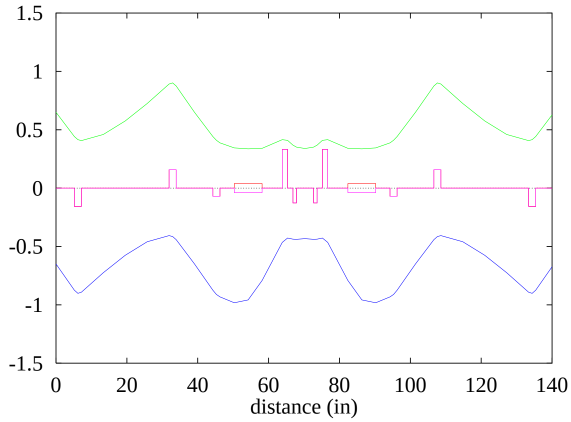

Figure 2: Beam envelopes in cm for $\epsilon = 50\,\pi\mu$m through the bend section, showing periodic sections on either side. The upper trace is for the bend plane, and the lower trace is the non-bend-plane envelope. The step-shaped traces are the focusing strength k; k_x plotted positive and k_y plotted negative. (The traces for k_x and k_y coincide in quads since $k_x = -k_y$, but not in spherical bends where $k_x = k_y$.)

Note that the 45° bend element can be installed in any long drift of the periodic section. Only the quadrupole nearest the bend needs to changed from its periodic setting. This is to be used in the Low Energy Experimental Area to allow switching into an experiment at any periodic cell.

The buncher insertion uses a triplet on either side to create the waist. The optics is sufficiently flexible that waist radii from 2 mm to 5 mm are possible.

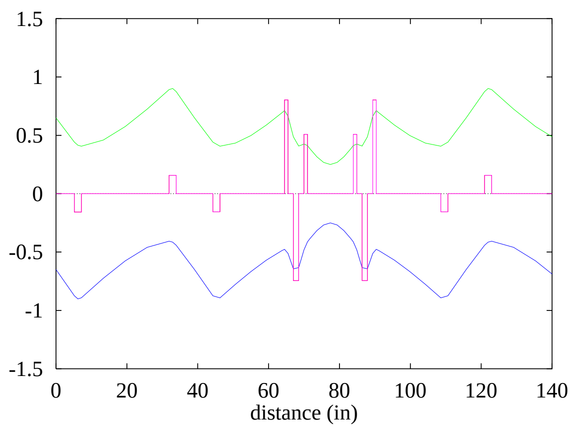

Figure 3: Beam envelopes for matching the periodic section to a narrow waist at the buncher. The tune shown is for a 2.5 mm waist.

Matching to the RFQ is achieved with 5 quadrupoles, the last one being half of normal size (radius = 12.5 mm, length = 25 mm, see Fig. 4). This is because the beam required by the RFQ is highly convergent (28 mrad), and a short final quad avoids the beam being overly large in the second-to-last quad in the direction of defocusing in the final quad. The matching section and the shapes of the electrodes at the RFQ entrance were optimized together[4]. Laplace's equation was solved for a given electrode shape, particles were tracked to find the acceptance ellipses, an optimal matching section was designed as described above by minimizing the 3$^{\rm rd}$ order quad aberrations; then a new RFQ configurationwas calculated again and the procedure repeated. In this way, a design was found in which the emittance increase for 200 πmm-mrad was only 10%.

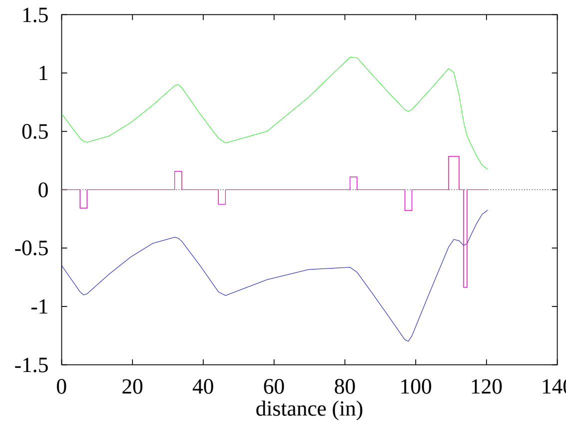

Figure 4: Beam envelopes matching the periodic section to the RFQ.

4 LAYOUT

The layout is shown in Fig. 1. The beam arrives from the separator at the lower left of the figure, traveling North. It is bent vertically, and here there is a 90° rotation of the coordinate system in the figure, so that when it is again bent onto the horizontal plane, it is traveling West. There are two locations where the beam can be bent onto the horizontal plane: on the top (ground) floor, and on a mezzanine between the separator pit and the ground floor. There is another coordinate transformation so that from the point on the figure where the beam is again bent to the horizontal plane, it is in Plan View. The beam can either cross over the beam from the Off-line Ion Source (OLIS), towards the RFQ, or it can be bent toward the North, to the Low Energy Experimental Area. If the radioactive ion beam is supplying the LE area, the OLIS can be used by the RFQ, and if the radioactive beam is supplying the RFQ, the OLIS can be used for the Low Energy experiments.

5 REFERENCES

[1] P.W. Schmor, et al. *Status of the TRIUMF ISAC Facility for Accelerating Radioactive Beams* These proceedings (8B.12).

[2] See, for example, P. Schmor, R. Baartman, et al., *Progress Towards Higher Intensities and Improved Beam Stability at TRIUMF* Proc. PAC IEEE Trans. **NS-30** (1983) 2092.

[3] R. Baartman, *Intrinsic Third Order Aberrations in Electrostatic and Magnetic Quadrupoles* These proceedings (4V.23).

[4] S. Koscielniak, et al. *Beam Dynamics Studies on the ISAC RFQ at TRIUMF* These proceedings (2W.28).