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DESIGN OF THE SLC DAMPING RING TO LINAC TRANSPORT LINES*

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Summary The first and second order optics for the damping ring to linac transport line are designed to preserve the damped transverse emittance while simultaneously compressing the bunch length of the beam to that length required for reinjection into the linac. This design, including provisions for future control of beam polarization, is described.

Introduction The SLAC linear collider will require electron and positron beams of very small transverse emittance (1.2×10^{-8} π radian-meters), after cooling in the damping ring. The transport of these beams will require beam lines that are fully corrected to second-order. Here we describe the damping ring to linac (RTL) transport line, the first of such corrected SLC beam lines. Figure 1 is a plan view of the SLC damping ring system showing the transport line and its relationship to other components of the system.

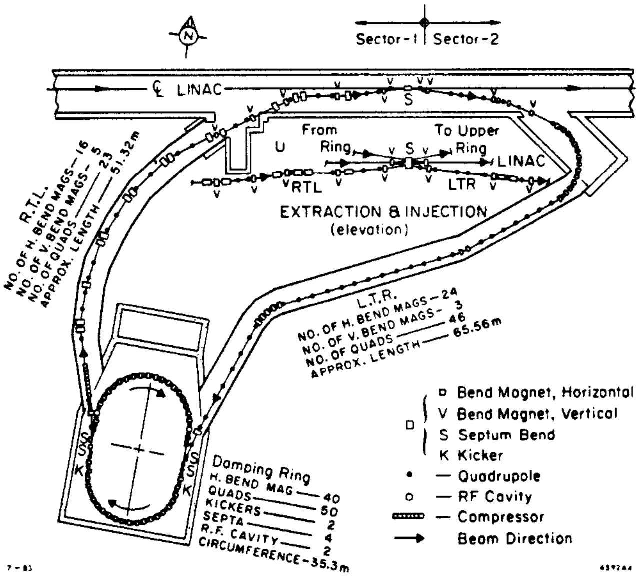


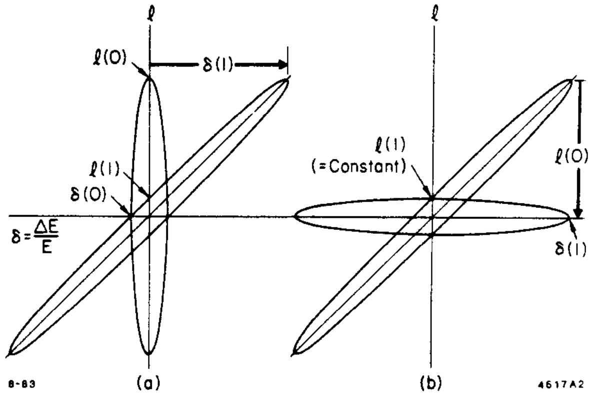
Fig. 1.

The design parameters for the SLC damping ring (DR) have been described elsewhere.[1] Those parameters important to the description of the RTL transport line are listed in Table 1 and were taken as given input conditions for the transport line. At the output of the transport line it is important to have control of the bunch length to reduce both the transverse emittance growth and the energy spread due to transverse and longitudinal wake fields as the particle bunches are accelerated through the linac. A delicate balance must be maintained to minimize these effects since the transverse emittance growth decreases with shorter bunch length while the opposite is true for the energy spread. Calculation of the effects of these fields[2] have shown that an rms bunch length on the order of 1.0 mm is suitable for the acceleration of 5×10^{10} particles/bunch. To assure that adequate control of this parameter can be provided the choice was made to design the RTL beam line such that compression of the 6.0 mm rms DR bunch length to a minimum rms length of 0.5 mm will be achieved.

Table 1. Damping Ring Parameters

Energy	1.21 GeV
Equilibrium emittance	9.1×10^{-9} π rad-m
Extracted beam emittance	1.2×10^{-8} π rad-m
Equilibrium related energy spread	7.4×10^{-4}
Equilibrium bunch length	5.9 mm

Compression The bunch length compression in RTL is accomplished by first passing the particle bunches through an S-band accelerating section at 0° central phase angle immediately after extraction from the damping ring. This maneuver introduces a correlation between the position of a particle in the bunch and its energy (see Fig. 2a). Compression then occurs due to energy dependent path length differences proportional to the momentum compaction factor α (see Fig. 2b).



(a) (b)

Fig. 2.

It can be seen from Fig. 2a that the slope of the required correlation between energy and bunch length is very nearly defined by the damping ring energy spread $\delta(0)$ and the chosen rms bunch length $\ell(1)$ of 0.5 mm after compression. Hence the energy spread at the end of RTL will be given by $\delta(1) \cong [\delta(0)/\ell(1)]\,\ell(0) \cong 0.009$. The required peak accelerating voltage $\hat{V}_{RF}$ then follows from $\delta(1) = (\hat{V}_{RF}/E_R)\sin(2\pi\ell(0)/\lambda)$ where E_R is the ring operating energy of 1210 MeV and λ is the S-band wavelength of 0.105 m. Thus $\hat{V}_{RF}$ is ~ 30 MeV which in practice can be easily supplied by a single 3-meter disc loaded waveguide identical to those used in the linac. The momentum compaction factor given by $\ell(1)/L\delta(0) = \alpha \cong 1/\nu^2$ can be used to estimate that the RTL should span approximately two betatron wavelengths.

Optical Design The RTL transport line will be required to have an energy acceptance greater than $\pm 2\delta(1)$. For such a large energy spread control of chromatic aberrations becomes a primary concern. The concept of the second-order magnetic optical achromat[3] was used as a design guide though strict adherence to its principles was precluded because of the need to fit the transport line into an existing linac housing. The theoretical principles of the second order achromat are described elsewhere.[4] Here we describe its application to the RTL design. The beam line consists of two stages (see Fig. 3) each charac-

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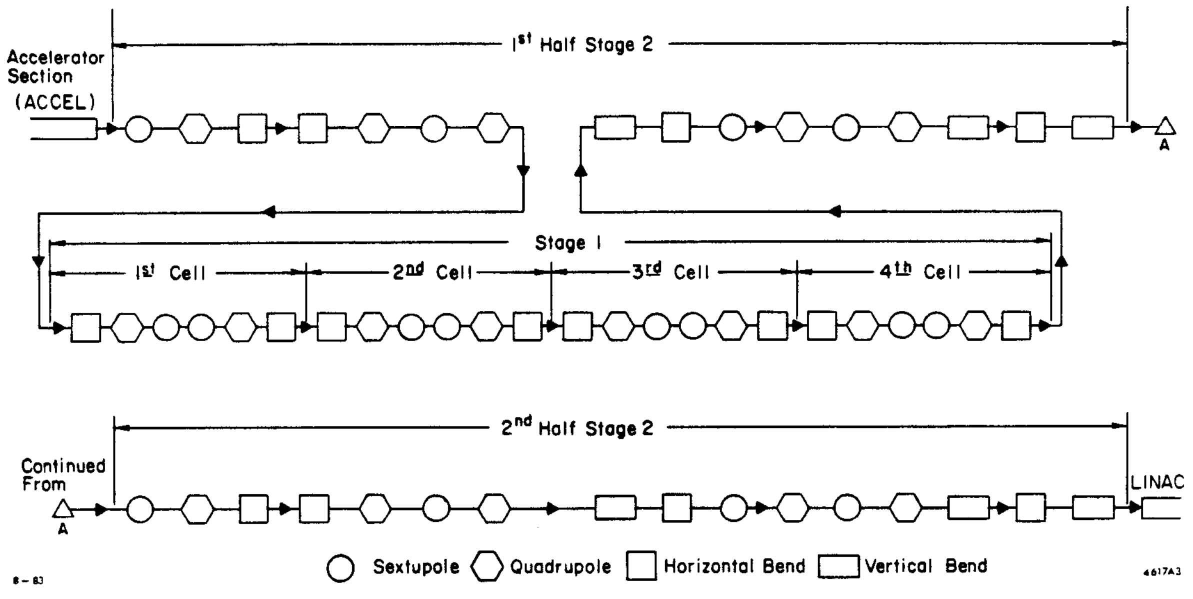

Fig. 3

terized by a transformation matrix equal to the identity matrix. Stage one consists of four identical cells, each cell containing two bending magnets, two quadrupoles and two sextupoles. The strength of the two quadrupoles and two drift distances are determined by the constraint that the overall transformation be the identity with a total phase shift of 2π. Then, since there are four identical cells the second-order geometric terms vanish due to symmetry. And, as shown by K. Brown, all second-order chromatic terms can be removed by properly setting the strength of the two sextupoles.

Stage two is not so neatly characterized. The placement of the bending magnets in this stage is dominated by the geometry of the RTL tunnel and the linac housing. With needed reverse bends and vertical as well as horizontal bends n-fold symmetry could not be maintained for $n > 2$. Instead the stage is composed of two identical "cells" giving "half wave symmetry." All components in this stage, including those special magnets used to re-inject into the linac are imaged by the negative of the identity matrix onto an identical component in the other "cell," assuring that overall dispersion and second-order geometric aberrations vanish. Thus stage two consists of six independent pairs of bend magnets, five independent pairs of quadrupoles and four independent pairs of sextupoles.

Another unusual feature of stage two can be observed in Fig. 3. It will be noted that the first half of this stage has been split and stage one has been inserted, a maneuver that was made possible by the stage one transformation being the identity. This "nested achromat" was introduced to take advantage of the large horizontal bend angle in the first two bending magnets of stage two to obtain a practical fit to the existing housing.

With the bend magnet strengths thus constrained by the geometry, six parameters, namely four of the quadrupole strengths and two pairs of intervening drifts are determined by the constraint that the overall transformation of stage two be the identity. One pair of imaged quadrupoles are used to match to a periodic η-function in the nested stage one, providing a smooth bunch length compression in this section.

Matching the Linac Lattice Figures 4a thru 4c illustrate the resulting machine functions after completion of the first order fitting described above and a match has been made to the linac lattice. This latter matching is achieved by inserting four quadrupoles between the damping ring extraction optics and the upstream end of the compressor waveguide. These quadrupoles are used to match to the desired linac lattice at the beginning of the two achromats just downstream of the compressor waveguide where there is an identical image of the linac entry point. Second-order effects in the region before the compressor waveguide are negligible because of the small momentum spread of the extracted beam.

Second Order Correction in Stage Two The mixture of horizontal and vertical bends in stage two results in mixed x, y dispersion at the sextupole sites. In order to avoid the introduction of cross-plane chromatic aberrations, this means that the four sextupole pairs must be rotated axially with respect to the beam coordinate system. That was done in conjunction with variation of the strengths of the four sextupole pairs to zero the T_{i66} $i = 1, 2, 3, 4$ and the T_{ij6}, $i = 1, 2$, $j = 3, 4$, elements of the second order transfer matrix.

It was found empirically that the foregoing prescription reduced all chromatic aberrations in stage two to insignificant levels. It may not, however, be generally applicable because we are not dealing with a theoretically perfect second-order achromat.

Bunch Lengths The progressive compression of a bunch as it moves through the RTL beam line is shown in Fig. 5a. Most of the compression occurs relatively smoothly in stage one. There is some unwanted but unavoidable fluctuation of the length of the fully compressed bunch in stage two. Figure 5b shows the correlation of the bunch length and the momentum spread as given by the r_{56} correlation term of the TRANSPORT sigma matrix. The locations in the second stage where this term is less than zero corresponds to over-compression. At the point of injection into the linac this term is equal to zero as intended.

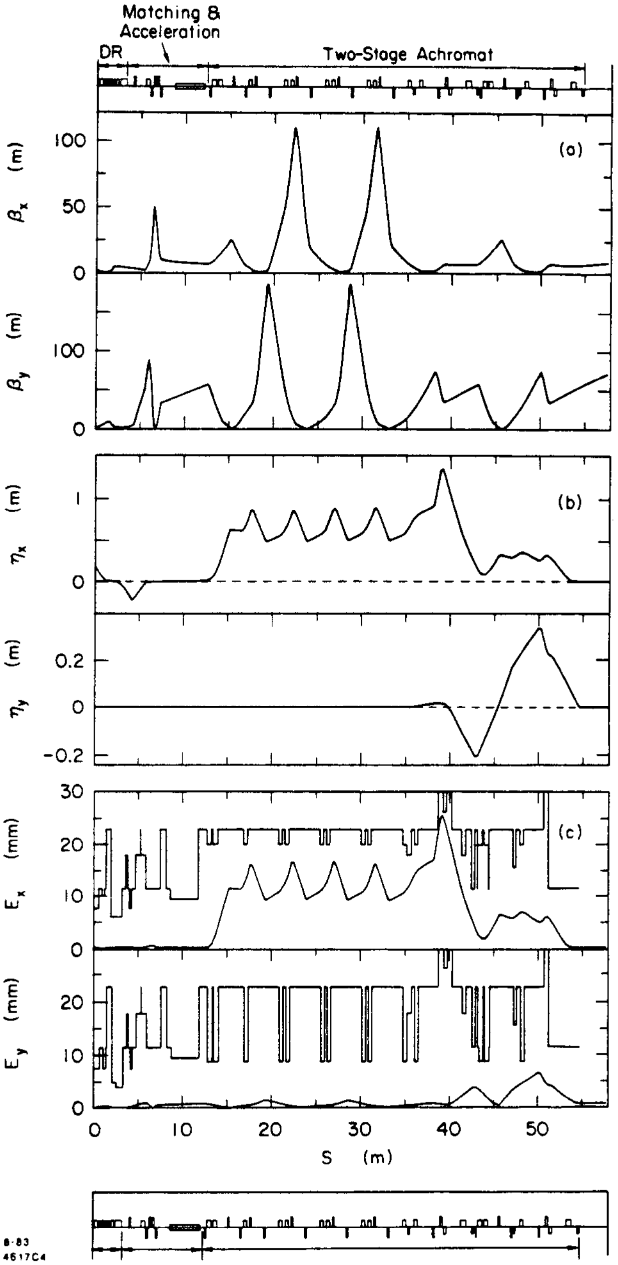

Fig. 4. (a) Beta vs. s (m); (b) Eta vs. s (m); (c) Envelope vs. s (m); where $E = \sqrt{\epsilon\beta + (\eta\delta)^2}$, for $\epsilon_x = \epsilon_y = 0.01$ mm-mrad and $\delta = 2\%$.

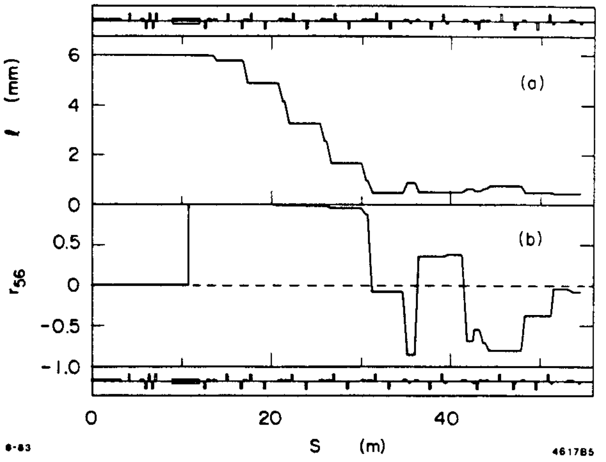

Fig. 5. (a) Bunch length vs. s (m) for $\hat{V}_{RF} = 33$ MeV; final rms length is 0.5 mm. (b) $r_{56}(\ell - \delta$ correlation) vs. s (m).

Bunch Lengthening Effects Figure 2a and 2b indicate a linear correlation for the particle position and its energy. This would only be true for $2\pi\ell(0)/\lambda \ll 1$. Antisymmetric bunch lengthening occurs when the small angle approximation is not satisfied. A second effect which is symmetric about the bunch center is also introduced by the second order momentum dependent path length differences. Both these effects have been examined[5] for this design and can be adequately compensated by trimming the compressor waveguide voltage and phase angle.

Coherent bunch lengthening due to the longitudinal wake field of the bunch has also been examined and shown to be negligible.

Spin Polarization of the Electron Beam It is expected that an electron beam from a polarized source will be injected into the DR with transverse spin polarization perpendicular to the plane of the DR. One of the design goals for the RTL electron beam is to be able to rotate the spin polarization to any arbitrary direction.[6] This will be done with the aid of suitably disposed solenoid magnets. In order to avoid disruption of the basic optics of the RTL beam, solenoids can only be located in places where there is no dispersion and where the beam is "round." Two solenoids are needed, and for arbitrary control the spin precession angle in the RTL-bends between them should be an odd multiple of 90°. There are only two possible locations which satisfy these criteria, one just before entry into the achromats and the other just after reinjection into the linac. The spin precession angle in the intervening beam line, the whole RTL beam, is almost exactly 270° at 1.2 GeV.

References

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