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LATTICE INSERTIONS FOR POPAE

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Summary

Four types of insertions are described for the six 200-m straight sections of POPAE. All have dispersion matched to zero. (1) Injection-ejection insertion - This has proper high- β values and phase advances for horizontal injection and vertical ejection. (2) Phase-adjust insertion - The phase advance in this insertion is adjustable over a range of $\sim 100^\circ$. (3) General-purpose insertion - The β^* is adjustable from 2.5 to 200 m and the crossing angle is adjustable from 0 to 11 mrad. (4) High-luminosity insertion - This gives an even lower β^* of 1 meter.

General Description of the Lattice

The design of POPAE¹ has evolved into a regular structure consisting of six, 720-m long curved sections, separated by 200-m long straight sections where the beams are focused and cross one another. Each sextant is composed of 12 lattice cells, having eight 6-m long bending magnets with a field of 60 kG at 1000 GeV. The two end cells of each sextant are modified to make the dispersion go to zero in the straight sections. One bending magnet is omitted from the end cells of the inner ring, achieving in a natural way the horizontal crossing of the beams at 11 mrad.

The regular cell is a separated-function FODO cell with 90° betatron phase advance. It consists of two quadrupoles and eight dipoles. Magnets are separated by 80-cm drift to accommodate cryostats and pump-out ports. One pair of beam-position sensing electrodes is located in the space immediately downstream of each quadrupole, and clearing electrodes are placed in all other spaces. Field-correction windings are located inside the magnets. The cold-bore vacuum is extended continuously through all regular cells in a curved section.

Dispersion Elimination

The end cells of each curved section have modified quadrupole strengths such as to set the horizontal dispersion in the adjoining straight section to zero. A single dipole has been removed from the end cells of the outer curved section, being necessary for the crossing geometry and to provide space for the injection kicker. Removal of these dipoles provides a horizontal crossing angle between the beams in the two rings equal to the bending of one dipole, 11 mrad. These cells are shown in Figs. 1 and 2. One could have alternatively produced zero dispersion by rearranging dipoles in several end cells, as in the ISABELLE design², but this leads to a lower packing factor and so was not done.

Injection-Ejection Insertion

The lattice insertion (I) in the injection straight section is shown in Fig. 3 together with the

dispersion-eliminating cells C1 and C2 at the upstream and downstream ends, respectively. Also shown are the stacking rf cavity, the injection septum, the ejection kicker on the upstream side of the crossing point, and the ejection septum and injection kicker on the downstream side.

Phase Adjust Insertion

The quadrupoles in the phasing straight section insertion (P) are so arranged that by varying their strengths, the betatron phase advances across the insertion can be adjusted over a range of some 100° , while keeping the amplitude functions at the ends properly matched. This insertion for two examples with different phase advance is shown in Fig. 4.

General Purpose Insertion

A general-purpose insertion that is intended to serve a great variety of physics experiments should have a long central drift space. On the other hand, it should also be able to yield an amplitude function β^* at the crossing point that is small. A low β^* coupled with a long drift space leads to high maximum β -value ($\beta_{\max}$) in the insertion, which is undesirable because it increases the variation of β with momentum. As a compromise, a central drift length of ± 45 m was chosen. At a low β_y^* value of 2.5 m and a horizontal β_x^* of 13.5 m, $\beta_{\max}$ is about 800 m, and the variation β^* across the momentum spread in the stacked beam is quite tolerable and need not be corrected. The tuning range of β^* for this insertion extends from this low value to several hundred meters. Fig. 5 shows the insertion (E) with two sets of running parameters corresponding to the low β_y^* value of 2.5 m and a high β_y^* value of 200 m.

High-Luminosity Insertion

To achieve very high luminosities the crossing angle can be reduced down to 0° by the insertion of four beam steering dipoles, EB1 to EB4, in the central drift space. In this case, the clear length is reduced to ± 10 m. The symmetry in geometry guarantees that, although the angle dispersion becomes finite, the displacement dispersion remains zero at the crossing point. The two inner dipoles are used in common by the two beams and hence must have a rather wide horizontal aperture of 18 cm. By adjusting β^* and the crossing angle, the luminosity can be varied over a wide range. As an example, high-luminosity insertion (H) with a central drift space of ± 10 m is shown in Fig. 6. This insertion can be tuned to the vertical values of $\beta^* = 1$ m and $\beta_x^* = 3$ m and still has a tolerable $\beta_{\max}$ of less than 1100 m.

Operational Considerations

Overall lattice characteristics with a variety of insertions were studied using the computer program SYNCH.³ Those for a typical mix are given in Table 1.

*Operated by the Universities Research Association, Inc., under contract with the Energy Research and Development Administration.

Driftless Section	2	2	2	2	2	2
Insertion	Inj. (I)	Exp. (I)	Exp. (I)	Exp. (I)	Phase (I)	Pl-Num. (I)
Grassing Angle (sard)	11	11	11	11	11	3
Control drift space (m)	0.0	0.0	0.0	0.0	0.0	0.0
θ_{max} (m)	210	2.5	231.3	231.9	29	1.0
θ_{min} (m)	81	23.5	25	25	81.7	1.0
θ_{max}	233	0.13	263	279	231	203
θ_{min} (m)	213	181	220	220	231	1082
Detuning Times			Characteristic			
Horizontal θ_{max} = 21.0			Horizontal θ_{max} = 21.0			
Vertical θ_{max} = 22.0			Vertical θ_{max} = 22.0			
Transmission Energy T_{max} = 19.53						

on a line parallel to and 0.02 away from the difference diagonal. This region is free of all resonances below sixth order and is large enough to accommodate tune spreads of at least 0.1 in both planes. At injection the chromaticity is tuned to a small positive value to suppress the head-tail effect. The tune spread in the stacked beam needed to suppress all other transverse instabilities by the Landau-damping mechanism is generally small enough so that the operating point on the injection orbit can also be accommodated in this region. Thus, only resonances higher than fifth need be crossed during stacking.

1. D. Ayres, et al., "A 1000-GeV on 1000-GeV Proton-Proton Colliding Beam Facility", Fermilab and Argonne National Laboratory Joint Proposal (May 1976)
2. "A Proposal for Construction of a Proton-Proton Storage Accelerator Facility ISABELLE", BNL 20161 (June 1976)
3. A.A. Carren and A. Kenny, notes dated Feb. 1974

Figure 1 consists of four sub-diagrams labeled (a) through (d).
 (a) A graph of vertical deflection η_b versus distance x in meters. The curve starts at approximately 3.5 m at $x=0$ and decreases to 0 at $x=60$ m. A label indicates $\eta_{b, \max} = 31.26 \text{ cm}$.
 (b) A graph of bending moment M in kN-m versus distance x in meters. The curve starts at 10 kN-m at $x=0$, reaches a minimum of about 3 kN-m at $x=30$ m, and ends at 15 kN-m at $x=60$ m.
 (c) A graph of shear force Q in kN versus distance x in meters. The curve starts at 5 kN at $x=0$, crosses zero at $x=10$ m, reaches a minimum of about -5 kN at $x=30$ m, crosses zero again at $x=50$ m, and ends at 5 kN at $x=60$ m.
 (d) A cross-section of the bridge deck. It is a rectangular box girder with a total width of 60.6 m. The diagram shows the internal structure with various reinforcement details and dimensions.

Fig. 2 **Dispersal-eliminating cell C2.**

<u>TIME/TYPE</u>		<u>freq1</u> (Hz)	<u>freq2</u> (Hz)	<u>freq3</u> (Hz)
<u>1/10/1975</u>		1000	1000	1000
<u>1/10/1975</u>		<u>Length (m)</u>	<u>Gradient (kg/m)</u>	
<u>Quadrupoles</u>	<u>101</u>	1.170	1188.4	
	<u>102</u>	1.170	-945.5	
	<u>103</u>	1.170	681.5	
	<u>104</u>	1.120	-1091.1	
	<u>105</u>	1.170	987.3	
	<u>106</u>	1.120	528.0	
<u>Drifts</u>	<u>111</u>	27.000		
	<u>112</u>	20.000		
	<u>113</u>	56.000		
	<u>114</u>	20.000		
	<u>115</u>	56.472

Fig. 3 Injection straight-section insertion 2, together with coils C1 and C2, showing injection, stacking, and ejection elements.

STRUCTURE	Q(1)P(1)P(2)P(3)P(4)P(5)P(6)P(7)P(8)	Q(1)P(2)P(3)P(4)P(5)P(6)P(7)P(8)
LENGTH	m	
	Length (m)	Gradient (m/m)
	SP1	SP2
Quadrupole		
Q1	1.422	116.1
Q2	1.428	332.1
Q3	1.440	-911.6
Q4	1.453	553.1
Q5	1.470	250.5
Q6	1.492	-831.5
Q7	1.503	719.3
Q8	1.460	762.8
Drifts		
D1	22.353	
D2	15.629	
D3	11.275	
D4	10.125	

	Expt. 1	Expt. 2
Horizontal ϕ_p	110.00°	115.00°
Vertical ϕ_p	210.15°	210.00°

Fig. 4 Phasing straight-section insertion P.

[illegible]

Fig. 2 General-purpose experimental straight-section insertion C.

[illegible]

Fig. 6 High-Luminosity Insertion M.