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DESIGN STUDY AND CONSTRUCTION OF A TRANSVERSE BEAM HALO COLLIMATION SYSTEM FOR ATF2

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Abstract

The feasibility and efficiency of a transverse beam halo collimation system for reducing the background in the ATF2 beamline has been studied in simulations. In this paper the design and construction of a retractable transverse beam halo collimator device is presented. The wakefield induced-impact of a realistic mechanical prototype has been studied with CST PS, as well as the wakefield beam dynamics impact by using the tracking code PLACET.

INTRODUCTION

ATF2 is a Beam Delivery System (BDS) built after the ATF Damping Ring (DR) providing a scaled-down version of the Future Linear Collider (FLC) Final Focus System (FFS) [1]. The two main goals of ATF2 are to obtain a vertical beam spot size at the virtual IP of 37 nm and to stabilize the beam at the nanometer level. The control and reduction of the beam halo that could be intercepted in the beam pipe producing undesired background is a crucial aspect for FLC and ATF2. A beam halo collimation system in ATF2 will play an essential role in the reduction of the background noise that could limit the performance of key diagnostic devices around the final focal point (IP), especially the Shintake Monitor (IPBSM) used for measuring the nanometer level vertical beam sizes and the recently installed Diamond Sensor (DS) in the post-IP beamline to investigate the beam halo distribution [2, 3]. A first feasibility study was done and reported in [4]. From these studies a vertical collimator system has been considered as the first priority. In this paper we present a first 3D mechanical design as well as a transverse wakefield study for the realistic 3D prototype by using the 3D electromagnetic solver CST PS [5]. Also the wakefield impact on the orbit and beam size has been evaluated by using the tracking code PLACET [6].

DETAILED 3D MECHANICAL DESIGN

A detailed version of the 3D mechanical design based on the optimized geometrical parameters reported in [4] and previous experiences in [7–10] is shown in Fig.1. The collimator jaws will be made of Copper (Cu) and the rest of the components including the transition part will be made of Stainless Steel (SS) because of stiffness and assembly considerations. The seal of the rectangular chamber will be made with indium wires and other seals will be Cu seals for DN40CF flanges. An important part of the collimation device will be the retractable movable system with a expected precision of $\pm 10\mu m$. Two step by step EMMS-ST-42-S-...-G2 motors will be used to move independently the two rectangular vertical tapered jaws. In Fig.1 (right) a more detailed picture of the movers and slides is shown. The collimator is under construction and it will be installed at ATF2 in the 2015 fall run.

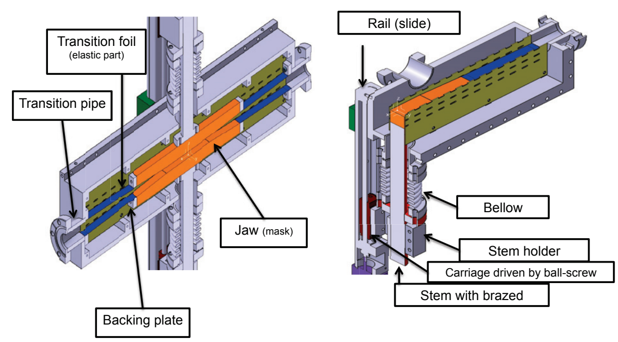

Figure 1: Detailed 3D mechanical design.

WAKEFIELD IMPACT STUDY: CST PS NUMERICAL SIMULATIONS

In this section we present a wakefield impact study of a realistic rectangular vertical tapered halo collimator structure based on the 3D mechanical design of Fig.1. The collimator system will add an impedance on the beamline that could perturb the beam stability, therefore it is important to minimize the wakefields and to demonstrate that the impact on the beam can be tolerated in terms of beam stability. The model simulated with CST PS is shown in Fig.2. The 3D model is divided in 3 millions of hexahedral mesh cells. The electromagnetic fields are exited by a gaussian bunch of 7 mm bunch length, 1 pC bunch charge and 1 mm offset in the vertical plane. The frequency up to which the fields will be taken into account for the wake potential calculation was set to 20 GHz. The main volume of the model is set to vacuum and it is surrounded by perfectly conducting material. The jaws are made of Cu and the material of the transition foil has been studied. Simulations have been made with SS and Aluminium (Al) transition foils. The resulting wakepotential can be seen in Fig.3. The impact of the material on this component of the collimator is small therefore SS has been

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chosen because of mechanical reasons. The other components of the collimator are also made of SS.

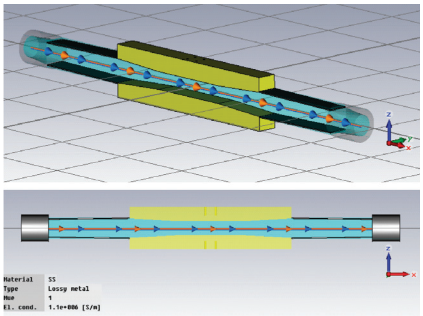

Figure 2: CST PS realistic model of the rectangular vertical tapered collimator.

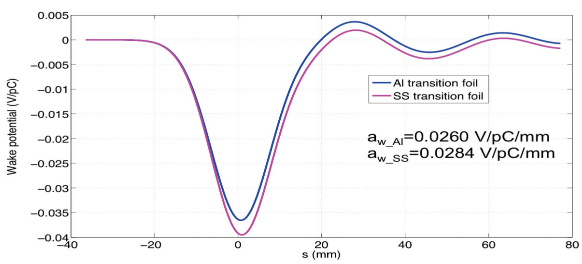

Figure 3: SS and Al transition foil wakepotential comparison.

The resulting wakepotential for the realistic model in Fig.2 (top) and the calculated average transverse dipole kick (bottom) as a function of the smallest half aperture of the collimator, a, are shown in Fig.4. For 5mm smallest half aperture of the collimation system corresponding to the required aperture to avoid any losses at the last bending magnet of the post-IP beam line the average transverse dipole kick is $0.028V/pC/mm$, which is three times smaller than the impact of the ATF2 reference cavities [11].

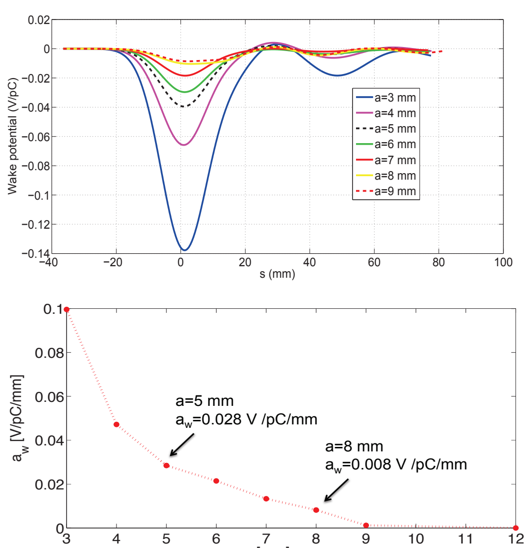

Figure 4: Wakepotential (top) and average transverse dipole kick as a function of a (bottom).

WAKEFIELD BEAM DYNAMIC STUDIES

Linear Approximation

The average dipolar wakefield kick induced by the collimation system is given by:

$$a_w = \frac{1}{q\Delta y}\int_{-\infty}^{+\infty}\rho(z)W(z)dz \tag{1}$$

Then, the orbit distortions at the IP due to the average dipole kick induced by the collimation system in the linear approximation can be estimated as:

$$\Delta y^* = \sqrt{\beta\beta^*}\sin\Delta\phi\frac{qe}{E}\Delta y a_w \tag{2}$$

where q is the bunch charge, Δy is the vertical beam offset that excites the wakefields, $\rho(z)$ is the beam distribution (a gaussian distribution is considered in this study) and $W(z)$ is the wake potential in units of V/pC calculated with CST PS, E is the energy of the beam, β and β^* are the twiss functions at the location where the kick is applied and at the IP, $\Delta\phi$ is the phase difference between the collimator position and the IP.

And the beam size growth at the IP, $\Delta\sigma_y^*$, can be estimated in the linear approximation as:

$$\Delta{\sigma_y}^* = \sqrt{\beta\beta^*}\sin\Delta\phi\frac{qe}{E}\Delta y\sigma_w \tag{3}$$

where the factors are the same described previously and σ_w is the spread of the wake potential obtained with CST PS calculated as:

$$\sigma_w = \left[\frac{1}{q(\Delta y)^2}\int_{-\infty}^{+\infty}\rho(z)W^2(z)dz - a_w^2\right]^{1/2} \tag{4}$$

.

In this case the ten times the nominal β_x^* and the nominal β_y^* optics ($10\beta_x \times \beta_y$) is considered with β=6640m at the middle location of the collimation system and $\Delta\phi$=$5\pi/2$. The calculations have been made for a collimator system with a tapered angle, α, of 3°, a flat part, L_F, of 100 mm, a collimator width in the non collimation plane, h, of 12 mm, a maximum half aperture, b, of 12 mm and Cu jaws. The results of the calculations can be seen in Fig.5 and Fig.6.

PLACET Tracking Code Simulations

In the tracking code PLACET the wakefield impact of a rectangular tapered collimator is implemented based on analytical models [12,13]. The PLACET tracking code used has been modified according to the analytical models described in [14] in order to have a good agreement with the linear approximation calculations and the CST PS simulations [15]. Both dipolar and quadrupolar contributions dependent o the longitudinal direction are taken into account [16]. The PLACET tracking simulations has been done for the same optics as the linear calculations. A gaussian electron beam is

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generated with an energy of 1.3 GeV and and energy spread of 0.08%. The beam is divided in 20 slices in the longitudinal plane with 5000 macroparticles in each slice. No coupling between x-y planes has been taken into account. Multipoles have been taken into account but not misalignments. The collimator description used for these studies is the same used for the linear calculations.

In Fig.5 the linear calculations and the PLACET simulations of the orbit displacement (top) and beam size growth (bottom) as a function of the smallest half aperture of the collimator are compared. The linear calculations and the PLACET simulations are compatibles. For a=5 mm the bunch is displaced at the virtual IP around 30% of the vertical beam size at the IP corresponding to 37 nm while for a=8 mm the impact is about 10%. For a=5 mm the beam size growth at the IP is about 16% of the vertical beam size at the IP and for a=8mm is about 1%.

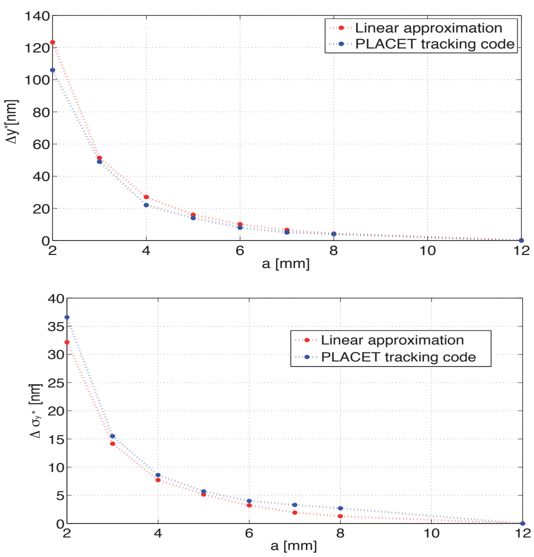

Figure 5: Linear approximation and PLACET tracking simulations of the orbit displacement (top) and beam size growth (bottom) at the IP as a function of *a* and 1 mm beam offset.

In Fig.6 the linear calculations and the PLACET simulations of the orbit displacement (top) and the beam size growth (bottom) as a function of the beam offset are shown for values of 5 and 8 mm of the smallest half aperture of the collimator. The orbit displacement has a linear dependence with the beam offset both in the linear approximation and in the PLACET simulations. However a non linear dependence can be seen in Fig.6 (bottom) of the beam size growth simulated with PLACET with the beam offset due to the quadrupolar contribution which is also implemented in the tracking code PLACET but not taken into account in the linear calculations. The quadrupolar contribution is important in our calculations due to the fact that the collimator is located at high β location where the vertical and horizontal beam size are σ_y=0.3mm and σ_x=0.5mm respectively. Therefore in order to perform precise calculation of the wakefield impact on the beam size growth the tracking code PLACET has to be used. For 5mm half aperture of the collimator and a beam offset of 500μm the impact on the orbit is 13% of the vertical beam size at the IP and on the beam size the impact is about 10% (from PLACET simulations). If we consider a smaller beam offset of 100μm the impact on the orbit is reduced to a 3% of the vertical beam size at the IP while it is almost the same value for the beam size growth corresponding to 9% (from PLACET simulations) of the vertical beam size at the IP. The top and bottom jaws are independently adjustable and 100μm alignment could be possible.

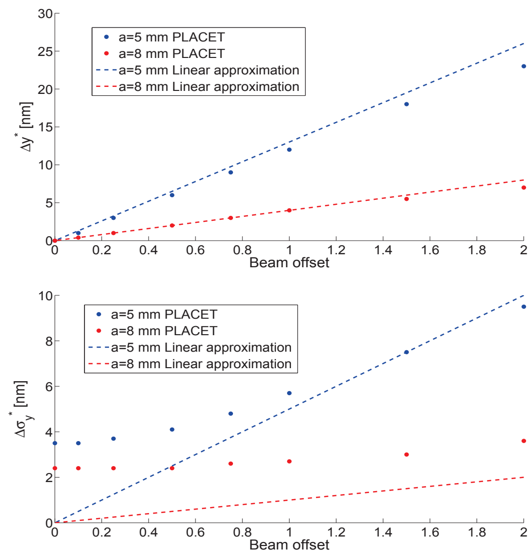

Figure 6: Linear approximation and PLACET simulations of the orbit displacement (top) and beam size growth (bottom) as a function of the beam offset for a=5 mm and a=8 mm.

SUMMARY AND FUTURE WORK

A vertical retractable rectangular halo collimator type for ATF2 has been designed. The geometry and materials of the vertical collimator prototype has been optimized in terms of wakefields. The collimator system is been constructed and it will be installed at ATF2 in the 2015 fall run. A wakefield study of the realistic 3D mechanical design has been done. Furthermore the orbit distortion and beam size growth by using linear approximations and the tracking code PLACET has been studied. From these studies we could conclude that the tracking code PLACET is necessary if we want to estimate the beam size growth due to the quadrupolar contribution dominant for small beam offsets. For 5mm half aperture the wakefield impact on the orbit amplification and beam size growth is lower than 10% of the beam size at the IP if alignment at the level of 100μm is achieved. The top and bottom jaws of the collimator are independently adjustable and 100μm alignment could be possible. In addition tracking studies considering the emission of secondary particles and halo regeneration with BDSIM [17] will be made.

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