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PROPOSAL FOR A NEW PS SLOW EXTRACTION

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INTRODUCTION

The slow extracted beam towards the PS East Area is at present widely used by groups of physicists for equipment tests. Keeping this facility is certainly an asset for our machine.

The layout of this extraction was conceived about 15 years ago to achieve two goals which have now disappeared: sharing with internal targets and possible choice between extraction channels 16 and 62 [1].

The present layout uses a large amount of straight section space in the machine: one electrostatic and three magnetic septa, together with six dipoles, two quadrupoles, and one special semi-quadrupole. Four short straight sections are occupied entirely (53,62,83,85), one is two thirds full (23), six are a third full (59,75,80,82,88,90), and a long one is half full (61).

The PS will soon have to provide electrons and positrons to the LEP machine. This new task will require extra instrumentation in the ring and space around the machine circumference is becoming scarce. Accelerating electrons in the PS will create other problems due to the synchrotron radiation emitted by the circulating beam. It will irradiate all the equipment placed towards the outside in the vacuum vessel, causing outgasing and damage.

To help cope with these difficulties, a new layout is proposed and presented here. It requires less straight section space and uses septum magnets placed towards the inside to avoid direct exposure to synchrotron radiation. It is designed for the same momentum of 24 GeV/c.

electrostatic and thin septa so that the image of the first at the location of the second is parallel to the angle axis in the phase plane (see appendix 1).

Moreover, it is desirable that β_h should be large in the electrostatic septum straight section to maximize the efficiency. β_v, on the other hand, should preferably be small in the thin magnetic septum magnet.

All these considerations guide us in the choice of the quadrupolar effect. It is rather obvious that the present semi-quadrupole should not be kept as it imposes the restriction of a common location for quadrupolar and sextupolar effect.

The kick enhancement quadrupole must be placed in SS 45 or 53 (-16k), the only locations where it actually increases the effect of the electrostatic septum. Position 53 must be rejected because it acts in the wrong way for the effect looked for in b). In fact , SS 45 is not available, and SS 29 becomes the first choice.

Concentrating all the quadrupolar effect in 29 is possible but it turns out that condition b) can only be met with a sextupole arrangement lowering drastically the chromaticity. This is obviously unsafe as it would occupy too much of the chamber width and increase the sensitivity to the ripple of the various magnet power supplies.

A second quadrupole must be added. There are 8 different locations possible (+16k), and a systematic study shows that only 2 give the wanted difference between the dispersions at the electrostatic and thin septa: 69 and 71. The second one is the best choice and we finally retain SS 87, located one betatron period further in the ring.

<u>Sextupoles</u>

The sextupolar effect must meet 3 requirements (see appendix 1):

i) the phase of the 19^{th}harmonic must be such that one of the separatrices in SS 23 makes an angle of 140^0 to 160^0 with respect to the x-axis in the normalized horizontal space phase,

ii) the amplitude of the 19^{th} harmonic must cause a spiral pitch of 10 to 12 mm at the electrostatic septum, this effect being proportional to the β fonction at the lense,

iii) the zero harmonic must modify the horizontal chromaticity to fulfill condition b), this effect being proportional to the dispersion fonction at the lense.

In fact, the spiral pitch can also be adjusted with the closed orbit bump amplitude at the electrostatic septum, and the horizontal chromaticity with the pole face winding current so that only 2 or 3 sextupoles are necessary. They can even probably be connected in series.

<u>Bumps</u>

Bringing the beam near the magnet is mandatory at each septum location. The exact value of the necessary bump depends on the residual closed orbit, so that some margin must be kept for the dipoles strengths.

SS 29 being chosen for the kick enhancement quadrupole, the electrostatic septum first possible location is SS 23 with bumpers in 19 and 27.

Bumps at the thin and extractor septa are very much coupled. SS 53 is an obvious location for the first dipole. The beam has to be displaced towards the extractor magnet in straight section 61 using a bumper in SS 59. The circulating beam must then be brought back towards the machine centre to avoid be 1.3 m and the total thickness 25 mm, acceptable but somewhat tight.

- The present septum magnet of SS 61 can be re-utilized in SS 57, as it gives the nominal deflection of 3.9 mrad for a current of 9000 A. The existing power supply SPG1 can also be kept to power it. If it is found later on that the losses are excessive in this straight section, a new magnet could be developed with a thiner septum (4 mm instead of 5 mm). As for the vacuum tank, its design will have to be completely new because of the presence of the antiproton beam line just outside, preventing the conventional installation of the vacuum pumps. Let us note here that the horizontal position and angle of the septum should be adjustable, but not the vertical position.

- The extraction septum of SS 61 is outside vacuum with a relatively low deflection power of less than 1.2 mrad. It should be located before the septum bumper, the septa thickness being the same for both devices. The existing power supply SPG2, capable of delivering 3000 A, is suitable. There again, one could use an existing type 212 magnet, since a septum thickness of 25 mm could be accepted if need be. The nominal current would then be 930 A. The vacuum chamber parts into the two circulating and extracted beam lines right at the beginning of the straight section, just after the coupling. The vessels for both channels will have to withstand the mechanical stress on the septa when they are pulsed.

- The extracted beam travels along straight section 62 at around 130 mm from the main vaccum chamber centre. There can be either one or two vacuum vessels but in any case this section is lost for most conventional installations.

- The total amount of power supplies required is 6 (not counting the high voltage generator for the electrostatic septum), namely:

a T700 for the quadrupoles with a current of about 650 A,
a T700 for the sextupoles with about 280 A,
a T700 for bumpers 19 and 27 with about 600 A,
a T700 for bumpers 53, 59, 61 and 67 with about 515 A,
a high current supply for septum 57 (SPG1) with 9000 A,
a high current supply for extraction septum 61 (SPG2).

EXPECTED BEAM DYNAMICS

In the vertical plane, the beam is away from resonance. Its size is given by the perturbed β_V during extraction. The main values of interest are:

$$\beta_{V_{57}} = 9.3 \text{ m}$$
$$\beta_{V_{61}} = 17.5 \text{ m}$$

The beam behaviour in the horizontal phase plane of the most important straight sections is shown on the figures at the end of this paper.

The closed orbit at resonance appears on all figures. For the chosen bare machine tune of 6.20 and the strength of .047 rad/m for both quadrupoles, the resonance is found for $\Delta p/p = -.0014$ as compared to the the central orbit. To a stable area inside the separatrices of nominal emittance 2π mm.mrad corresponds $\Delta p/p = +.0001$. The instantaneous energy spread of the extracted beam is thus $\Delta p/p = .0015$, somewhat more than the present .0011 for the same emittance with the Square extraction.

One sees that the clearance for the first magnetic septum is 8 mm for an electrostatic septum deflection of -.28 mrad, which corresponds to a voltage of 150 kV across 18 mm. This is an improvement compared to barely 3 mm obtained at the present thin septum 85 for the same electrostatic septum conditions and a π mm.mrad circulating beam horizontal emittance. Moreover, in

EXTRACTION EFFICIENCY

Theoretically, the only losses should occur on the electrostatic septum, whereas in the present scheme, there are also some on the next thin magnetic septum. These losses will be inversely proportional to the spiral pitch at the electrostatic septum.

With the present lens QF001, the pitch must be limited to 7 or 8 mm and the efficiency to 97 %. If this beam transfer aperture restriction is suppressed through the use of a new specially designed lens, then the pitch can be raised to 10 or 12 mm and the efficiency to a theoretical value of more than 98 %.

The practical efficiency will turn out to be somewhat less due to several factors like, for instance, misalignement and irregularities in the electrostatic septum anode or beam halos. The comparison with the Square extraction is thus difficult at this stage. The losses on the electrostatic septum are likely to be higher in the proposed new scheme, because the angular dispersion of the beam is larger at the entrance of this element. On the other hand, the margin is larger at the first magnetic septum, and the losses should be lower there, so that one cannot altogether expect a large difference between the efficiencies of both schemes.

CONCLUSION

As already stated, this new extraction scheme presents several advantages as compared to the present one:

- there are only two septa in vacuum,
- these septa are protected from the synchrotron radiation,
- less straight section space is used.
- one power supply less is needed.

Eleven short straight sections are involved: two are full (23 and 57), one is two third full (19), eight are a third or a forth full (7,27,29,53,59,67,87 and 95). One long straight section is partly occupied (61). Finally, straight section 62 is hindered by an extra wide chamber.

Among the drawbacks of this scheme, one should quote an increase of the vertical emittance by 50 % compared to the Square extraction, and a tighter margin in the strength of the elements which could very probably exclude extraction at 26 GeV/c.

One must add that this scheme can at present be only judged on computer simulation. But comparisons between model and observation on the machine check rather closely for the present layout and a few points have been further verified with the AGS programme. This gives a reasonable confidence in this proposed new extraction scheme which could guarantee the future of the PS East Area test facility.

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APPENDIX I

SOME ANALYTICAL RESULTS ON SLOW EXTRACTION

Some of the results obtained from the analytical model [2] are presented here as they help us in our design.

Stable area

If S is the normalized amplitude of the sextupolar 19^{th} harmonic, β_h the horizontal amplitude Twiss parameter , ΔQ the distance to resonance counted in betatron wave number, then the stable area emittance ε is:

$$\varepsilon = \frac{144\ \pi\ \Delta Q^2}{\sqrt{3}\ S^2}$$

It must be remembered that S takes into account the values of β_h as perturbed by the quadrupoles at every sextupole location.
If ξ_h is the perturbed horizontal chromaticity, then

$$\Delta Q = \xi_h\ Q\ \frac{\Delta p}{p}$$

and finally

$$\frac{\Delta p}{p} = \frac{S}{12\ |\xi_h|\ Q} \sqrt{\frac{\sqrt{3}\ \varepsilon}{\pi}} \qquad (1)$$

which gives the difference in energy between the particles extracted from the centre and from the outskirts of the beam emittance ε.

Optimisation of the thin septum clearance

Each of these two groups of particles follow a separatrix towards the centre of the machine with increasing "jumps" every 3 revolutions. After a large number of revolutions, they eventually pass in SS 23 beyond the electrostatic septum. Figure 1 shows the points A and B where the separatrices hit the septum. These points transform into A' and B' at the thin septum location SS 57 on figure 2 . Obviously the clearance for the thin septum is optimized if A'B' can be made parallel to the angle axis in the phase plane.

The quadrupoles are chosen to modify the local dispersion parameters α_p so that it becomes relatively small in SS 23 and large in SS 57. For quadrupoles of equal strength .048 r/m , placed in SS 29 and 87, the values are:

$$\alpha_{p_{23}} = 1.32\ \text{m}$$
$$\alpha_{p_{57}} = 5.02\ \text{m}$$

Now if we lower $|\xi_h|$, equation (1) shows that $\Delta p/p$ is increased. The effect of the dispersion in SS 57 is much larger than in SS 23, and point B' is moved to the right. It is possible to find a reasonable ξ_h so that A'B' becomes vertical on figure 2. This is achieved by a careful choice of the zero harmonic of sextupolar effect.

Spiral pitch

Figure 3 shows the separatrices at locations in phase with the 19^{th} harmonic. The displacement of particles over 3 revolutions is given by:

$$\Delta x = \frac{3}{2}\ S\ xx' + 6\ \pi\ \Delta Q\ x'$$

The second term is zero for the central particles so that the spiral pitch becomes directly proportional to S . It is not very different for particles of other energies.

APPENDIX 3

PROPOSED LAYOUT

SS	element	nomin.defl.	max. defl.	strength	length	comments
7	sextupole	-.35 rad/m^2	-.4 rad/m^2	32 T/m	.24 m	type 608 sext
19	sextupole	-.35 rad/m^2	-.4 rad/m^2	32 T/m	.24 m	type 608 sext
19	dipole	-.0021 rad	-.0022 rad	.18 Tm	.3 m	type DNH 206
23	elec.sept.	-.00028 rad	-.00033 rad	8000 kV	1 m	as present 83
27	dipole	-.0021 rad	-.0022 rad	.18 Tm	.25 m	type DLH 205
29	quadrupole	-.047 rad/m	-.05 rad/m	4 T	.305 m	type 409 quad
53	dipole	-.0018 rad	-.0022 rad	.18 Tm	.3 m	type DNH 206
57	septum	.0039 rad	.005 rad	.4 Tm	.831 m	old 61 magnet
59	dipole	.0018 rad	.0022 rad	.18 Tm	.25 m	type DLH 205
61	ext.septum	.0012 rad	.003 rad	.24 Tm	?	new design
"	int.septum	-.0018 rad	-.0022 rad	.18 Tm	?	new design
67	dipole	.0018 rad	.0022 rad	.18 Tm	.3 m	type DNH 206
87	quadrupole	-.047 rad/m	-.05 rad/m	4 T	.305 m	type 409 quad
95	sextupole	-.35 rad/m^2	-.4 rad/m^2	32 T/m	.24 m	type 608 sext

NEEDED ENLARGED HORIZONTAL APERTURES

location	side	dim.	remarks
magnet 22	inside	105 mm	
SS 23	inside	105 mm	tank for electr. septum
magnet 23	inside	105 mm	
magnet 56	both	105 mm	
SS 57	both	105 mm	tank for magnetic septum
magnet 57	both	105 mm	
1st 1/2 magnet 60	outside	105 mm	
2nd 1/2 magnet 60	outside	115 mm	
magnet 62	outside	105 mm	
SS 63	outside	105 mm	
magnet 63	outside	105 mm	

ENLARGED VACUUM CHAMBERS TO BE SUPPRESSED

Magnet 61

All chambers from ss 82 to 86

ELEMENTS OF PRESENT EXTRACTION TO BE SUPPRESSED

SS	elements
23	2 quadrupoles
53	semi-quadrupole
59	dipole BLG
61	magnetic septum
62	magnetic septum
75	dipole BLG
80	dipole BNO
82	dipole BNO
83	electrostatic septum
85	magnetic septum
88	dipole BNO
90	dipole BNO

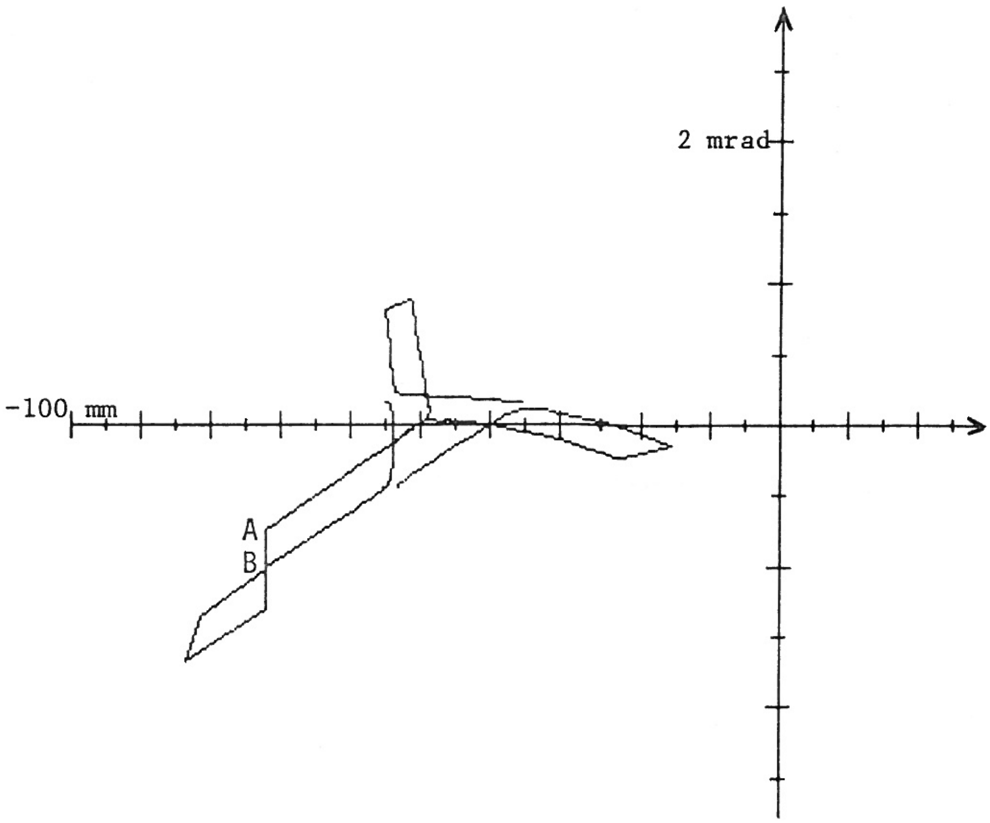

Fig. 1 - Phase space in straight section 23 (exit of electrostatic septum)

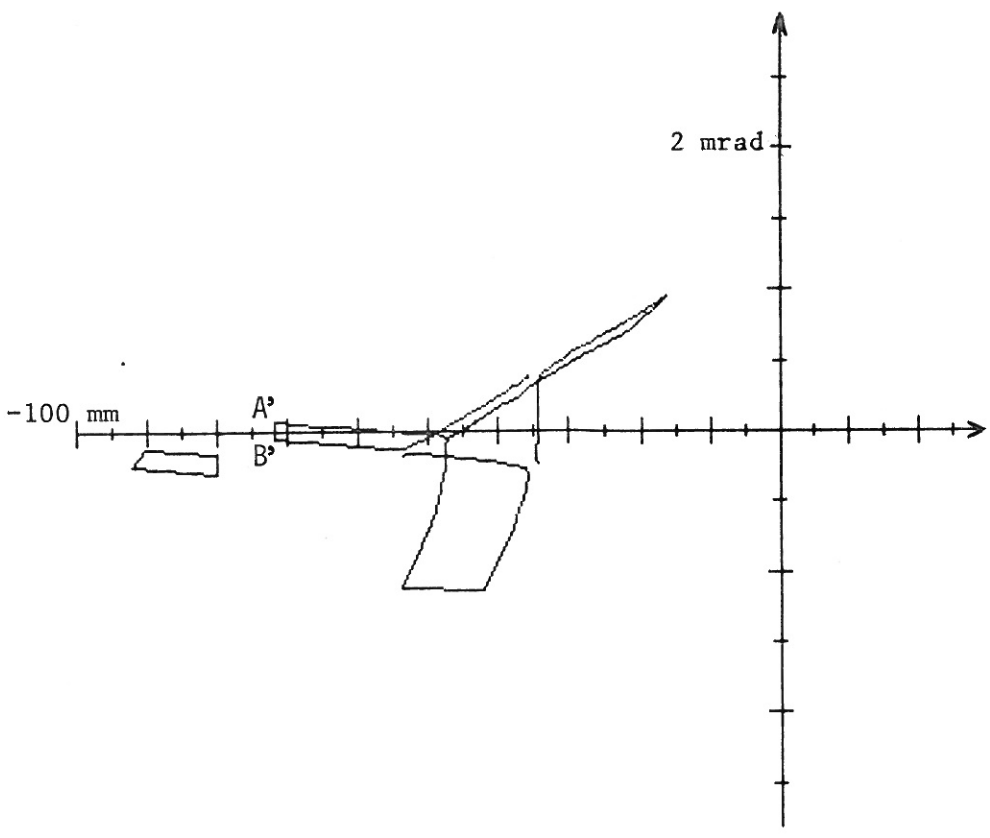

Fig. 2 - Phase space in straight section 57 (entrance of thin magnetic septum)