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LOSS CONCENTRATION IN SLOW CYCLING RINGS WITH APPLICATION TO THE CERN PS BOOSTER

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ABSTRACT

The on-line isotope separator facility ISOLDE at present operated at the CERN 600 MeV Synchro–Cyclotron (SC) will be transferred to the 1 GeV CERN PS Booster (PSB) which has unused capacity to supply the proton intensity required. For the PSB this implies an up to fourfold increase in average proton current and essentially operation at highest intensity possible where losses are highest too. An analysis of the loss occurence suggests that the most vulnerable element in the machine is the extraction septum and ought to be protected. In order to optimize hardware specifications, possible loss concentration was studied by a simple analytical model and by the computer tracking code ACCSIM [1], recently updated to include Monte-Carlo simulation of a thick collimator. As the PSB is a slowly cycling machine, the problems and the results are related to storage rings.

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Abstract

The on-line isotope separator facility ISOLDE at present operated at the CERN 600 MeV Synchro–Cyclotron (SC) will be transferred to the 1 GeV CERN PS Booster (PSB) which has unused capacity to supply the proton intensity required. For the PSB this implies an up to fourfold increase in average proton current and essentially operation at highest intensity possible where losses are highest too. An analysis of the loss occurence suggests that the most vulnerable element in the machine is the extraction septum and ought to be protected. In order to optimize hardware specifications, possible loss concentration was studied by a simple analytical model and by the computer tracking code ACCSIM [1], recently updated to include Monte-Carlo simulation of a thick collimator. As the PSB is a slowly cycling machine, the problems and the results are related to storage rings.

Introduction

The move [2] of the on–line isotope separator facility ISOLDE from the aging CERN SC to the CERN PSB will raise the average current of the latter from about 1 μA to 2.8 or, ultimately, 4 μA. Losses will rise even steeper because they are more pronounced the higher the intensity, and some maintenance problems can be anticipated.

Analysis of loss occurrences yields several processes distinct in mechanism and particle energy, virtually requiring different types of concentrators, which cannot be implemented within the budgetary constraints of the project. As the most irradiated elements in the machine i.e.the septa are at the same time very delicate and vulnerable elements, it was decided to protect the ejection septum, being hit by 1 GeV protons.

As all loss mechanisms considered share the feature that the circulating beam approaches the intercepting aperture very slowly, the face of the latter will be hit rather shallow, and there is a significant probability that particles will be outscattered [3] into the vacuum chamber and continue their orbit until they are lost somewhere else. Older studies [4] suggest that edge interception depths of more than 50 μ are required to avoid outscattering. None of the loss mechanisms in the PSB and probably in any storage ring is driving particles fast enough

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into the interceptor to reach a depth of this order of magnitude. In order to force protons to hit the collimator edges deeper, we propose to excite an artificial fast blow-up of the beam halo in the vicinity of the limiting aperture by a scatter foil of appropriate thickness located upstream of the collimator.

The PS-Booster – Performances and Losses

It should be recalled for convenience that the PSB is a stacked four-ring synchrotron of 25 m radius (1/4 of the CPS) which can operationally accelerate about 8 10^{12} p/ring from 50 MeV to 1 GeV at an 1.2 s cycle. Best rings have accelerated more than 10^{13} p/ring, which was the design goal for the whole machine. One price to pay for this intensity are larger emittances and higher loss. The latter occurs (i) at multiturn injection (40% at 50 MeV, lost at the injection septum and the downstream bending magnet), (ii) at rf capture (10% at 50 MeV, spiraling inwards), (iii) during the first 50 ms of acceleration (15% at 50-100 Mev, probably vertical blow-up on stopbands), (iv) at 400 - 800 MeV (3-5%, spurious, due to longitudinal instabilities), and (v) at the ejection, when an orbit bump approaches the circulating beam to the septum where its halo is scraped off – due to the tight design, which aimed at half the present high-intensity emittances.

Although losses are predominant at lower energies, lost protons are easy to stop (range of a few mm in commonly used metals). We consider the protons lost at hundreds of MeV as more dangerous and attribute highest priority to the protection of the complicated ejection septa. Second priority is the collimation of the spiraling particles lost out of the bucket and collected at the inside of the aperture. At present the budgetary limits of the ISOLDE transfer project allow only for one stack of collimators. Consequently the study concentrates on the top priority item, i.e. the ejection septum. A local orbit bump starts rising sinusoidally 6 ms before a fast kicker ejects the beam horizontally outwards to the septum. The bump drives the orbit towards the collimator at a speed which decreases from initially 6 μm/turn to zero. This is very slow as compared to fast cycling synchrotrons where non-accelerated particles spiral at a few mm/turn. Consequently the halo particles have little chance to hit the collimator face deeper than a few hundredths of a mm, and outscattering will be significant.

Enhanced Blow-up through a Scatter Foil

A method to increase the interception depth at the collimator face appears to be a scatter foil placed upstream of the absorbing collimator, protruding into the acceptance. A particle approaching the collimator will (possibly multiply) traverse the foil and experience a fast emittance blowup before hitting the collimator. A slowly approaching particle will hit the foil the first time nearly at maximum local betatron amplitude. In the foil it experiences a random angular kick by multiple scattering and energy loss, which can be considered as practically deterministic. The kick will increase the emittance and the energy loss will change the closed orbit if the dispersion $D,D' \neq 0$, which also contributes to the emittance change. Betatron phase changes also, but for adequate choice of lattice functions the proton will have orbit parameters that enable it to hit the foil, or a collimator, at more depth. For horizontal collimation it should be noted that according to the sign of D and the position (interior or exterior) of the foil the new orbit will carry the particle either away from or further into the foil or the collimator, respectively. Inspection of standard formulae [5] for rms. scattering angle θ and momentum loss $\delta p/p = \delta$ reveals that lighter elements show more energy loss for comparable scattering angle. Consequently for positive dispersion, one would choose a light element like carbon for scraping the inside of the beam and a heavy one for a foil associated with an exterior collimator. The latter is the case relevant for the protection of the PSB ejection septa and tungsten as foil material has been chosen in the simulations.

PSB Extraction System and Simulation Parameters

Fig.1 displays the layout of the PSB extraction system. The virtually sole location where a collimator of reasonable depth (the range of 1 GeV protons in W is about 0.35 m) can be placed is where is at present the downstream bumper dipole (dashed line indicates present bump) which has to be pushed further downstream to the next straight section (solid line = new orbit). A short postabsorber to collect protons not stopped in the principal collimator can be situated in a very short straight section downstream of the F quadrupole. The most convenient choice for the foil is adjacent to the collimator face (Foil position A), as there is no need for a separate remotely controlled positioning device. The argument also holds when the foil is placed at the exit of the septum itself, which has its position and angle controlled (Foil position B). We assume that the beam halo is scraped to a final horizontal emittance $\epsilon_{final} = 30\ \pi$ mm mrad (a value typical for a high intensity beam), and compute the outer envelope for it including maximum orbit bump and a momentum deviation of $\hat{\delta}$=0.135 % corresponding to the bucket height. This envelope determines the reference position for all apertures concerned (foil, collimators, the septum blade etc.): $X = \sqrt{\epsilon_{final}\beta} + \hat{x}_{co} + D\hat{\delta}$. Obviously one should watch that at any time during the bump rise the stay-clear acceptances between apertures and closed orbit meet $A_{Septum}(t) > A_{Coll}(t) \geq A_{Foil}(t)$, which may also be expressed by an equivalent inequality relating $\hat{x}_{co}/\sqrt{\beta}$ at these locations. Inspection of these quantities for the PSB shows that foil position A, the main collimator and the entrance of the septum have essentially the same value of 12 mm/m$^{-1/2}$, while the septum exit shows 17 mm/m$^{-1/2}$. Recession of apertures, in particular of the septum, changes the inequalities but it remains that foil position B suffers from this penalty. It means that halo particles of large amplitude will hit the collimator without passing through the foil.

Simulation : Method and Results

All simulations have been done with the ACCSIM [1] Code, which tracks ensembles of macroparticles through lattices, and includes Monte Carlo codes dealing with foil interactions. Moreover it allows definition of thin multipoles, apertures and performs loss statistics. Sinusoidal variation of dipole strength has been added for the purpose of this study. In a first series of simulations to assess the effect of scatter foils of varying thickness and geometry, hollow shells in x,x' phase space representing halo emittances of typically 40 or 50 π mm mrad were driven by the rising bump into the foil and apertures at collimator and septum locations, including the existing standard scrapers (two per machine period) of the machine. Average and variance of coordinates of loss locations are recorded.
As already found and explained in earlier investigations[6], a foil location upstream gives significantly deeper hits of the collimators than an adjacent one like position A. While without foil the average entrance coordinate is 0.10 mmm deep, a 13900 μg/cm^2 tungsten foil raises

this figure to 0.15 mm (pos. A) and 0.24 mm (pos. B). A 3 times thicker foil yields 0.25 mm (pos. A) and 0.8 mm in case of foil position B ! Mainly for this reason the latter was investigated further, and appropriate recession of the septum and of the collimator was foreseen. In any case a recession of the collimator of 0.5 - 1 mm is indispensable to get favourable result.

A second series of simulation drives a whole beam of 60 π mm mrad and more realistic m=3 binomial distribution into the absorbing apertures, recording average loss locations. The following Table 1 summarizes the results:

Average hitting depth [mm], collimator 0.54 mm recessed

	Foil position A	Foil position B
No foil	0.07	0.07
W 13900 $\mu g/cm^2$	0.21	0.05 - 0.42
W 41700 $\mu g/cm^2$	0.28	0.05 - 1.24

Table 1: Comparison of Foil locations with respect to hitting depth of collimator entrance face

Recently a new version of ACCSIM, still under test, became available, that is able to track primary protons through bulk material and can this way predict the fate of particles leaving the collimator before being stopped. Fig. 2 shows tracks of 1 GeV protons entering a tungsten half space, as produced by the implemented code. These diagrams tell us that even at more than 1 mm entrance depth a large fraction of incident protons will be backscattered into the vacuum pipe. They will however have lost a considerable fraction of their energy, and be definitely lost in the first downstream bending magnet, if not intercepted by auxiliary absorbers. Hence a "postabsorber", consisting of a rigid rectangular frame of overall machine acceptance was inserted in the lattice. Not needing any position control such a device would not raise significantly the cost of the implementation.

At present only a few geometries with the foil at B position have been simulated. Tabulated results are tentative and have to be interpreted with caution. It should be noted that both main- and postabsorber are only 0.28 m long while the range of the protons from Fig.2 is rather 0.32 m – a length which might be technically feasible for the main collimator. Another pessimistic factor is that a totally unrealistic waterbag distribution had been used in x-x' space to improve the statistics of halo absorption. As mentioned above the outer halo hits the collimator before the foil in this geometry. This explains the difference between the results of the two binomial distributions.

Conclusions

Simulation results indicate that by appropriate choice of parameters and geometry a scatter foil can enhance the hitting depth of collimator face from 0.1 to > 1 *mm* at the considered energy of 1 GeV. It remains to be investigated whether this is sufficient to significantly improve the fraction of particles actually stopped in a main collimator and only one or two postabsorbers. It should be noted that these results concern also high-intensity storage rings, which in form of accumulation- and holding rings figure in all hadron facility designs.

Distribution	Water Bag	Parabolic
Emittance (100%)	40 π	40 π
Total loss	36.9%	4.5%
Rel. Loss:		
Main Collimator	60.0%	68.9%
Postabsorber	15.2%	17.8%
Other Scrapers	24.8%	13.3%
Septum	0	0

Table 2: Loss Concentration by Tungsten Foil 41700 $\mu g/cm^2$

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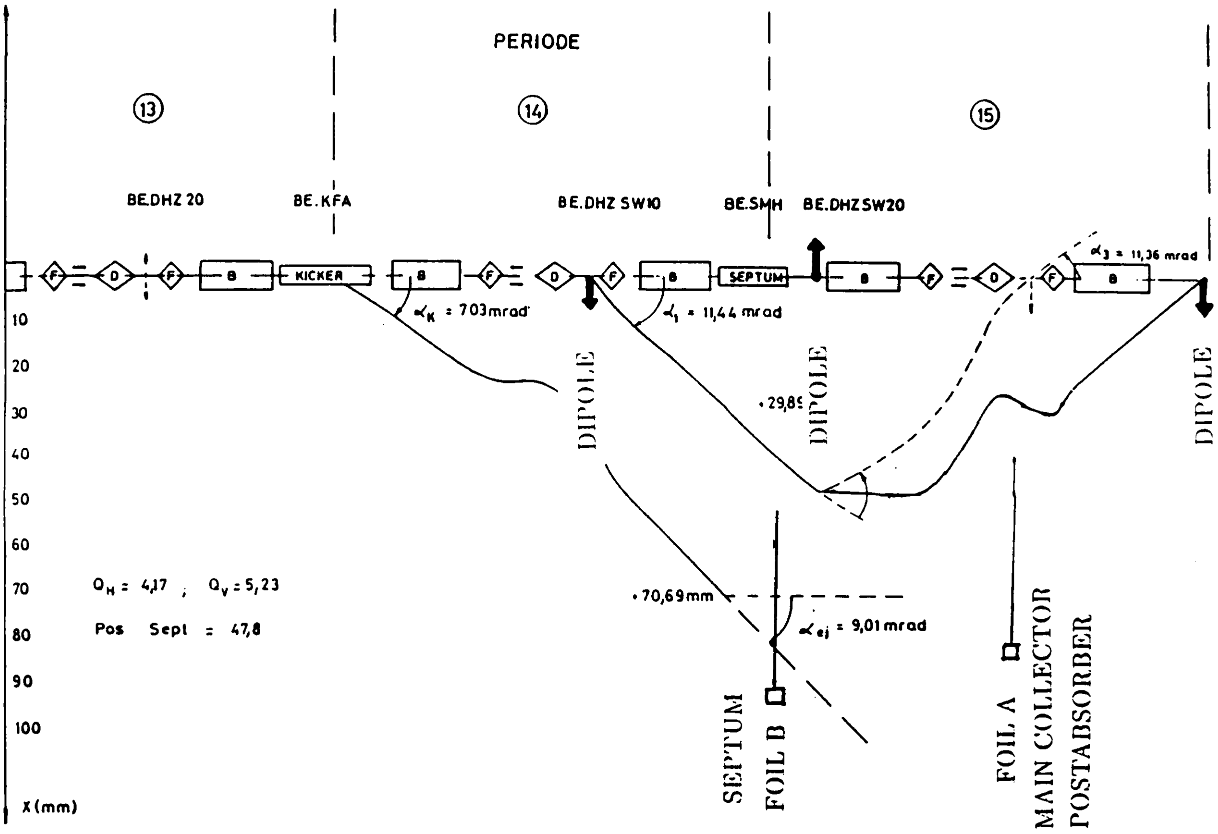

Figure 1: Layout of PSB Extraction System

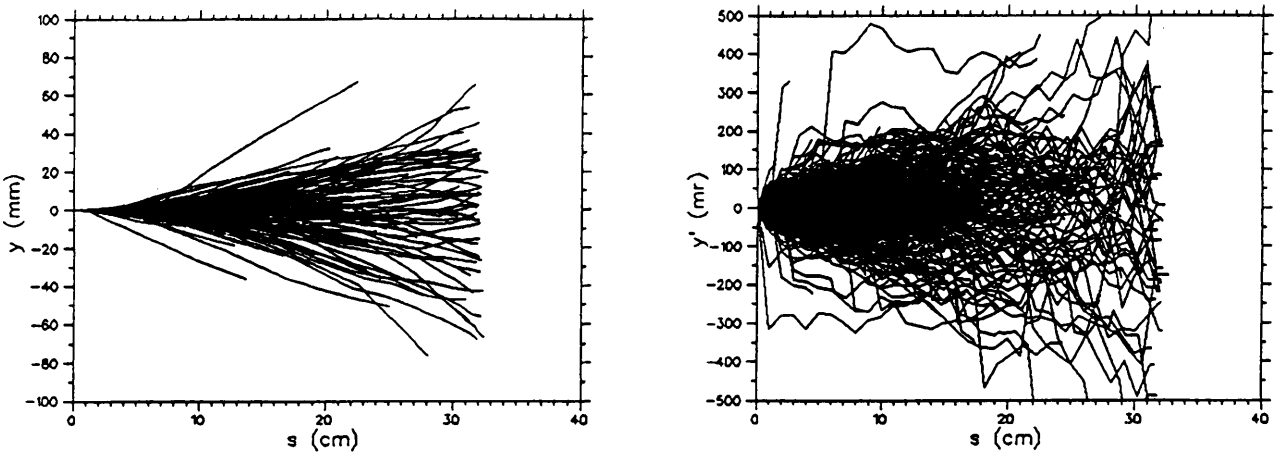

Figure 2: Tracks of 1 GeV Protons in Bulk Tungsten (1000 particles)