EFFICIENCY AND ROBUSTNESS OF THE PS2 COLLIMATION SYSTEM

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Abstract

A 50 GeV proton synchrotron machine is foreseen to replace the current PS (PS2) in the framework of the LHC complex upgrade. For high intensity beams, losses constitute a great concern in terms of hands-on maintenance and radioactivation. To minimize the uncontrolled losses all around the ring a collimation system is required. Lattice design and collimation studies are carried out in parallel in order to optimize the cleaning efficiency. To this end, the robustness of the system is tested for different lattice configurations against orbit errors and optics distortions.

INTRODUCTION

The PS2 will accelerate from a kinetic energy of 4 to around 50 GeV, a wide variety of beams. Among them the beam delivered for the CNGS experiment is the most intense with 1.28 $\times 10^{14} p^+$ translated to a maximum instantaneous power of 0.5 MW. This power is of the same order of magnitude as compared to other high intensity rings now in operation or commissioning [1, 2]. Beam losses is a primary concern in high intensity rings, as even a small fraction of the beam can radio-activate or, in a worse case scenario, damage parts of the accelerator.

The first step for designing the collimation system is to fix the geometrical aperture for all the magnetic elements which is closely related to the lattice optics functions. Next, the choice of the material for the primaries and secondaries is reviewed and the length of the collimators is chosen with respect to the global cleaning (in)efficiency of the system. Finally, the comparison of a one versus a two collimation system is presented along with some first estimations for the robustness of the collimation system against orbit distortions and beta variation.

PS2 LATTICE

Several PS2 lattice configurations have been studied [3], including lattices producing Negative Momentum Compaction (NMC), with imaginary transition energy. Transition crossing along with injection and ejection are the processes where most of beam losses occur (without taking into account other accidental beam loss. In the case of NMC lattices transition crossing is avoided improving the performance in terms of losses. The lattice used in this study has $\gamma_t = 20i$. The optics in that case are more relaxed ($\beta_{x,max} = 51$ m, $\beta_{y,max} = 54$ m, $D_{x,max} = 5.71$ m) than in other NMC configurations, and comparable to the ones of a FODO cell based lattice with real transition energy.

Geometrical Aperture

The aperture for the different lattice elements will be calculated according to [4] as in equation (1),

$$A_{x,y} = k_\beta (N_{x,y}\sigma_{x,y} + D_x \frac{\delta p}{p}) + CO_{x,y} + \delta^m_{x,y} + \delta^{al}_{x,y} \quad (1)$$

where $k_\beta = 1.1$ denotes the beta variation, $CO_{x,y} = 4$ mm is the peak closed orbit excursion, $\delta^m_{x,y} = \delta^{al}_{x,y} = 1$ mm are the aggregate mechanical and alignment tolerances of the vacuum chamber. High intensity machines, like the PS, are characterized with large beam sizes which diminish the available geometrical aperture. Scaling from the actual PS, the parameter is chosen as $N_{\sigma_{x,y}} = 4.5$. In Table 1 elements apertures for different lattice configurations are shown. The FODO lattice and the high γ_t have comparables apertures, significatly smaller than the two others NMC configurations.

Table 1: Horizontal/Vertical half aperture in dipoles, arc and straight section quadrupoles and sextupoles for different PS2 lattices.

Lattice	MB [mm]	QF/QD [mm]	LSF/LSD [mm]
FODO	(60,35)	(60,60)	(60,60)
NMC Low γ_t	(75,40)	(80,80)	(80,80)
NMC High γ_t	(60,50)	(65,65)	(65,65)
Hybrid NMC	(85,45)	(80,80)	(85,85)

COLLIMATION SYSTEM DESIGN

The characteristics to be taken into account in the choice of the collimators material are the absorption rate for increasing the cleaning efficiency and high robustness to resist beam impacts. At the same time, the material's conductivity should be large in order to reduce impedance. For low energies, materials with high atomic number Z (like Platinum or Tungsten) have been proposed [5], in order to increase the scattering angle. On the other hand their high cost and large production of secondary particles are certainly drawbacks. At this early stage of the design, Copper and Graphite are chosen, as they present a good comprise between cost and ease to be shaped. In table 2 are shown the main parameters related to scattering processes, where Z is the atomic number, A is the atomic mass, ρ is the density, $-\frac{dE}{dx}$ is the ionization energy and χ_0 is the radiation length.

Table 2: Material properties for different collimator candidates.

	Z	A $\left[\frac{g}{mol}\right]$	ρ $\left[\frac{g}{cm^3}\right]$	$-\frac{dE}{dx}$ $\left[\frac{GeV}{m}\right]$	χ_0 [m]
C	6	12.01	2.26	0.3978	0.1880
Cu	29	63.55	8.96	1.3530	0.0143
W	74	4.0	19.3	5.7900	0.0035

The collimation system should be able to clean the particles that drift out of the beam's core and populate its tails. These particles form the so-called halo and are candidates to be lost somewhere in the ring. The efficiency of the collimation is defined as the flux of particles absorbed in the collimation system (controlled losses) and the total number of particles that form the halo. For our simulations we consider the system inefficiency, $Ineff = \frac{\dot{N}_{p,lost}}{\dot{N}_{p,total}}$, which is defined as the ratio of the particles escaping the collimators and the total number of particles. In [6], the PS2 were scaled from the PS with a maximum global inefficiency allowed of 30%.

The two collimators are placed in an empty FODO cell straight section as shown in Figure 1, the optimal phase advance is given by $\mu_{opt} = \cos^{-1}\left(\frac{n_1}{n_2}\right)$ [7]. Considering $n_1 = 3.5$ and $n_2 = 4.0$ we get $\mu_{opt} = 28°$ and $152°$.

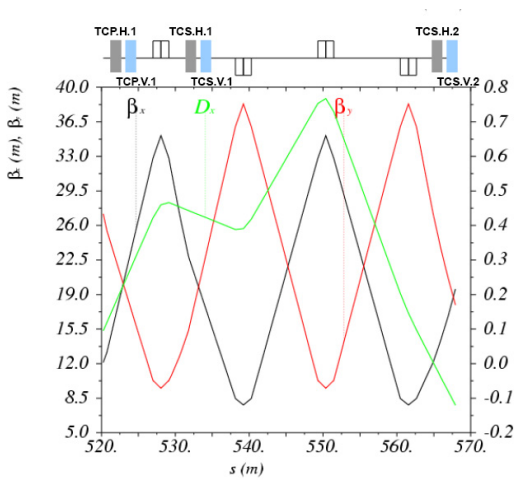


Figure 1: Optics and layout of the two stage collimation system.

Low energy particles when passing through the collimator material receive large kicks due to the multiple Coulomb scattering (mCs). This means that most of the losses will occur just after the primaries. The first step is to check whether it is possible to obtain the desired inefficiency with only a one-stage system. In Figure 2, it is shown that for a two-stage system, the 1W/m requirement is not fulfilled only in the quadrupole right after the collimator, while for a one-stage system, there are several hot locations. In addition, the global inefficiency drops by around a factor of 2 with a two-stage system (see Fig. 3).

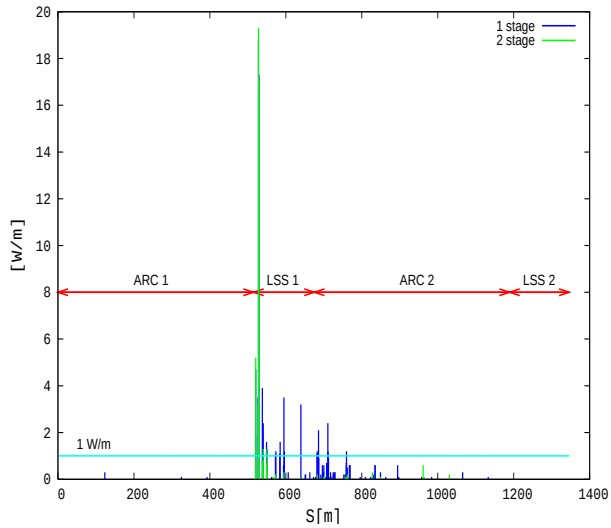


Figure 2: Loss distribution for one and two collimation system.

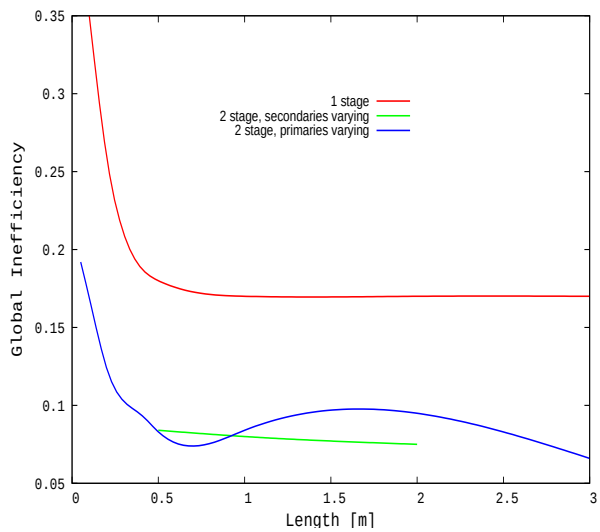


Figure 3: Efficiency for several one and two stage collimation systems.

In Figure 3, the global inefficiency is plotted as a function of the length of the collimators. For a one-stage collimation system the inefficiency does not improve for a length of the primaries above 0.5 m (red line). In a second step for a fixed length of the primaries of 0.5 m, we simulate for different length of the secondaries obtaining showing not a strong correlation (green line). Finally for a fixed

length of the secondaries of 1 m and different lengths of the primaries same behaviour as in one-stage is observed. This means that the addition on a second stage in the collimation system improves the inefficiency in a similar way quite independent of the length of the secondaries.

Robustness against errors

Collimators settings were calculated for a static orbit, but several processes can produce orbit distortions and beta beating without re-optimizing the collimators. In order to make sure that the inefficency is not affected these distortions have to be studied.

The orbit errors are simulated by misaligning the quadrupoles, in the horizontal plane $\Delta_x = 100\mu$m and in the vertical $\Delta_y = 50\mu$m and distributed according to a gaussian function. The error configuration producing the maximum horizontal orbit distortion is used for the simulations.

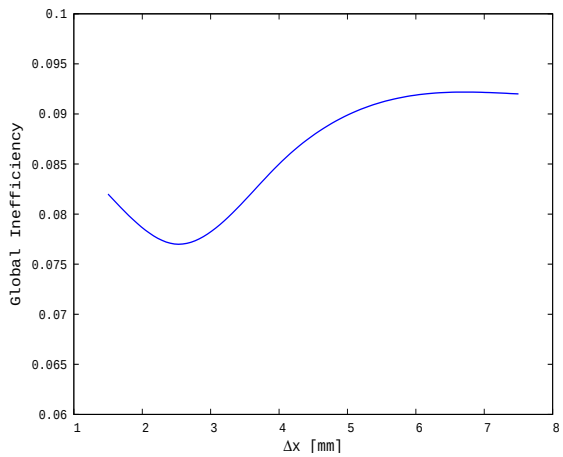


Figure 4: Global ineffiency with respect to several orbit errors.

As it can be observed in Figure 4, the inefficiency is barely affected by the errors, going up to 9% inefficiency for 7mm.

In the presence of a quadrupole field (gradient) error at s_0, the betatron beta function is modified according to

$$\frac{\Delta\beta}{\beta}(s) = \frac{\Delta k L \beta_0 \cos(2\pi Q - 2|\mu(s) - \mu_0|)}{2\sin(2\pi Q)} \qquad (2)$$

where Δk is the gradient error, L is magnet length, $\mu(s)$ is phase function and Q is the tune. A beating in the optics can produce a decrease in the aperture available and taking into consideration that the aperture retraction between the primaries and the secondaries is $n_1 - n_2 = 0.5\sigma$, it is necessary to check whether secondaries can become primaries and how the inefficiency is modified.

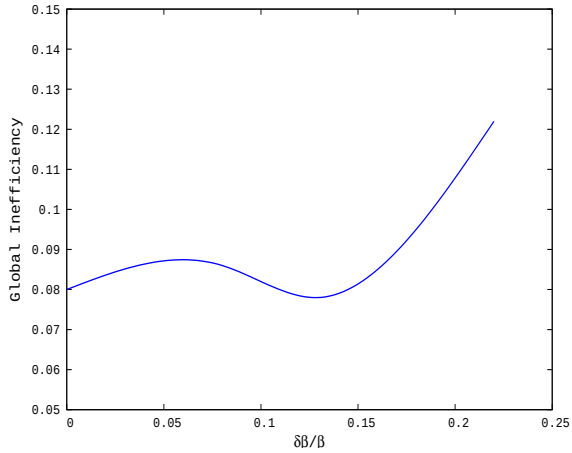


Figure 5: Global ineffiency versus beta beating in the horizontal plane.

In Figure 5 it is shown again that the inefficency is not changed significantly reaching 12% for a maximum beta beating of 20%. Even for high beta beatings the retraction between both stages seems to be enough for assuring the correct function of each stage.

CONCLUSIONS

Simulations in preliminary lattice configuration have shown that a two stage collimation system with the correct phase advances provide an inefficiency that assures the 1 W/m in most the accelerator apart from a few hot areas in the collimator region. It has been further noticed that beam collimation at low energies is a one turn process after the particle touch the collimator and so the absorption rate increase with the length of the primaries. An insignificant amount of particles manage to complete one turn after the collision. In addition orbit distortion and beta beating studies have shown that the inefficiency is only slightly increased.

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