A SPIN CONTROL SYSTEM FOR THE SOUTH HALL RING AT THE BATES LINEAR ACCELERATOR CENTER

T. Zwart, Boston U, Boston MA 02215; P. Ivanov, Yu. Shatunov, Budker INP; R. Averill, K. Jacobs, S.Kowalski,W. Turchinetz; MIT-Bates Linear Accelerator Center

Abstract

An optical design for a spin rotater for the MIT-Bates South Hall Ring is presented. This design maintains longitudinally polarized electrons at both internal and external targets.

I. Introduction

The MIT-Bates South Hall Ring (SHR) was designed and constructed to provide essentially CW extracted beams and stored beams for a unique internal target physics program. [1]. The SHR facility is shown below in Fig.1. An important component of this physics involves measurements with longitudinally polarized electron beams and polarized targets. The measurement of spin observables provides access to interference terms which are directly sensitive to small but important nuclear form factors and excitations.

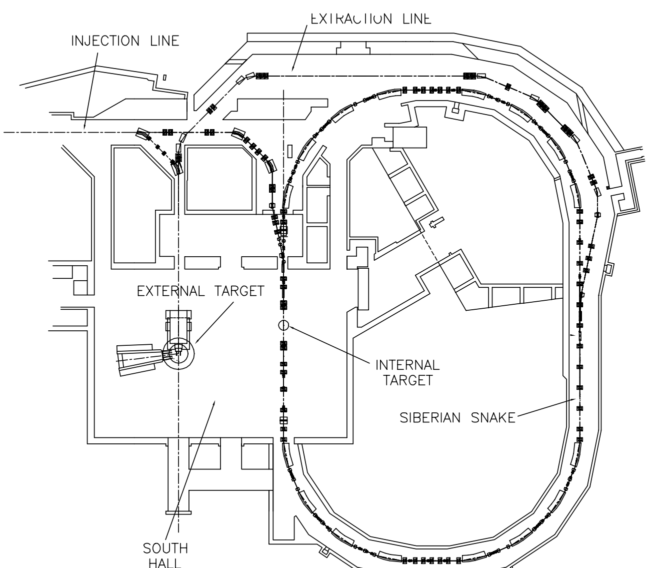

Figure. 1. The MIT-Bates South Hall Floor and South Hall Ring

Maintaining longitudinal polarization for internal target operation and for extracted beam operation is complicated by the fact that for the electron $g-2$ is non zero. Except for 'magic' energies the spin precesses with respect to the momentum over successive circulations in the SHR. A Siberian Snake (SS) approach [2] is being implemented to ensure purely longitudinal polarization at the internal target. The beam is injected with longitudinal polarization on the first pass through the internal target. A superconducting solenoid system on the opposing straight precesses the spin vector by π about the momentum vector. As a result any transverse polarization components are subsequently rotated back into the longitudinal direction by the dipoles in the North half of the SHR. This fixes the spin tune at $1/2$ and eliminates the linear dependence of the spin tune on the beam energy. The magnets in the SS can be scaled to maintain longitudinal polarization at the internal target for any energy.

In the SHR's extraction mode the electron beam is also parallel to the injection line as it passes through the external target on the South Hall floor. Thus the same SS sytem maintains longitudinal polarization on the external target without any additional magnetic elements on the extraction line.

II. Lattice modification

Implementation of the SS scheme requires that the ring lattice be modified because the standard drift length between two quadrupoles (Fig.2) is not long enough to insert a solenoid of reasonable field strength (10.5 Tm/GeV) and the skew quads which compensate for the coupling introduced by the solenoid.

A suitable solution to this problem could probably be achieved in many ways. We developed a new set of machine optics in the extraction straight section that is suitable for the SS insertion and does not affect the beam extraction system. To realize this particular optics it is neccesary to move two quadrupoles (LQ 41 and its symmetric partner, LQ 49) and add two additional quadrupoles (Fig.2). This provides two 4.81 m drift sections. The snake will be in the first drift section and the second is now available for other insertions. Fig.2 shows the matched behavior of the horizontal β_x function along half of the extraction straight section. The solid curve shows the optics of the new lattice. The dashed curve shows the new lattice with the spin rotator elements energized and the dotted line shows the optics of the previous lattice.

This solution satisfies the requirements for both SHR operation modes. There is still optical flexibility to keep the tune away from machine resonances in the storage mode. The optical functions near the extraction septum, between LQ44 and LQ45, are not significantly affected. The positioning of three octupoles for beam extraction is still satisfactory, meeting the requirements of proper phase advance and large values of β_x. In the section for the snake insertion the $\beta_{x,y}$ functions are relatively small and smooth to avoid difficulties in the machine tuning with strong solenoids.

III. Siberian Snake scheme

The SS insertion will not disturb the machine optics if its transfer matrix is equivalent to the drift length physically occupied by the insertion and the betatron tunes are shifted by an

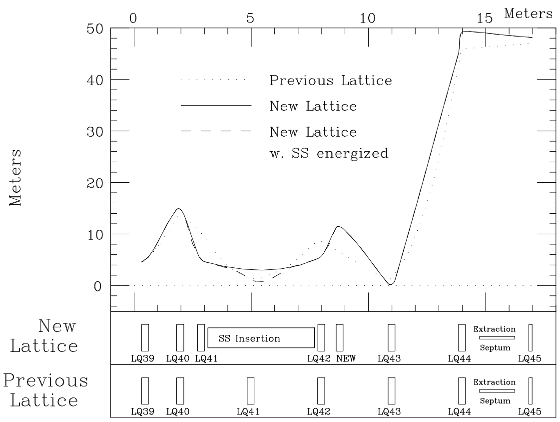

Figure. 2. β_X in the Siberian Snake Region

amount $m \cdot \frac{1}{2}$ where m is an integer. This approach was suggested in [3] and recently applied to the AmPS ring [4].

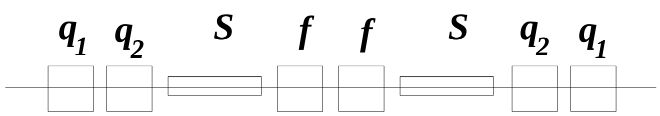

Figure. 3. Siberian Snake scheme

Fig.3 shows a mirror-symmetric SS scheme that consists of two solenoids, a pair of skew quads (q) at each end and two regular quads (f) in the middle. This scheme has four parameters to vary its focusing, three quadrupole strengths and the length of the two solenoids. Of course the solenoid's field integral must be fixed such that the total spin precession angle equals exactly π. A solution for an energy of 1 GeV which satisfies the above requirements is given in Table I.

Note that this solution, which is very economical in number of elements and their strengths, shifts the horizontal tune by integer while the vertical tune will be shifted by an integer and a half. An important feature of these optics is that inside the insertion the β-functions decrease considerably (Fig.2) due to the strong solenoidal focusing dominating over the quadrupole's action. This means that aperture requirements over the insertion are relaxed.

IV. Tolerances and Nonlinearities

An investigation of the effects of errors in positioning, orientation and powering shows that there are not any particularly difficult requirements in alignment and current stability of the snake elements. A possible residual $x - y$ coupling caused by a misalignment of the SS magnets can be easily be compensated by adjusting the skew quadrupoles.

We can use the flat beam approximation to consider the non-linear effect of the solenoidal fringe field on the extraction process. Certainly the flat beam approximation is valid in the case of the extracted beam where $\epsilon_x >> \epsilon_y$. The beam will see a

Element	**Length(m)**	**Field**	**α(Deg.)**
Skew Quad	0.300	0.61 kG/cm	45°
Drift	0.180		
Skew Quad	0.300	-0.485 kG/cm	45°
Drift	0.175		
Solenoid	0.805	65.00 kG	
Drift	0.175		
Quad	0.300	-1.397 kG/cm	0°
Drift	0.030		
Quad	0.300	-1.397 kG/cm	0°
Drift	0.175		
Solenoid	0.805	65.00 kG	
Drift	0.175		
Skew Quad	0.300	-0.485 kG/cm	−45°
Drift	0.180		
Skew Quad	0.300	0.61 kG/cm	−45°
Total Len.	4.500		

Table I

Position and Strength of Siberian Snake Magnets

non-linear force in the fringe field of the solenoid whose strength can be written:

$$F(s) = \int B(s)B''(s)ds$$

The strength of the non-linear perturbing function, $F(s)$, is a product of the longitudinal field and its second derivative and like the extracting octupole its influence depends on the cube of the radial position. When we compare the kick induced in the fringe field of the solenoids to the kick induced in the extracting octupole we obtain [5]:

$$\frac{\Delta x'_{Fringe}}{\Delta x'_{Oct}} = 0.1$$

Thus we expect that the fringe field focussing will not interfere with the extraction process.

Real field configurations in the solenoids and quadrupole magnets must be taken into account for the actual design.

V. Resonant Depolarization

One concern for the SHR Siberian Snake is that the beam polarization could be destroyed by coupling to the radial betatron motion in the extraction mode. The spin tune and the radial betatron tune are both very close to the half integer. As these two frequencies approach one another the influence of small imperfections in the machine will be maginified and the the polarization could be lost. The magnitude of these imperfections which we expect for the SHR was estimated using the code Apsirin [6]. The strength of this imperfection, ϵ, is a measure of the degree to which the spin eigen vector is not oriented exactly along the beam axis. Using a 10% residual coupling between the radial and vertical betatron motions we obtain a value for

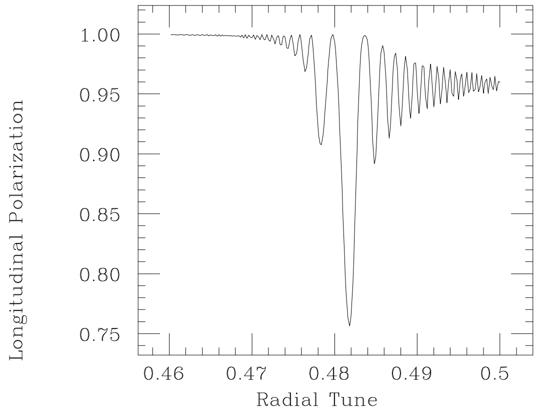

Figure. 4. Polarization over one Extraction Cycle

this intrinsic resonance strength, $\epsilon = 2 \times 10^{-3}$. Following the work of Nghiem and Tkatchenko [7] we have simulated the spin motion in the SHR.

In Fig.4 we use the value of ϵ obtained above and show the average longitudinal polarization over 10 turn intervals while the horizontal tune is ramped from 0.46 to 0.50 over 2000 turns as is done in the extraction process. Note that the polarization is reasonably well preserved until the SHR reaches a tune of 0.48 at which point the polarization drops rapidly to 75% of its initial value. This indicates that some special effort will be neccesary in adjusting the skew quadrupoles to make sure the $x - y$ coupling is kept well below the 10% level.

VI. Conclusion

The Siberian Snake presented here for the SHR will serve to maintain the beam's longitudinal polarization at internal and external targets. This is done with an economy of elements. The solenoids for the spin rotator are now being built at the Institute for Nuclear Physics in Novosibirsk. The lattice on the extraction straight will be modified over the next year and we hope to install the solenoids by January 1996 after which the testing program will begin.

References

[1] J.Flanz, *"South Hall Ring Design Report"*, 1990.

[2] Ya.S.Derbenev, A.M.Kondratenko, A.N.Skrinsky, *Sov. Phys. Doklady*, 15, 1970, p.583.

[3] A.Zholents, V.Litvinenko, *Preprint INP 81-60*, Novosibirsk, 1980.

[4] V.V.Danilov *et al*, *Proc. of 10th Int. Symp. on High Energy Spin Physics*, Nagoya, 1992,p.445.

[5] P.Ivanov, Yu.Shatunov,T.Zwart, *"A Universal Superconducting Spin Rotator for the MIT Bates South Hall Ring"*,Bates Doc. B/SHR 93-10, 1993.

[6] Yu.Shatunov, *Proc. of 10th Int. Symp. on High Energy Spin Physics*, Nagoya,1992

[7] P.Nghiem, A.Tkatchenko, *Nuclear Instruments and Methods in Physics Research*,1993,p.349-366.