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# RECIRCULATING SLAC WITH A SUPERCONDUCTING SECTION

## PART II

### Introduction

In the original note bearing the above title,[1] it was proposed that higher energies be reached at SLAC by means of a recirculating beam line that stores the beam for the full interpulse period of ~2.8 msec. A superconducting accelerator section would be used to restore the energy lost to synchrotron radiation.

In the present note, we further explore the possibilities of this scheme with attention focused on the beam stability and on the rf system specifications. The notation is intended to conform to that used by Sands[2] and where equations have been taken from Sands' report, the notation (S4.51), for example, gives the equation number.

The earlier warning must be repeated, namely, that the details presented here are only presented as a possible solution, not as a firm proposal. This warning is specifically intended to apply to the choice of the alternating gradient system for the main bend lattice. Based on the example from Cornell,[3] it appears that the AG system is the least expensive for the specific range of parameters being considered. The limitations and implications of the AG system will be explored in what follows.

### Basic Parameters and Damping Rates

Table I gives some of the basic parameters relating to synchrotron radiation and phase and orbit stability. These results depend only on the geometry and on the magnet parameters, not on the rf parameters, although it is assumed that there is an rf system. It is assumed that the basic parameters of Ref. 1 apply; bending radius r = 100 m and total bend = $450^{\circ}$.

Some recent discussion of stage 1-1/2 has been coupled with this proposal. Accordingly, the parameters in Table I are extended to 35 GeV recirculating beam energy. The system length from Fig. 1 is assumed to be 7724 m so that the recirculating period is $T_0 = 25.7\ \mu$sec. Thus the beam would be stored for 108 periods.

Table I

Synchrotron Radiation and Damping Parameters

| $E_0$(GeV) | U(MeV) | $\alpha_v$(sec$^{-1}$) | $\alpha_\epsilon$(sec$^{-1}$) | $N_\epsilon$(rev) | $\alpha_x$(sec$^{-1}$) | $t_x$(msec) |
|---|---|---|---|---|---|---|
| 15 | 56 | 72.5 | 263 | 147 | - 44.3 | 22.5 |
| 20 | 178 | 173 | 627 | 62.4 | -106 | 9.4 |
| 25 | 430 | 335 | 1215 | 31.7 | -204 | 4.9 |
| 30 | 890 | 577 | 2090 | 18.4 | -353 | 2.8 |
| 35 | 1650 | 915 | 3320 | 11.7 | -560 | 1.8 |

$E_0$ is the recirculating beam energy in GeV.

U is the synchrotron radiation per cycle of 450° in MeV.

$\alpha_v$ is the vertical damping rate from $\alpha_v = U/2E_0T_0$. (S4.51) (1)

$\alpha_\epsilon$ is the energy damping rate from $\alpha_\epsilon = \alpha_v(2 + D)$ where $D = 1.62$. (2)
Here D is a damping factor which will be defined below.

$N_\epsilon$ is the number of revolutions per energy damping period, $N_\epsilon = 1/(\alpha_\epsilon T_0)$. (3)

$\alpha_x$ is the horizontal damping rate from $\alpha_x = \alpha_v(1 - D)$. (4)

$t_x$ is the e-folding time, $t_x = -1/\alpha_x$, for horizontal antidamping (5)

The damping factor, D is given by Sands[2] as

$$D = \frac{\oint \eta(s)\, G(s)\left(G(s)^2 + 2K_1(s)\right) ds}{\oint G(s)^2 ds} \qquad \text{(S4.18)} \qquad (6)$$

where the integrals are to be made along the complete beam path. The function G(s) is

$$G(s) = 1/r(s) = \frac{ec}{E_0} B(s) \qquad \text{(S2.3)} \qquad (7)$$

and the function $K_1(s)$ is the focusing term

$$K_1(s) = \frac{ec}{E_0}\left(\frac{dB(s)}{dx}\right)_0 \qquad \text{(S2.4)} \qquad (8)$$

evaluated on the design orbit, $x = 0$. The function defined by $\eta(s)$ is the equilibrium orbit

$$x(s) = \eta(s)\ \epsilon/E_0 \qquad \text{(S2.28)} \qquad (9)$$

In a separated function design using flat field magnets, such as the SLAC storage ring, D is typically a small positive number, very much less than unity. The result, as shown by Rees,[4] is that all three damping rates are positive, i.e., all three modes are damped. However, in the case of an alternating gradient design, the first order focusing terms, $K_1(s)$, even though they alternate in sign, contribute substantially more to the integral than the $G(s)^2$ terms. The parameters chosen in Ref. 1 are based on the Cornell Electron Synchrotron which is an alternating gradient design. In the Cornell case, $D \approx 2$ and the horizontal damping rate is negative which results in antidamping. Physically, the antidamping is due to the fact that there is increased radiation while the particle is in the high field part of the horizontal focusing magnets.

In the case in which all the bending magnets have the same field on the design orbit, Eq. 6 reduces to

$$D = \frac{1}{\Phi} \oint \eta(s) \left( G(s)^2 + 2K_1(s) \right) ds \qquad \text{(isomagnetic)} \tag{10}$$

where $\Phi$ is the total bend around the entire path. For the recirculator,

$$\Phi = 5\pi/2 \tag{11}$$

In Ref. 1 it was suggested that the main bend loops should be achromatic, and that this should be accomplished by making each main bend be an integral number of betatron wave lengths. Rees has suggested that the achromatic condition can be realized by matching the straight sections to the bends according to the method described by Rees and Morton.[5] This eliminates the requirement for an integral number of betatron wavelengths in each bend. More importantly, it reduces the magnet gap width needed for energy dependent displacement, that is $\eta(s)_{max}$, by a factor of two. The matching system consists of a single flat-pole bending magnet and a small horizontal focusing quadrupole singlet. This combination is required at each end of each main loop. To calculate the $\eta$ function and from it, the integral D, it is necessary to choose the lattice parameters. The main bend angle of $195^o$ must be divided into an integral number of FDDF cells plus the two matching magnets. In order that the total number of magnets, hence the cost, be about the same as given in Ref. 1, we choose that each main bend should consist of 100 magnets arranged in 25 FDDF cells. Each magnet bends the beam $1.9^o$ and is thus 3.316 meters long measured on the arc length. The chord length of each magnet is 3.3 meters. The two matching magnets bend the beam $2.5^o$ each and are 4.36 meters long. Other combinations of lengths and angles will give essentially the same results. The $\eta$ function for a single FDDF cell, as calculated by TRANSPORT,[6] is shown in Fig. 2. Part of the integral of Eq. (10) can be made from Fig. 2 and is

$$2\oint \eta(s)\, K(s) ds = .254 \qquad \text{(one cell)}$$

where $K(s) = n(s)/r^2 = \pm .045$ where $n(s) = -\frac{r}{B}\frac{dB}{dr}$ is $\pm 450.0$ for defocusing or focusing magnets respectively. This value for n is an arbitrary choice and can be compared to $n \approx 430$ at Cornell.[3] In the reverse bends, K(s) is zero and $\eta(s)$ is negative, thus the integral $\int \eta(s)\, G(s)^2 ds$ for these sections is a small negative number, about -.04. The integral $\int \eta(s)\, G(s)^2 ds$ for all the main bend cells is about 0.07. Adding up these contributions to the integral for the full system of 50 cells yields

$$D = \frac{2}{5\pi}\,(0.07 - 0.04 + 50 \times 0.254) = 1.62 \qquad (12)$$

By way of comparison, Fig. 2 also contains a plot of the $\eta$ function for one cell of a ring made up of 48 identical cells, where the cell parameters are similar to those used above except that the magnet length is adjusted so that a closed loop results. This is almost the same as the Cornell design; it differs mainly in details of straight sections and transition sections. For this design, the integration of Eq. (10) gives D = 2.02. The function of interest is Eq. (4); (1 - D) = -1.02 for the "Cornell" ring and -0.62 for the recirculating SLAC. "Cornell" is in quotes to distinguish this model from the Cornell 10 - 20 GeV synchrotron. The chief reason for the difference in the two values of D is that the recirculator has the two reverse bends that have flat field magnets. These contribute ~13% of $\Phi$ without adding significantly to the integral. When comparing the actual damping rates for the "Cornell" design at $E_0 = 15$ GeV, $T_0 = 2.41\ \mu$sec and $U_0 = 45$ MeV; $\alpha_v = 625$ sec$^{-1}$. Thus, the e-folding time for "Cornell" from Eq. (5), is $t_x = 1.57$ msec compared to 22.5 msec for the recirculator at 15 GeV.

Sands[2] gives an approximate expression for the equilibrium value of the standard deviation of the energy spectrum after several damping times as

$$\sigma_\epsilon = \sqrt{E_0 \mu_c}/2 \qquad \text{(S5.30)} \qquad (13)$$

where $\mu_c$ is the critical energy of the synchrotron radiation spectrum. Table II lists the values for $\sigma_\epsilon$ and the damping time $t_e$. It is apparent that only for the higher energies is $t_e$ low enough that the energy distribution can approach equilibrium in the 2.8 msec storage time. Also, since all the values are substantially less than the energy distribution from the accelerator (~± 0.3%), it is the accelerator spectrum which will have to be considered.

In contrast to the energy spectrum which is naturally damped, the horizontal phase space will grow because of quantum fluctuations. Following Rees,[4] the growth per turn of the betatron amplitude squared is

$$\frac{d}{dn}\langle x^2\rangle = \frac{1.32\, U_0 \mu_c}{2E_0^2}\, \eta^2_{rms} \tag{14}$$

where $\eta^2_{rms}$, from Fig. 2, is about 1.7 $m^2$. Without extra damping, for times short compared to the antidamping time constant ($t_x$ in Table I), the squared amplitude $\sigma_x^2$ can be considered to be just n (the number of cycles) times the expression in Eq. (14). Table II includes a column $\sigma_x^2$ for the undamped squared amplitude of the betatron oscillations in the magnet rings using n = 108.

Table II

Equilibrium Energy Spectrum and Horizontal Phase Space Growth

| $E_0$(GeV) | $\mu_c$(KeV) | $\sigma_\epsilon$(MeV) | $\sigma_\epsilon/E_0$(%) | $t_e$(msec) | $\sigma_x^2$($cm^2$) | $A_a/A_r$(%) |
|---|---|---|---|---|---|---|
| 15 | 77 | 17 | .11 | 2.8 | .02 | 125 |
| 20 | 182 | 30 | .15 | 1.6 | .1 | 28 |
| 25 | 375 | 47 | .19 | .82 | .3 | 9 |
| 30 | 615 | 69 | .22 | .48 | Not applicable where | |
| 35 | 980 | 92 | .26 | .37 | $T_0 \geq t_x$ | |

The phase space of the undamped beam is large enough that only some fraction of the beam can be transported through the accelerator. Using the present quadrupole spacing, the accelerator admittance is about $A_a = 0.7 \times 10^{-4}\ \pi$ cm-rad. The phase space of a beam of amplitude squared $\sigma_x^2$ with a betatron wavelength of λ (about 30 meters) is approximately

$$A_r/\pi = 2 \times \frac{2\pi}{\lambda}\, \sigma_x^2 \tag{15}$$

where the first factor of two comes from considering the full amplitude as $\sqrt{2}$ times $\sigma$. Since the growth occurs only in the horizontal coordinate, the fraction of the beam that can be transported through the accelerator is just $A_a/A_r$. This ratio is also shown in Table II. This could be improved by a factor of from 3 to 10 with the addition of damping such as proposed by Robinson.[7] Such a system could be conveniently located in the drift lines near the reverse bends. Further improvement in transmission could be made by the addition of more quadrupole focusing along the accelerator.

Momentum Compaction

The momentum compaction parameter $\alpha$ is defined by

$$\delta \ell / L = \alpha \; \epsilon / E_0 \tag{16}$$

where $\delta\ell/L$ is the fractional change of path length as a function of the fractional change of energy. In most cyclic accelerators, $\alpha$ is a fixed number determined by the magnet lattice. In the recirculator, $\alpha$ is a free parameter determined simply by adjusting the appropriate bending magnets in the reverse bend. If $\alpha$ is set to zero, the system is isochronous by definition, but there is no phase stability. That is, the synchrotron phase oscillation period becomes infinite. As $\alpha$ is made larger, the peak rf voltage must be increased to keep the same bunch length. The equilibrium expression for the standard deviation of bunch length, expressed as time from the center of the bunch, is given by Sands[2] as

$$\sigma_\tau^2 = \frac{\alpha \, T_0 E_0 C_q \gamma_0^2}{e\dot{V}_0 J_\epsilon r} \qquad \text{(S5.66)} \tag{17}$$

where $\gamma_0 = E_0/mc^2$, $J_\epsilon = 2 + D$ and $C_q = 3.84 \times 10^{-13}$ m. The rate of change of the rf voltage can be found from the assumption that the rf field is sinusoidal,

$$eV = e\hat{V} \; \sin(2\pi f\tau + \phi). \tag{18}$$

where $\phi$ is the phase angle such that the center of the bunch, at $\tau = 0$, receives an acceleration to make up the energy lost to synchrotron radiation,

$$U = e\hat{V} \sin \phi \, . \tag{19}$$

Then the rate of change of the rf voltage at $\tau = 0$ is;

$$e\dot{V}_0 = e\hat{V} \, 2\pi f \cos \phi \tag{20}$$

where

$$f = 2856 \text{ MHz}$$

It is convenient to express the standard deviation of bunch length in radians, thus

$$\sigma_\theta = \sigma_\tau \omega \tag{21}$$

Substituting Eqs. (19), (20), (21) into Eq. (17) yields

$$\sigma_\theta^2 = \alpha \tan \phi \frac{T_0 E_0^3 C_q}{U J_\epsilon r (mc^2)^2} \tag{22}$$

Equation (22) can be simplified by using the relation for synchrotron radiation in an isomagnetic bend angle $\Phi$;

$$U = \frac{\Phi}{2\pi} C_\gamma E_0^4/r \qquad \text{(S4.8)} \tag{23}$$

where $C_\gamma = 8.85 \times 10^{-14}$ meter/MeV$^3$. Using Eq. (23), Eq. (22) becomes

$$\sigma_\theta^2 = \alpha \tan \phi \frac{2\pi T_0 \omega C_q}{\Phi C_\gamma E_0 J_\epsilon (mc^2)^2} \tag{24}$$

When all the assumed parameters for the recirculator are substituted, including $\Phi = 5\pi/2$, Eq. (24) becomes

$$\sigma_\theta^2 = \frac{\alpha \tan \phi}{E_0(\text{GeV})} \times 1.7 \times 10^3 \tag{25}$$

The main requirement on bunch length comes from the energy resolution needed after the second pass through the accelerator. If the beam is accelerated on the rf crest on the second pass, then the energy spread due to that pass alone is $\delta E = E\sigma_\theta^2/2$. Assuming that the total energy comes from two passes, both at E, then the final spectrum width is

$$\frac{\delta p}{p} = \frac{\delta E}{2E} = \sigma_\theta^2/4 \tag{26}$$

For $\delta p/p = \pm$ 1%, $\pm$ .5%, $\pm$ 0.25%, then $\sigma_\theta^2$ = 0.04, 0.02, and 0.01 respectively. Since the equilibrium spectrum width from Table II approaches 0.25%, the assumption that the second pass is the chief contributor to the spectrum is only valid down to about 0.25%. Figure 3 shows a family of curves of Eq. (25) for the above three values of $\delta p/p$. The curves are plotted for selected energies to show the reasonable operating ranges for the recirculator. The dashed curve is the function $1/\sin \phi$ which is the over-voltage ratio as a function of $\phi$.

The angular frequency for synchrotron phase oscillations is given by Sands[2] from

$$\Omega^2 = \frac{\alpha e V_0}{T_0 E_0} \qquad \text{(S3.43)} \tag{27}$$

Substituting Eqs. (20) and (21) into Eq. (30), we have

$$\Omega^2 = \frac{2\pi f \alpha U}{T_0 E_0 \tan\phi} \tag{28}$$

Making the further substitution from Eq. (25), and plugging in the other numbers for the recirculator, we have

$$\Omega = 6.42 \times 10^5 \ \sigma_\theta \sqrt{U(\text{GeV})/\tan\phi} \tag{29}$$

The synchrotron phase oscillation period is $T_s = 2\pi/\Omega$. Some selected values of $T_s$ are plotted on Fig. 3 to show the operating range. The lower limit on $T_s$, corresponding to the one-cavity limit of four orbit periods, is $4 \times 25.7$ $\mu$sec or about 0.1 msec.

The range of values plotted in Fig. 3 appears to represent the useful range for operation. One would not expect to go to higher values than $\tan\phi = 3$ because the over-voltage ratio is already only 1.06 at $\tan\phi = 3$. One could not go much below $\tan\phi = 1$, even if the extra rf voltage is available, because of the lower limit on $T_s$. It is convenient that the higher energies phase focus more readily because the over-voltage costs so much more at high energies. If, for example, the superconducting section is capable of 470 MeV, it would supply an over voltage of 10% at 25 GeV, which would permit operation at $\tan\phi = 2.1$ and above. Lower recirculating energies could make use of the extra rf power by either running with higher beam current or by running at a high value of $\alpha$.

The practical lower limit on $\alpha$ is probably due to second order effects on bunching. One can make a simple estimate considering the transverse focusing system for the long straight sections. We assume a number of fairly large quadrupole doublets to transport the beam in 300 meter steps. Since the steps are three times longer than the accelerator steps, the apertures should also be three times larger. This results in some fraction of a millimeter for the second order debunching due to transverse focusing. If one assumes that the phase focusing should be greater than the second order debunching, then $\alpha_{min}$ should correspond to a $\delta\ell$ large compared to one millimeter. Since the damped energy spectrum is only about 0.2%, the useful range of $\alpha$ is that above $\delta\ell \approx 2$ mm, for example at $\epsilon/E_0 = 0.2\%$. Several such values of $\alpha$ are noted on Fig. 3. Incidentally, there should be no second order problems in chromatic aberrations. The main bend magnets, following the lead of Cornell,[3] are assumed to include a sextupole correction so that the tune is independent of energy. There will need to be a sextupole in each reverse bend to correct for chromatic aberrations.

## Reverse Bend Systems

The reverse bend systems perform three functions:

1. They return the beam to the accelerator tunnel, thus saving the expense of additional tunneling.

2. They restore the bunch length; that is, they provide for a continuously variable control on $\alpha$.

3. They provide a convenient place to adjust total path length.

In the following discussion, it will be assumed that an isochronous loop is desired, i.e., $\alpha = 0$. Actually, there is no difference between setting the reverse bend for $\alpha = 0$ or for any other suitable value. The technique of adjusting both $\alpha$ and the total path length will be explored.

The principal elements of the entire recirculator are described first with assumptions according to the values used in this note:

1. The long straight section of 3470 meters (see Fig. 1). This section may contain an arbitrary number of quadrupole lenses such that the transverse betatron frequency of the entire loop is nonintegral. The superconducting rf section is assumed to be located in this section.

2. The main bending ring at the east end consisting principally of 100 alternating gradient magnets. This system introduces a debunching given by

$$\delta\ell = -3.64\ \delta p/p \qquad (30)$$

The main ring also includes the matching magnets; a 2.5 meter long flat bending magnet and a small quadrupole singlet separated by about 30 meters.

3. The drift part of the oblique straight section. This drift line of about 700 meters length contains probably three pairs of quadrupole lenses which define the position of the line.

4. The reverse bend system which will be detailed below.

5. The short straight section of 1688 meters length; also containing some quadrupole doublets to define the position of the line.

6. Item 4 repeated at the west end.

7. Item 3 repeated at the west end.

8. Item 2 repeated at the west end.

The elements of the reverse bend do not include any transverse focusing. Transverse focusing is assumed to be provided by the quadrupoles in the adjacent drift lines. The elements of the reverse bend are as listed in Table III.

The zero-order path length, that is, the length of the design orbit, must be adjustable to about 0.01 cm if errors in path length are to be negligible compared to the second order consideration discussed earlier. Detection of the phase error can be done with an rf monitor cavity at the superconducting accelerator section. Adjustment of the path length can be made by moving the quadrupoles within the reverse bend system, i.e., elements 6 and 15. The change in path length due to a translation of distance x is given by

$$\delta\ell = x\theta \qquad (31)$$

where both quadrupoles are assumed to be moved by x. The angle $\theta$ is that included angle between the lenses, i.e., $\theta = 15^{\circ}$ or $\pi/12$ in this case. Thus

$$\delta\ell = .262x \approx x/4 \qquad (32)$$

which shows that the tolerance on x is about 0.04 cm ($\sim$16 mils). The maximum possible motion that is needed is that corresponding to one-half of an rf wavelength. Since both reverse bends can be used to make adjustments, the range needed for x in each corresponds to $4(\lambda/4)$ or just 10.5 cm. Since these quadrupoles are between the wide gap bending magnets it probably would not be necessary to move the bending magnets. Thus, for only the quadrupoles, which can probably be small, "Panofsky" type quads, it would be desirable to have automated alignment. The translation of the quads must be accompanied by a shift of the beam line from the main bend loop. Since this line is determined by other quads, probably a doublet just ahead of element (1) in Table III, that doublet also should have automatic alignment.

In practice, a misaligned quadrupole is simply equivalent to an aligned quadrupole plus a bending magnet. Since the quads are small, it may well be that small steering magnets next to the quads would do the same job. Since the beam must actually be moved, this could add somewhat to the necessary bore of the quadrupoles, but it may simplify the control problem. For calculations, the moveable quads are simpler and will continue to be discussed here.

The first order (in $\delta p/p$) path length correction is that which controls isochronicity, i.e., determines $\alpha$. There are two independent variables which determine the amount of the dispersion, hence the amount of the correction; one is the strength of magnet elements (1), (2), (4), and (5) (and their symmetric counterparts), in Table III. The second is the length element (3) which is given as 131.63 meters. This is the design value for isochronous operation with the fields in the above mentioned magnets set to the same field as the main bend magnets. Small adjustments in this field, or again, adjustments to small trimming magnets, will adjust the path length correction to any arbitrary value over a reasonable range. The error in bunch length correction will be

$$\delta \ell_e = \delta \langle \delta \ell | \delta p/p \rangle \delta p/p \qquad (32)$$

where $\delta\langle\delta\ell\,|\delta p/p\rangle$ is the uncertainty in setting the reverse bend correction. Assuming a spectrum of $\delta p/p = 1.0\%$, to keep $\delta\ell$ small compared to the second order errors, $\delta\ell_e = .01$ cm, thus

$$10^{-2} = \delta\langle\delta\ell|\delta p/p\rangle \times 1.0 \text{ or } \delta\langle\delta\ell|\delta p/p\rangle = 10^{-2} \text{ cm/\%}$$

which corresponds to an error of 0.01 in the matrix element for either bend. Since $\langle\delta\ell|\delta p/p\rangle$ for one bend is 3.76, an error of 0.01 represents about 0.3% in the correction. This is a large error which actually requires a shift of 2.6 cm in the horizontal position of the quadrupole element (6) which defines $\langle\delta\ell|\delta p/p\rangle$. The tolerance requirement on the field strengths of the bending magnets is also only 0.3%.

## Conclusion

The significant results of this note are in the good energy damping and in the acceptable antidamping of the transverse phase space. The suggested[1] limit of 5 mA of recirculating beam current only appears significant if the available rf power is a restriction. Thus if a superconducting section is built for 25 GeV operation at 5 mA, there would be adequate rf power for any reasonable current at lower recirculating energies. The costs suggested in Ref. 1 still appear to be realistic at this time as long as operation is limited to 25 or 30 GeV. Although the basic ideas of this proposal could be extended to "stage 1-1/2 prime," i.e.,

Table III

Transport Description of the Reverse Bend System

| Element Function | Transport Card | | | | Comment |
|---|---|---|---|---|---|
| Rotate pole face | 2. | 0.937 degrees | | | |
| (1) Bend | 4. | 3.2725 meters | 3.3356 kG | 0.0=n | (1.875°) degrees |
| | 2. | 0.937 | | | |
| Drift | 3. | 0.5 meters | | | |
| (2) | 2. | 0.937 | | | |
| | 4. | 3.2725 | 3.3356 | 0.0 | (1.875°) |
| | 2. | 0.937 | | | |
| (3) | 3. | 131.63 | | | Long Drift |
| | 2. | -0.937 | | | |
| (4) | 4. | 3.2725 | -3.3356 | 0.0 | (-1.875°) cancel (1) |
| | 2. | -0.937 | | | |
| | 3. | 0.5 | | | |
| | 2. | -0.937 | | | |
| (5) | 4. | 3.2725 | -3.3356 | 0.0 | (-1.875°) cancel (2) |
| | 2. | -0.937 | | | |
| | 3. | 0.5 | | | |
| (6) | 5. | 1. meters | -0.48 kG | 10 cm bore | Horizontal defocusing |
| | | quadrupole to adjust dispersion at the point of widest dispersion. | | | |
| | 3. | 0.5 | | | |
| | 2. | -0.937 | | | |
| (7)-(14) | 4. | 3.2725 | -3.3356 | 0.0 | $(-1.875^{\circ}) \times 8 = 15^{\circ}$ bend |
| | 2. | -0.937 | | | |
| | 3. | 0.5 | | | |
| (15) | Repeat (6) | | | | |
| (16) | Repeat (5) | | | | |
| (17) | Repeat (4) | | | | |
| (18) | Repeat (3) | | | | |
| (19) | Repeat (2) | | | | |
| (20) | Repeat (1) | | Total length = 324.5 meters | | |

20 elements include 16 bending magnets, 2 quadrupoles and 2 special long drift lengths.

35 GeV at 180 pps, it appears clear that the design of the main ring would be affected. Also, both conventional power as well as superconducting rf power would be more extensive and more expensive.

The preliminary look at some of the required tolerances that was presented here is also most encouraging. There appears to be no need to be especially restrictive, for example, in regulating the magnet power to much less than the spectrum width. Thus, 0.1% regulated power supplies would appear entirely adequate.

Although the choice of the "Cornell-like" ring was made just to have a starting point, it appears to have been a fortuitous choice. The next step would appear to be to make preliminary design studies to put the cost estimates on a better footing. Further studies of the orbit dynamics, including instabilities and tolerances, are also needed. The theoretical beam break-up limit needs to be established.

The superconducting accelerator section is, of course, the key to this proposal. It is significant that this would be a most interesting device with a very modest start on the superconducting system. A single 20 foot accelerator section providing 100 MeV of CW rf power would convert SLAC to a 35 GeV accelerator with the present complement of 20 MW klystrons. Operation would still be at 360 pps and currents would be limited probably by BBU in the conventional accelerator.

Acknowledgements

Special thanks to John Rees, Dick Helm and Roger Miller.

## References

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## Figure Captions

1. Proposed layout of a recirculating beam transport system. The dimensions show the recent developments and thus differ from that used in the calculations. Most significant is the reduction of the radius to 85 m actual bending radius.
2. The $\eta$-function is shown for a single FDDF cell proposed for the recirculator. For a useful gap width of 5 cm, as was achieved at Cornell, the maximum full width energy spectrum admittance would be 3.5%.
3. The dependence of the momentum compaction parameter $\alpha$ is shown vs tan $\phi$, where $\phi$ is the phase angle of the synchronous electron. The useful range corresponds to the higher values of tan $\phi$ where the synchrotron oscillation period $T_s$, is greater than 1.0 milliseconds.

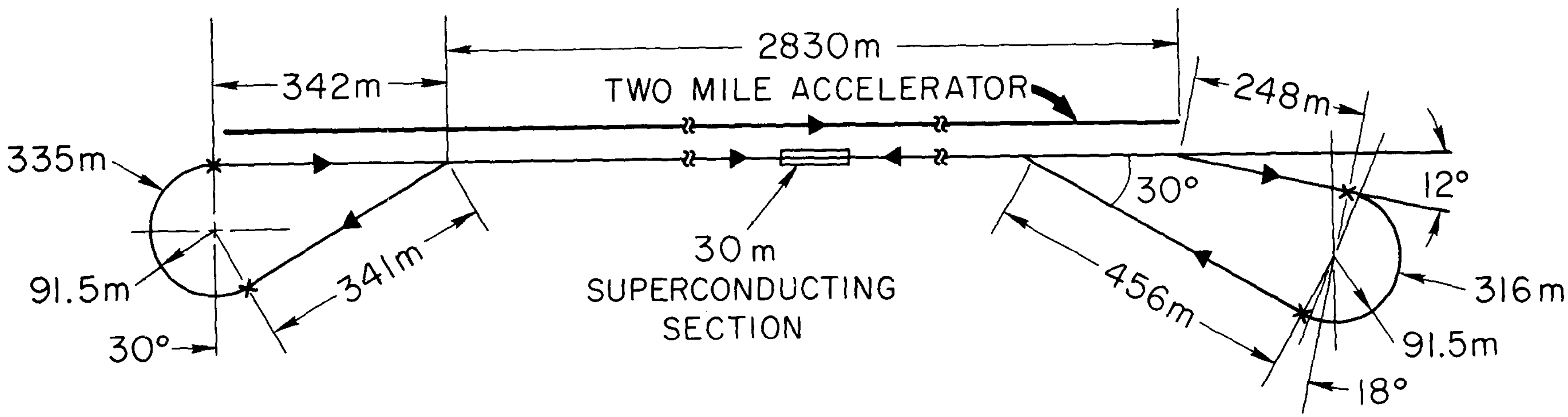
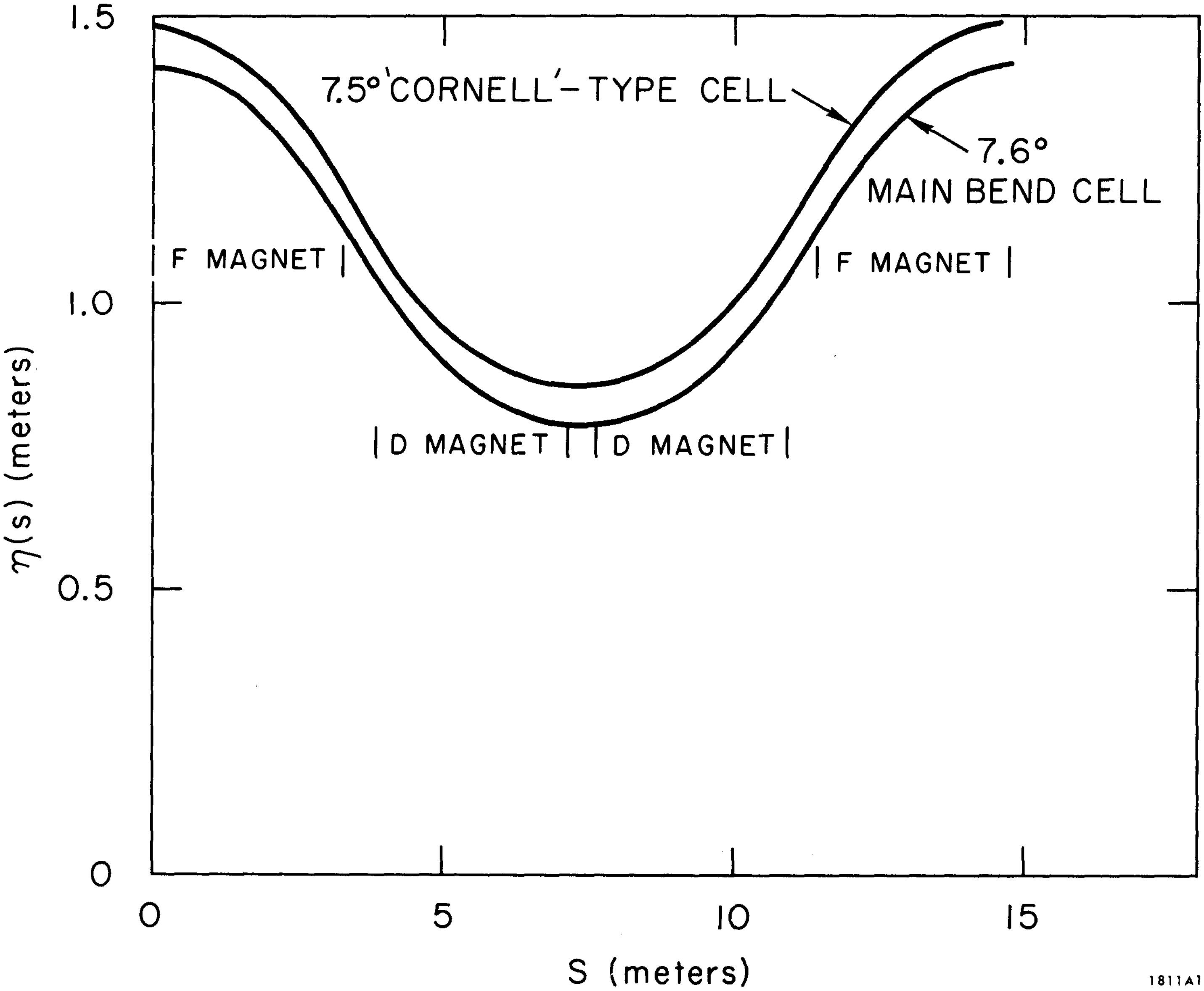
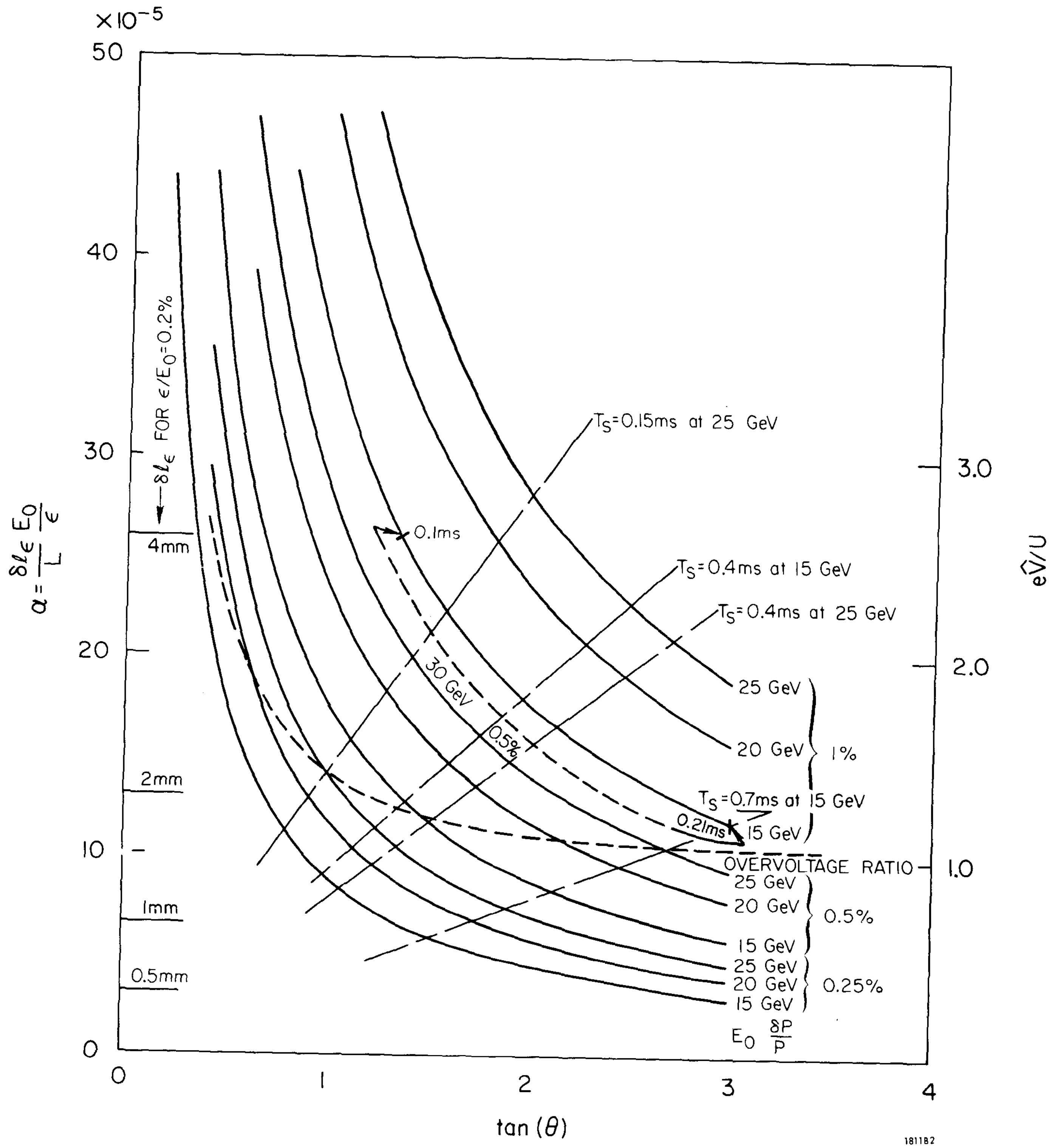

2830m
342m
TWO MILE ACCELERATOR
248m
335m
12°
30°
91.5m
341m
30 m
SUPERCONDUCTING
SECTION
456m
316 m
91.5m
30°
18°
181183

Fig. 1



1.5
1.0
0.5
0
0
5
10
15
η(s) (meters)
S (meters)
7.5° 'CORNELL'-TYPE CELL
7.6°
MAIN BEND CELL
F MAGNET
F MAGNET
D MAGNET
D MAGNET
1811A1


Fig. 2



×10⁻⁵
50
40
30
20
10
0
0
1
2
3
4
tan (θ)
eV̂/U
3.0
2.0
1.0
4mm
2mm
1mm
0.5mm
0.1ms
0.2lms
30 GeV
0.5%
Ts=0.15ms at 25 GeV
Ts=0.4ms at 15 GeV
Ts=0.4ms at 25 GeV
Ts=0.7ms at 15 GeV
25 GeV
20 GeV
15 GeV
1%
OVERVOLTAGE RATIO
25 GeV
20 GeV
15 GeV
0.5%
25 GeV
20 GeV
15 GeV
0.25%
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Fig. 3