COLLIMATION CONSIDERATIONS FOR PS2

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Abstract

A main concern in high intensity rings is the evaluation of uncontrolled losses and their minimization using collimation systems. A two-stage system is foreseen for the PS2. The fundamental design strategy for the collimation design is presented, including machine apertures and collimator materials. The dependence of the collimator system efficiency on the primary scraper length and the impact parameter of the particle is evaluated for different collimator locations. Beam loss maps are finally produced displaying the detailed power load deposited around the ring.

INTRODUCTION

The PS2 is a high intensity machine which will accelerate beams with maximum intensity of 1.0×10^{14} protons to a final kinetic energy of 50 GeV translated in an instantaneous power at extraction of ~400 kW. Even a small fraction of uncontrolled beam loss may radio-activate and harm the ring elements. In order to permit hands-on maintenance and fast intervention in the accelerator, a fractional power of 1W/m [1] is considered as the maximum acceptable uncontrolled beam loss level. A two-stage collimation system is under study to localize the losses in a confined area. Due to the machine racetrack shape, there is no space for a dedicated collimation insertion and the collimators will be placed in one of the two long straight sections (LSS), sharing the space with magnetic elements. One of the important parts of the collimator strategy is to compare the efficiency of the collimation system with respect to its position. At the same time, the length of the primary collimators for different materials is chosen and the system's efficiency is evaluated for different impact parameters, which depend strongly on the halo growth rate.

COLLIMATOR APERTURES, MATERIALS AND LENGTH

In order for a two stage collimation system to be efficient, the secondary collimators should not become primaries under any circumstances so the relative retraction between both should be large enough. The primary collimators are placed in terms of rms beam size at $n_1 = 3.5\sigma$, in order to avoid interaction with the core of the beam. Considering a maximum beta-beating of 15% the minimum aperture for the secondaries is at $n_2 = 4\sigma$. Following the same principle the machine elements are set to $n_3 = 4.5\sigma$. These magnet apertures are similar to the actual PS, considering the injected emittance of the high-intensity beams.

Graphite (low Z) and copper (high Z) are the two material options considered for the collimators. The rms angle due to Multiple Coulomb Scattering as a function of the length of material traversed is given by [2]

$$\theta_0 = \frac{13.6MeV}{\beta cp}\sqrt{\frac{x}{\chi_0}}\left(1 + 0.038\ln\frac{x}{\chi_0}\right) , \qquad (1)$$

where $\frac{x}{\chi_0}$ is the thickness of the material in terms of radiation length χ_0. This formula shows that the kick grows inversely with the radiation length of the material. Considering that the radiation length for C is approximately 13.5 times higher than the one of Cu, the minimum required material length which gives a sufficient kick for reaching the secondary collimators is 1mm for copper and 20mm for graphite. The upper limit for this kick is set by the acceptance of the machine, which is reached with a scraper of 2mm of copper and 30mm of graphite, respectively. In all the simulations the former set of scraper lengths was used.

For the secondaries a length of 1m is considered in order to stop the out-scattered particles. As for both materials this thickness is several times the interaction length, so the probability for the particles to be absorbed is high enough. The final length adjustment and material choice should be guided by energy deposition studies for evaluating the mechanical integrity of the collimators.

COLLIMATION SYSTEM LAYOUT

The latest PS2 lattice can be found in [3]. The ring is of racetrack shape and the two arcs are filled with negative momentum compaction cells. Each LSS consists of a triplet in the middle and two FODO cells at each side. In the absence of a dedicated insertion, the LSS are the alternative areas for placing the collimator system. One LSS (denoted LSS1) is dedicated to injection and extraction [4] and almost completely filled with the required elements whose location is shown in Fig. 1. In this section, the collimation can profit from the existing beam dump for the H^-, that could be used as secondary collimator. The other LSS (LSS2) accommodates the RF system. The RF cavities can be placed in the upstream part of the section leaving the rest of the cells for the collimators. These two location options will be compared with respect to their efficiency.

Considering scattering in only one plane, the optimal phase advances between primary and secondary collimators are given by [5]

$$\mu_1 = \cos^{-1}\left(\frac{n_1}{n_2}\right), \qquad \mu_2 = \pi - \mu_1 , \qquad (2)$$

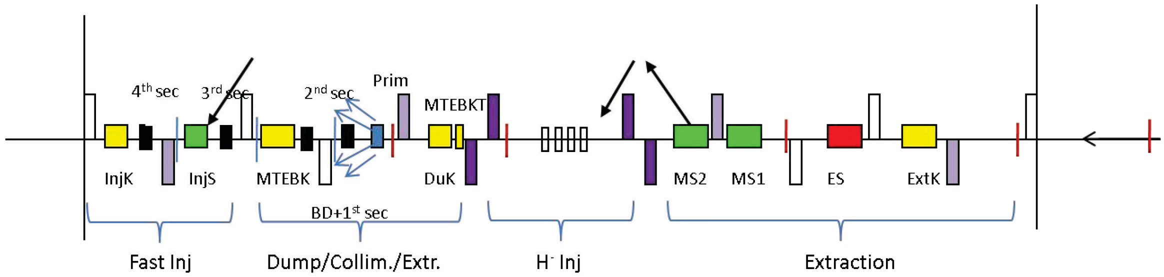

Figure 1: Long straight section layout, including collimators, injection and extraction elements.

Table 1: Main Collimator Parameters

Name	β_x [m]	β_y [m]	μ_x [deg]	μ_y [deg]	N_σ	Half apert. [mm]
TCP.H.1	30.5	17.9	0.0	0.0	3.5	32.6
TCP.V.1	24.5	20.4	2.6	3.5	3.5	19.5
TCS.H.1	13.3	28.6	18.6	14.8	4.0	24.6
TCS.V.1	11.0	31.6	25.2	17.2	4.0	27.7
TCS.H.2	22.8	16.5	83.2	41.3	4.0	32.3
TCS.V.2	26.9	14.2	85.8	46.1	4.0	18.6
TCS.H.3	11.3	33.8	116.0	80.4	4.0	22.7
TCS.V.3	9.5	38.8	123.1	82.2	4.0	30.7
TCS.H.4	11.3	35.6	153.5	88.9	4.0	22.6
TCS.V.4	13.5	31.3	158.7	91.1	4.0	27.6

which gives $\mu_1 = 28°$ and $\mu_2 = 152°$. The maximum phase advance available in each plane is $\Delta\mu_x = 208°$ and $\Delta\mu_y = 141°$, so it is not possible to fullfil the optimal phase advances in the vertical plane. However the scattering processes take place in two dimensions, thus additional secondary collimators are needed in order to increase the cleaning efficiency. The optics in both LSS are identical and the relevant parameters are displayed in Table 1.

TRACKING SIMULATIONS

The collimation system should be able to clean the particles that drift out of the beam core and populate the tails. These particles form the so-called halo and may be lost somewhere in the ring. The efficiency of the collimation system relates the flux of particles absorbed by the collimator jaws and the total number of particles. Conversely, the inefficiency is defined as the beam power lost in any other element than a collimator with respect to the total halo power

$$\eta_{\text{eff}} = 1 - \eta_{\text{ineff}} = 1 - \frac{\dot{N}_{p,\text{lost}}}{\dot{N}_{p,\text{total}}} \,. \qquad (3)$$

In order to estimate the collimation system inefficiency, tracking of 10^4 particles is performed for 100 turns through the lattice thin elements model. The collimator scattering processes are simulated with K2 and the particle positions are compared with a detailed aperture model [6]. This method allows to estimate the power deposited in each element considering a total halo power of 4kW, representing a few percent of the injected high intensity beam.

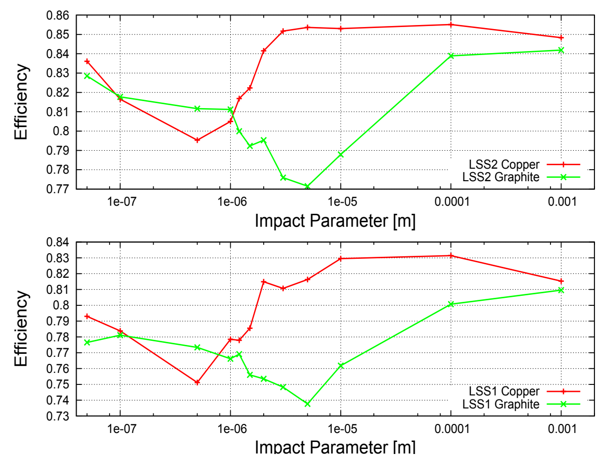

Figure 2: Global efficency for different impact parameters with collimators in LSS1 (bottom) and in LSS2 (top).

Impact Parameter

The halo distribution depends strongly on the emittance growth rate. Several processes influence the halo formation such as space charge, magnet imperfections and non-linearities. The faster the diffusion and the emittance growth the bigger is the impact parameter. As the halo growth rate is generally unknown, the collimation inefficiency has to be evaluated versus different impact parameters in order to understand the robustness of the cleaning system for the two materials considered.

In Fig. 2 the collimation efficiency is plotted versus the impact parameter for copper (red curve) and graphite (green curve), when placing the collimators in LSS1 (bottom) and LSS2 (top). The efficiency of copper seems to be higher than graphite, especially for impact parameters of 10μm. For higher or lower impact parameters than 10μm, the efficiency of the graphite increases. This may be explained by the fact that at lower impact parameters the scattering angle is small enough to let the particles escape the

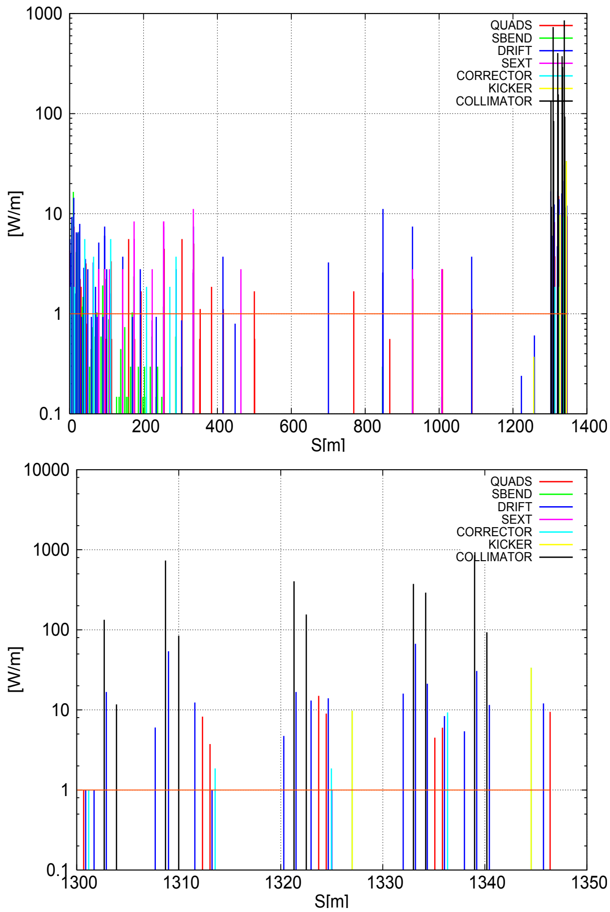

Figure 3: Beam loss maps when collimators are placed in LSS1 (top) and zoom around the collimator section (bottom).

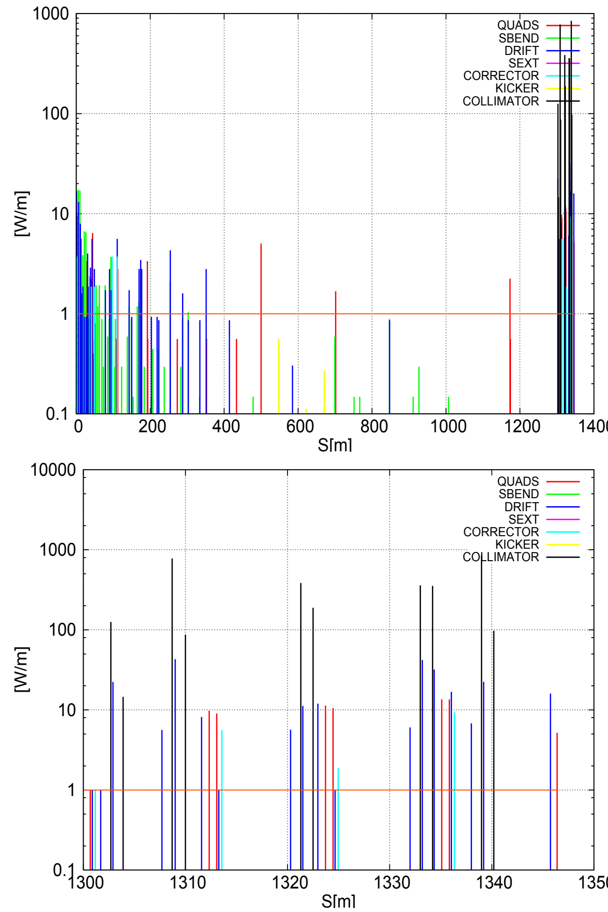

Figure 4: Beam loss maps when collimators are placed in LSS2 (top) and zoom around the collimator section (bottom).

system and return to it after several turns with larger impact parameters. In that case, the scattering angle is large enough to drive the particles towards the secondary collimator [7]. The minimum efficiency results when the scattering is low enough to let the particles escape for several turns but large enough to drive the particles towards machine elements with aperture limitations. The same behavior is shown in the case of copper, although the minimum is displaced towards lower impact parameters. As it is also revealed in the following section by the detailed beam loss maps, the efficiency is higher when placing the collimators in LSS2 than in LSS1.

Beam Loss Maps

In order to protect the machine elements and allow hands-on maintenance a maximum of 1 W/m [1] distributed all around the machine are accepted. Beam loss maps for collimators placed in LSS1 and LSS2 are presented in Figs. 3 and 4. The bottom of both plots presents the beam loss details on the respective collimator sections. For both cases, the collimators are made of graphite and 1μm impact parameter is considered. Although the overall efficiency is very good, there are several locations around the ring where the deposited beam power exceeds the target of 1W/m. The loss pattern around the ring is quite similar in both cases, where the highest losses occur around the collimation section. The zoomed plots reveal the clear difference between the two sections. The beam loss patterns are almost identical in the two collimation areas apart from the yellow peaks in LSS1 corresponding to injection and extraction elements. This clearly demonstrates that the placement of the collimators in LSS2 is superior with respect to cleaning efficiency and machine protection.

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