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SORE - A PULSE STRETCHER FOR THE SASKATCHEWAN 300-MeV LINAC

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Introduction

A design study has been made of a pulse stretcher to increase the duty factor of the 300 MeV electron accelerator of the Saskatchewan Accelerator Laboratory. The design was constrained by the desire to house the pulse stretcher within the existing accelerator building and to make maximal use of existing beam transport lines. Only minor alterations will be required to the accelerator vault architecture and a minimal length of additional beam transport lines will be required.

The pulse stretcher ring (PSR) consists of two 180° bend regions connected by achromatic straight sections (Fig.1). The overall length is 50.49 m and the width is 6.64 m. This allows it to fit comfortably within the existing structure. The circumference of the PSR is 108.78 m and the bending radius of the dipole magnets is 1 m.

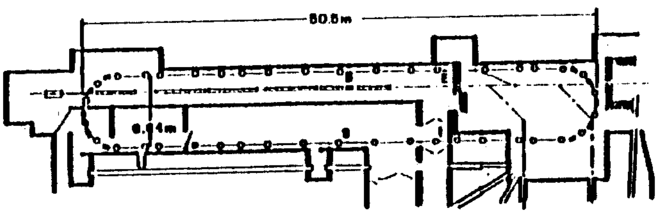

Fig. 1. Floor plan

The median plane of the PSR will be at a height of approximately 0.6 to 0.8 meters above that of the existing beam lines. This will effectively avoid any interference between the elements of the PSR and those of the linac and existing beam lines. The cost for the additional elements required to transport the beam to the higher level is small compared to that for the modifications that would be required to accommodate the PSR at the linac beam line level.

Two modes of injection and extraction will be available. In the first mode a shortened linac pulse of 300 ns duration will be injected during a single turn directly into the closed orbit of the pulse stretcher. After injection the energy of the stored electrons will be maintained using a CW rf system. Extraction will proceed using half-integer resonant extraction with the resonant tune being approached by varying a pair of quadrupoles.

A second mode of injection/extraction involves use of a longer linac pulse. By so doing one can increase the number of electrons injected into the ring during each filling and can therefore increase the output current. It is this latter mode which has been analyzed in the greatest detail.

The linac pulse length is 300 m, or about 25 m less than three times the PSR circumference. Three turn injection will therefore be employed. The 25 m (75 nsec) gap following the tail of the injected pulse will provide time for the strength of the injection bumpers (kickers) to fall sufficiently that the previously stored electrons will miss the injection system. As in the first mode injection will take place in the horizontal plane.

The beam will be extracted from the ring using the technique of third-integer resonant extraction in the horizontal plane. Particles will be forced onto this resonance by a coupling of the horizontal betatron tune of the PSR to the particle energy. The energy loss to synchrotron radiation is responsible for the required change in particle energy. This technique is the "Monochromatic" extraction technique discussed in the EROS proposals.[1]

The parameters of the extracted beam will be good. Preliminary calculations indicate that a transverse emittance of 0.3 π mm-mr should be attainable in the horizontal plane. The vertical emittance of the extracted beam will be determined primarily by that of the injected beam since both injection and extraction occur in the horizontal plane. The energy spread of the beam will be of the order of 0.1% when the monochromatic extraction technique is employed.

Pulse Stretcher Ring (PSR)

Lattice Description

The basic geometry of the PSR is dictated by the dimensions of the accelerator vault and access room. The available space is approximately 55 m by 7.4 meters. The overall; length dictated that the circumference of the PSR be about 110 m. The width places severe constraints on the 180° bend regions.

Bend Regions. The choice of bend radius (ρ_B) was dictated by the requirements a) that the overall width of the bend region cannot exceed 7 m and b) that the rate of synchrotron energy loss be suitable for the monochromatic extraction scheme. The first requirement places an upper limit of 2 meters on ρ_B. The maximum pulse repetition frequency of the linac is 360 Hz, so the bend radius must be such that electrons with a maximum energy of 300 MeV will lose a reasonable fraction of their energy in 1/360 Hz = 2.78 msec. From these considerations a value near 1.0 m is strongly favoured.

The space restrictions dictate that a combined function lattice be employed in the bend regions. Further, the desirability of minimizing higher order terms in the transport matrix favours the use of a set of n identical cells.[2] Two possible values for n were considered; n = 4 and n = 5. Both choices yielded stable solutions but the latter value was preferred because it results in much lower values of the momentum dispersion (η) function in the bend regions.

For a bend region composed of n identical cells to be achromatic it must have a unit transport matrix in the bend plane; (i.e., $\Delta\nu_x$ = 1,2,...). $\Delta\nu_x$ = 2 was

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adopted. The beam functions (β_x, β_y, η_x) through half of one bend region are shown in Fig. 2.

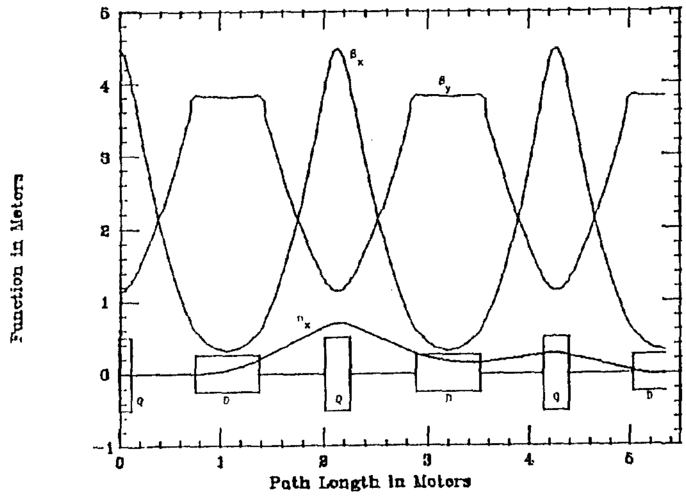

Fig. 2. Beam functions through half arc

The arrangement of magnets in the bend regions is shown in Figs. 1 and 2. The dipole magnets each bend the beam through 36°. The pole faces are rotated through 18° so that the central axis of the beam enters and exits at an angle of 36° to the perpendicular of the corresponding face. This pole face rotation provides the vertical focus for the beam.

Straight (Achromatic) Regions. The straight regions connecting the bend regions are achromatic to first order. Space is provided in them for injection and extraction of the beam. Figure 3 shows half of one of the straight regions. Of note is the fact that the β-functions have significantly higher values than in the bend regions. This "change of scale" was required to prevent the number of elements becoming prohibitive. Note also the region between the two short quadrupoles where the β_x-function is essentially flat. These regions were provided to facilitate injection and extraction of the beam.

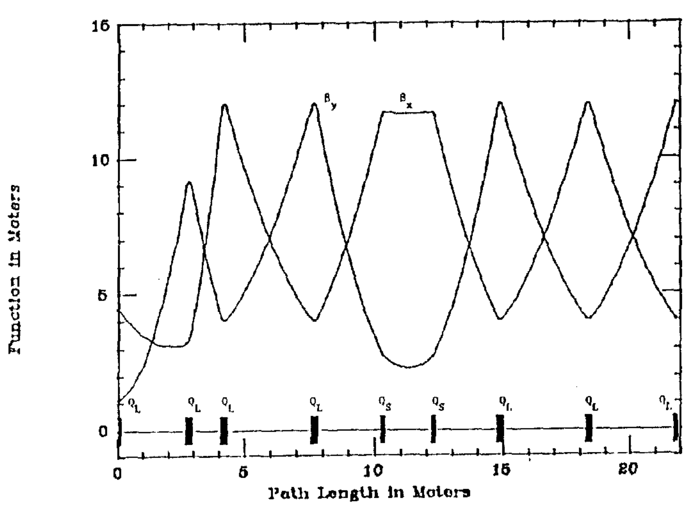

Fig. 3. Beam functions through half straight

Not shown in Fig. 3 but denoted by S in Fig. 1 are the two sextupoles (or octupoles for first mode) required to excite the extraction resonance. These two magnets are located symmetrically about the midpoints of the two straight regions.

Beam Optics

The functions characterizing the first order beam optics of the PSR when tuned for the second mode of operation are shown in Figs. 2 and 3. The relevant beam optics parameters (evaluated at the extraction point when relevant) are summarized in Table 1.

Table 1. PSR Beam Parameters

	Horizontal	Vertical
Betatron tune	6.28	4.45
Chromaticity	-8.60	-9.43
$d\beta/d\delta$	35.40	2.50
Momentum compaction (α)	0.00552	
Bend Region:		
β_{min} (m)	0.59	1.13
β_{max} (m)	4.47	3.83
η_{max} (m)	0.70	0.00
Straight Region:		
β_{min} (m)	3.20	1.13
β_{max} (m)	12.00	12.00

Beam Extraction (Monochromatic Mode)

One third integer resonant extraction will be employed to extract the beam from the PSR. With this method the region of the transverse phase space in which particles have stable orbits is slowly reduced. The dimensions of the stable region are proportional to the difference between the tune of the PSR (as seen by a particular electron) and the extraction resonant tune (n + 1/3). Thus, extraction is achieved by slowly varying the PSR tune onto the resonant tune.

The monochromatic method of resonant extraction requires a coupling of the electron energy to the PSR tune (i.e., non-zero chromaticity). The change in energy which is required to shift the particle onto the resonant tune is provided by synchrotron radiation losses. This method works best when the time required for all the particles to be shifted onto the resonance equals the time between linac pulses. When this condition cannot be satisfied then either current or duty factor suffer.

Preliminary simulations of extraction have been made. Figure 4 shows an illustrative extraction of two particles. A septum placed at about 1.5 cm from the

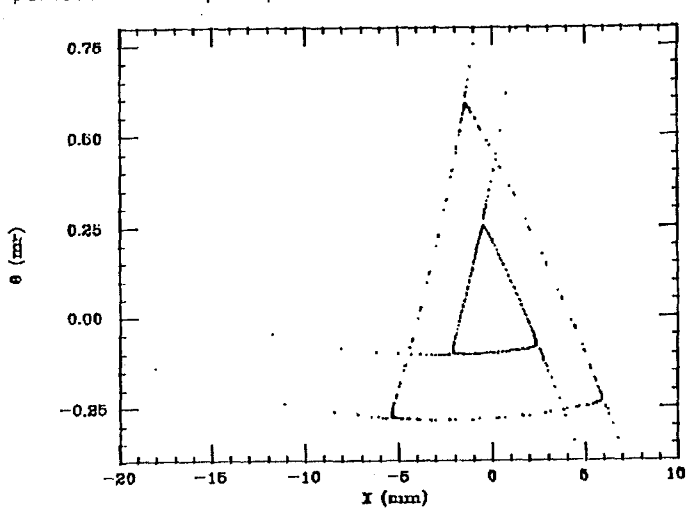

Fig. 4. Third integer resonant extraction

closed orbit would cause the particles to be extracted at a very small angle. More complete simulations indicate that an emittance in the horizontal plane of 0.3 π mm-mr should be attainable.

The extraction channel is shown in Fig. 5. The magnet locations can be referenced to Fig. 1. Electrons leaving the first short quadrupole and falling outside the electrostatic septum[3] receive a 10 mr deflection. After the second short quadrupole the deflected electrons are separated from the stored electrons by 1.5 cm. This provides ample separation for a magnetic septum[4] which further deflects the electrons so that they leave the PSR at an angle of 10°.

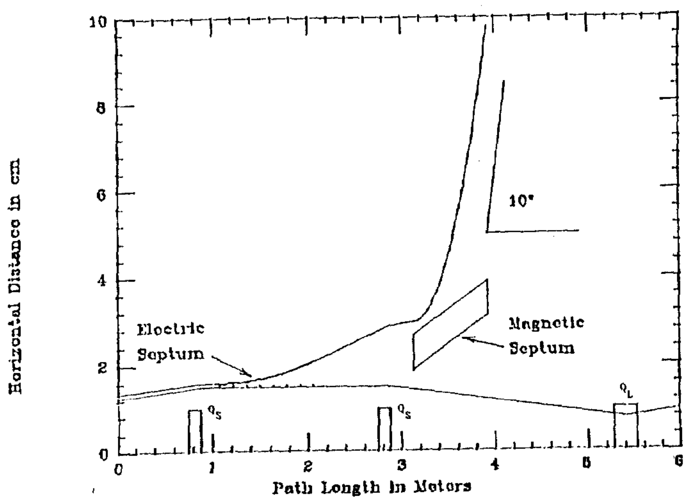

Fig. 5. Extraction channel

Injection

To achieve a smooth resonant extraction requires an even population of the transverse phase space. For one third resonant extraction three turn injection is ideally suited to providing the desired phase space filling, while for half integer extraction single turn injection may be used.

Uncertainties regarding availability of some hardware and the degree to which architectural modifications can be made (i.e., which walls can be broken down) make the details of the injection scheme uncertain. However, a schematic study of the optics involved has been performed for the more complicated three turn case under the assumption that the injection will occur at the point in the PSR opposite the extraction point (labelled I in Fig. 1).

At injection the central closed orbit (C.O.) of the PSR will be bumped horizontally by electrostatic deflectors so that it will lie 1 to 2 mm from an electrostatic septum similar to that in the extraction channel (see Fig. 5). Electrons will be injected on axis in the vertical plane and off axis in the horizontal into the ellipse labelled 1 in Fig. 6. After circling the PSR once they will reappear at 2, and after another turn at 3. After a third turn they would reappear near ellipse 1 but during the time after the last electrons of the linac pulse have entered the PSR but before the first electrons complete their third revolution the closed orbit is moved towards its normal location a distance sufficient to make the electrons miss the septum.

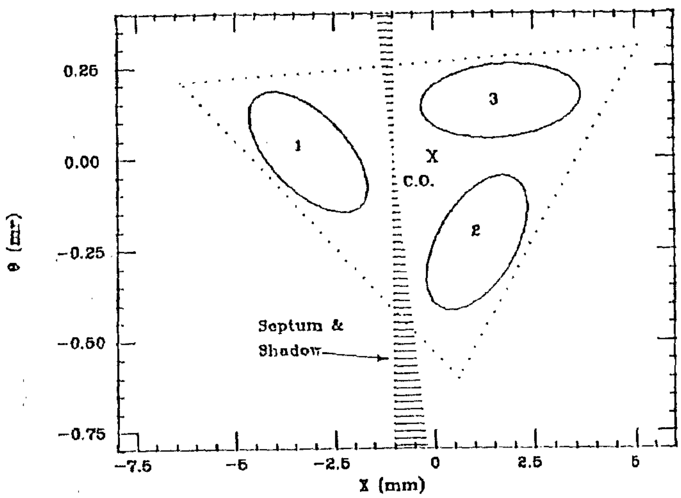

Fig. 6. Three turn injection

RF System

The rf system required for the first mode of operation as well as for the storing of short pulses for diagnostic purposes is very modest. The maximum energy loss rate (at 300 MeV) is 720 eV per turn, so a system capable of a 1 to 2 keV energy gain will suffice.

The frequency of the rf system must be a subharmonic of the linac frequency of 2856 MHz. A frequency of 714 MHz is favoured since an rf system operating at exactly this frequency is in operation at SLAC.

Conclusion

The design presented here is preliminary. However, while details may change the basic structure, dictated as it is by the constraints of the existing facility, should not. It therefore serves as a model upon which sound performance and cost estimates can be made.

References

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