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A SYSTEM FOR OBTAINING LONGITUDINAL BEAM POLARIZATION AT PEP WITH VERTICAL DIPOLES LOCATED OUTSIDE OF THE INTERACTION REGION

A. Garren and J. Kadyk

I. INTRODUCTION

Recent experiments at SPEAR[1] demonstrate that circulating e^+ and e^- beams become highly polarized along the field direction, to a degree consistent with the theoretical maximum, 92.4%.[2,3] This property of the beams allows use of new and powerful techniques with which to study the weak and electromagnetic interactions. Particularly interesting applications of the spin polarization become possible if the spins are rotated to the longitudinal direction at the interaction point.[4]

To maintain full polarization it is necessary to keep the particles' spin vertical in the circular arcs of the machine, rotate it to the longitudinal direction at the interaction point and then rotate it back to the original vertical direction in the following arc. This can be done by utilizing the g-2 precession of the electrons in vertical bending magnets, or in a combination of solenoidal and horizontal bending magnets.[5,6] In our opinion, the most feasible method proposed to date for use at PEP is that of Schwitters and Richter.[7] This method, shown in Fig. 1, uses

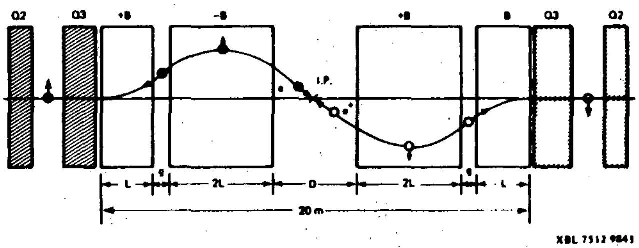

Fig. 1. The Schwitters-Richter Scheme for Producing Longitudinal Beam Polarization (PEP-87). The diagram shows the four vertical bending magnets (unshaded rectangles) inside the 20 m interaction region. They are used to produce longitudinal polarization at the interaction point, IP, as indicated. Spin directions are indicated at various points along the trajectory.

four vertical bending magnets in the interaction region (IR). The spin rotates relative to the momentum by 90° for every 2.305 Tesla-meters of net bending, independent of beam energy. The four magnets have virtually no effect on the beam throughout the ring. The principal change is to introduce vertical dispersion in the IR, except at the interaction point (IP), where it vanishes. However, the magnets fill most of the IR, leaving only a small space (about 3m) for the experimental apparatus, and the fields are high (0.82 T compared to 0.3 T for the horizontal bending magnets). Consequently, a great deal of synchrotron radiation is emitted (~600 kW) locally within the IR, just the region where background should be minimized to assure efficient detector performance.

It is thus important to search for ways to rotate the electron spins that leave more space for the experimental detectors and reduce synchrotron radiation in their vicinity. Wenzel was the first to consider this question. In a previous note he discusses two schemes, each using two dipoles, one or both of which were placed beyond the IR.[8] The focussing doublets at either end of the IR bend both the central orbit and the dispersion to cross the median plane at the IP. The quadrupoles must have very large apertures (about one meter) and be considerably longer than the present low-β quadrupoles. Moreover, their chromatic aberrations result in substantial loss of luminosity.

In this note we propose a spin rotation system (SRS) in which the central orbit is bent by vertical dipoles located outside of the interaction region, and follows the path shown in Fig. 2. The spin is rotated as before by the (g-2) precession in these magnets. Some important features of the system are the following:

1) There is no reduction in luminosity resulting from adding the SRS. 2) Somewhat less (about 30% less) synchrotron power is radiated than in the Schwitters-Richter scheme. 3) Low-field vertical bending magnets and masks are included in the SRS in order to shield the detector from the synchrotron radiation, at least in part. 4) Selection of either the SRS mode or the conventional operating mode is achieved simply by choice of alternative settings of magnet currents. 5) The IR is left completely unencumbered for disposition of the experimental apparatus.

II. DESCRIPTION OF THE SYSTEM

A side view of the spin rotation system (SRS) is shown in Fig. 2, where the standard PEP lattice magnets are shown as open rectangles, and those of the SRS by shaded/black rectangles for vertical dipoles/quadrupoles. Figure 2 shows only half of the system to the left of the IP, the right half being produced by inversion through the IP.

The beam coming from the left enters the SRS at the vertical dipole BV1, the lattice before this element being unmodified. There the beam is deflected upwards 58 mrad, and the following elements are centered on the vertically displaced central orbit. Vertical dipole BV2 deflects the beam back to the horizontal direction. BV3 and the two low field magnets, BVL, bend the beam downwards by 46 mrad to cross the median plane at the IP. These five dipoles, having a net $\int Bdl$ of 2.305 Tm, rotate the polarization of the beams from the vertical direction in the circular arcs to the longitudinal direction at the IP. The corresponding dipoles on the opposite side of

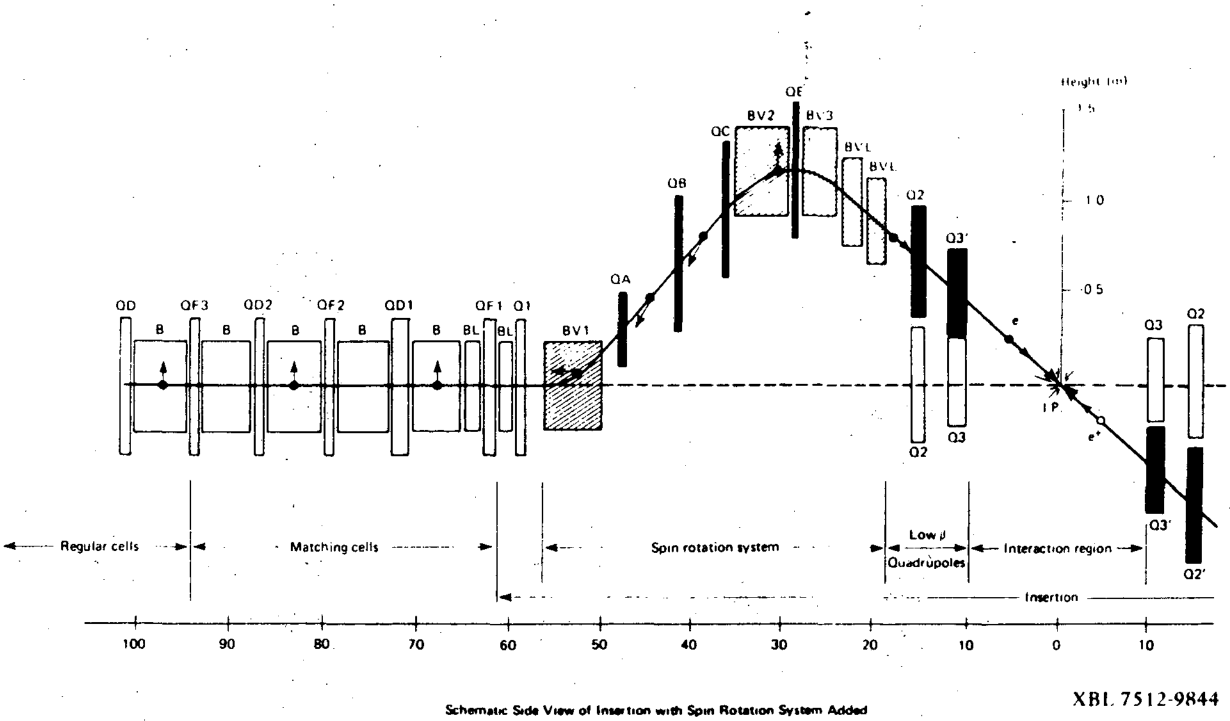

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Fig. 2. Schematic Side View of Insertion with Spin Rotation System. magnets of the basic PEP lattice are shown as open rectangles; these are not to be replaced or moved. The new elements, belonging to the spin rotation system, are shown as black (quadrupoles) or shaded (vertical bending magnets). Small arrows indicate spin polarization directions at several points along the beam trajectory.

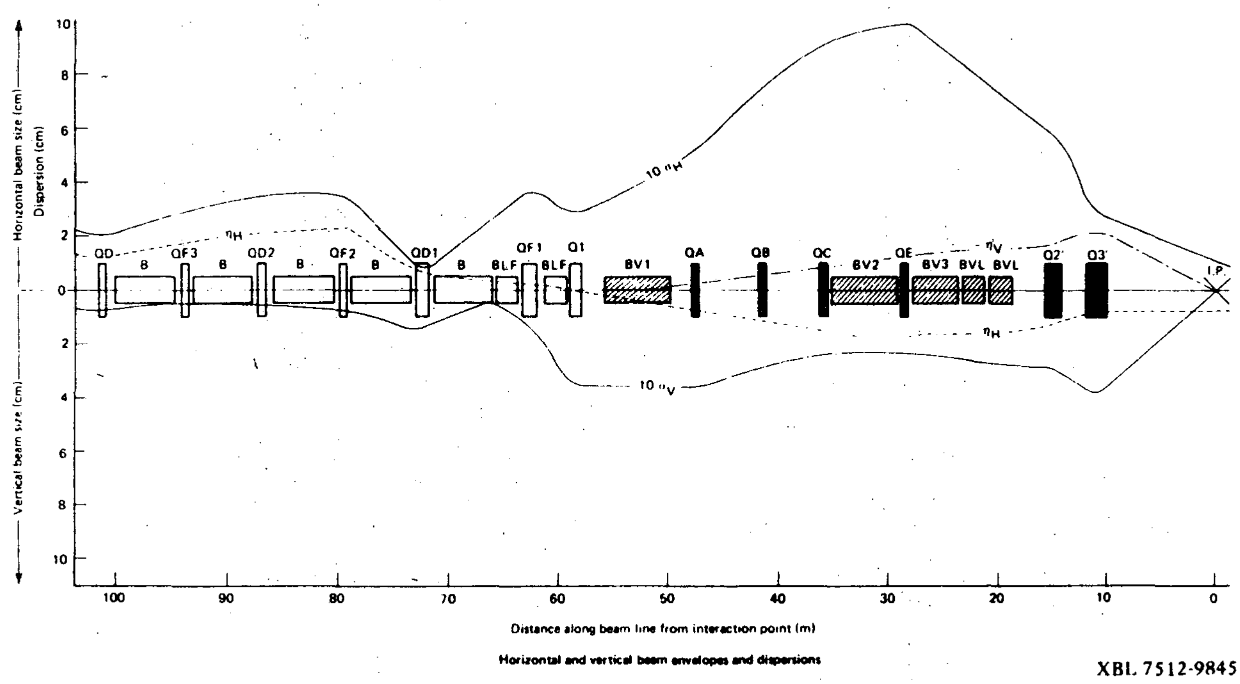

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Fig. 3. Horizontal and Vertical Beam Envelopes and Dispersions. Beam envelopes are plotted for the horizontal (upper solid line) and vertical (lower solid line) planes, corresponding to 10σ (10 times the expected rms width). Also shown are the dispersed rays, horizontal and vertical, corresponding to energy spread $\Delta E/E = 1\%$, the $10\sigma_E$ value for 15 GeV beam energy. The envelope width as shown includes the dispersion, combined quadratically with the betatron beam width.

0 0 0 0 4 5 0 2 1 0 3

the IP rotate the spin back to the original vertical direction. The vertical low-field magnets, BVL, each deflect the beam 1.6 mrad downwards. Together with appropriate masks, they are intended to shield the detector system from the radiation emitted in BV3. This is similar to the use of the horizontal low-field magnets BL to shield the IR from radiation emitted in the main lattice bending magnets.

The four quadrupoles, QA, QB, QC, QE, lie between the vertical dipoles, and the doublet, Q2', Q3', is placed above the corresponding doublet Q2, Q3 of the standard configuration. These six new quadrupoles are all centered on the displaced beam line.

III. Beam Optics

A. Requirements on Vertical Dispersion

In order to maintain full polarization, the spins must be vertical in the circular arcs of the storage ring. In order to maintain this condition, the particle spins must precess through equal and opposite angles on the two sides of the IP. Since the precession angle is proportional to the rotation of the momentum vector, it follows that in order to keep the spins vertical in the arcs, the dispersion function, $\eta_V(s)$, must be an odd function of s about the IP. If, in addition, $\eta_V(s)$ is identically zero throughout the rest of the ring, systematic spin oscillations outside of the SRS will be eliminated. The vertical dispersion $\eta_V(s)$ has these properties in the method of Schwitters and Richter, shown in Fig. 1, due to the absence of quadrupole lenses in their system. In fact, $\eta_V(s)$ in that case is identical, but reversed in sign, from the vertical displacement of the central orbit.

Unfortunately, this automatic matching of the vertical dispersion does not occur in the system presented here, because of the action of the lenses Q2' and Q3'. In the absence of the elements QA, QB, QC and QE, a nearly parallel beam would be focussed at the IP, vertically. However, the dispersed (off-momentum) rays would be parallel when entering BV3, and therefore not parallel after leaving BV3 and entering Q2'. Thus, the dispersed rays would not be focussed at the IP.

The four new lenses, QA-QE, are added to focus the dispersed ray as well as the beam envelope at the IP. In addition, the strengths of the other quadrupoles between the normal lattice (left of QD) and the IP are altered from the values of the standard configuration.

B. Beam Matching and IP Conditions

The linear beam properties are determined by the betatron functions and the dispersion. In order to obtain the full design luminosity, and minimize the effects of the SRS on the operation of the ring, the betatron functions and dispersion at QD and at the IP were constrained to be the same as in the standard configuration (both horizontally and vertically). Only the slope of the vertical dispersion, $\eta_V' = d\eta_V/ds$, was allowed to be different (non-zero), but this is expected to have a negligible effect. Therefore to the left of QD, in the normal lattice, the beam envelope will also be constrained to be everywhere unchanged from that of the standard configuration. The betatron-function and dispersion values are given in Table I.

Table I. Required Values of the Betatron Function at the Interaction Point And at the Center of QD, the First Normal Cell Quadrupole.

	QD Center		IP	
	Horizontal	Vertical	Horizontal	Vertical
β (m)	12.18	34.12	3.80	0.20
α	0.040	-0.052	0	0
η (m)	1.238	0	-0.74	0
$d\eta/ds$	0.0025	0	0	arbitrary

The matching problem was solved by allowing the strengths of the 12 quadrupoles, QF3 through Q3' inclusive, to be varied. The number of variables may seem unnecessarily large for the seven constraints involved, but this many variables were needed to resolve the conflicting requirements of beam and dispersion focussing discussed above. Even so, the problem is not trivial, and two fitting programs were employed to solve it.[9,10] The resulting quadrupole strengths and other parameters of the system are given in Table II. Beam envelopes and dispersion functions corresponding to ten times the runs widths σ are shown in Fig. 3.

Table II. Magnet Parameters of the Spin Rotation System (See Figs. 2 and 3).

For quads, positive gradient corresponds to horizontal (H) focussing.
For vertical (V) bends, positive field bends upwards.

Name	Function	Length (m)	Strength (T or T/m)	Distance, IP to Magnet Mid-Point
QD	Quad	0.64	-7.610	101.303
B	H Bend	5.40	0.3023	97.463
QF3	Quad	0.64	2.567	93.853
B	H Bend	5.40	0.3023	90.563
QD2	Quad	0.64	-2.201	86.953
B	H Bend	5.40	0.3023	83.113
QF2	Quad	0.64	10.469	79.503
B	H Bend	5.40	0.3023	76.213
QD1	Quad	1.28	-11.170	72.603
B	H Bend	5.40	0.3023	68.763
BL	H Bend (low field)	2.00	0.0201	64.853
QF1	Quad	1.15	7.018	62.773
BL	H Bend (low field)	2.00	0.0201	60.408
Q1	Quad	1.00	-7.518	58.543
BV1	V Bend	6.00	0.4841	53.000
QA	Quad	0.50	-4.049	47.750
QB	Quad	0.50	2.117	41.750
QC	Quad	0.50	1.845	36.250
BV2	V Bend	6.00	-0.4841	32.500
QD	Quad	0.50	3.995	28.750
BV3	V Bend	4.00	-0.5562	26.000
BVL	V Bend (low field)	2.00	0.0200	22.500
BVL	V Bend (low field)	2.00	0.0200	20.000
Q2	Low-β Quad	1.50	2.390	15.200
Q3	Low-β Quad	2.00	-4.078	11.000
IP	Interaction Point			0.

IV. LOGISTICS OF INSTALLATION AND OPERATION

A. Operating Modes

Since the technique of spin rotation has never been used in a storage ring, it is inevitable that full operation will only occur after a period of testing and development. Therefore, it is desirable to have operation of the SRS be optional, and to be able to switch over easily to the conventional (non-SRS) operation. A rather natural way to accomplish this is to install two sets of low-β quadrupole doublets, Q2'-Q3', along the vertically displaced beam line as part of the SRS, and Q2-Q3 along the conventional beam line as part of the standard configuration. This will require also two separate beam pipes, which will diverge at BV1 (at 58 mrad) and merge again at the IP (at 46 mrad). With this arrangement, the entire set of new magnets can be turned on or off to permit operation either in the spin rotation mode or in the conventional way.

As presently designed, quadrupoles Q2, Q3 are somewhat too high to give sufficient clearance for the new set Q2', Q3' to be directly above, as shown in Fig. 2. Therefore these elements may have to be staggered with Q2, Q3 or designed with smaller vertical dimensions.

B. Use of the SRS at Different Energies

The design presented here is intended to produce longitudinal polarization at 15 GeV. Since the condition for 90° of spin rotation, 2.305 T-m of vertical bending, is independent of energy, a full polarization capability requires that the system be movable, with the height of the BV2-BV3 line varying inversely with energy, the net $\int Bdl$ being fixed. Although occasional changes in beam line of this nature may be feasible, it is obviously not desirable to make frequent changes. A possible compromise is to change $\int Bdl$ proportionally with beam energy, E, so that the beam optics remains invariant. Then the spin rotation is not precisely 90°, and the net longitudinal polarization will be $\approx 0.924 \sin(\pi E/2E_o)$, where E_o is the design energy for 90° rotation. Since polarization is never complete anyway, one might tolerate values as low as ≈ 0.75 (as long as it is known), allowing E to deviate by ±40% from E_o. For example, this would allow beams to be operated through the SRS over the energy range from about E = 8 to 18 GeV without a beam line alteration.

IV. PRACTICAL CONSIDERATIONS

Although we see no fundamental problems associated with use of the SRS, some important considerations come to mind that will need to be examined in detail.

A. Periodicity

The insertion containing the SRS has a different structure from the others. Since it is only perfectly matched to the rest of the ring for the central momentum, the ring has one-fold periodicity and linear stop-bands exist at half-integral intervals of the tunes ν_x, ν_y for the off-momentum orbits. These may be corrected with suitable adjustments in the sextupole correction system. These, however, must be so designed that third and higher order resonances are not excited.

A one-fold periodicity is also introduced by energy loss in the vertical dipoles. This effect could be removed with compensating rf cavities located in the SRS, between BV2 and BV3.

B. Chromaticity

Not only will the ring have one-fold periodicity, but the chromaticities are increased by large gradients and beta function values in some quadrupoles of the polarization insertion. The maximum beta value is increased from 500 m in the standard configuration to 800m. Again, the consequence of these increases are probably managable.

C. Apertures

Beam sizes are rather large in some magnets of the SRS. Care will be needed in the design, fabrication, and testing of these elements to be sure they meet the somewhat tighter tolerance requirements.

D. Synchrotron Radiation

The new low-field magnets introduced in the present design should permit the shielding of the IR from synchroton radiation emitted from the vertical bending magnets BV1-BV3. However, a detailed study of this question will need to be made to determine where the shielding masks should be placed, and how effective such shielding will be.

V. CONCLUSIONS

This is a "first look" at this particular configuration, not an optimized design. It is intended rather as a demonstration of the feasibility of a system in which the large spin rotation magnets are located outside the IR. The system can, in principle, be turned on or off to allow conventional operation of PEP or operation with the SRS. Operation over a wide energy range also appears possible without moving magnets, with only a relatively small loss in longitudinal polarization. The IR is left unencumbered by the SRS, and the sources of synchrotron radiation are moved out of the IR. However, a careful study is necessary to determine the best design for reducing or eliminating this background radiation.

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