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A Precise Beam Dynamics Model of the PSI Injector 2 to Estimate the Intensity Limit

A PRECISE BEAM DYNAMICS MODEL OF THE PSI INJECTOR 2 TO ESTIMATE THE INTENSITY LIMIT

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Abstract

We describe a precise beam dynamics model of the production set up of the Injector 2 Cyclotron at the Paul Scherrer Institut (PSI). Injector 2 is a 72 MeV separate-sector cyclotron producing a high intensity proton beam up to 3 mA CW, which is then injected into the 590 MeV Ring Cyclotron. The model includes space charge and is calculated for matched initial conditions. The presented steps are required to estimate the limits to the intensity obtainable from Injector 2. The precise beam dynamics model is based on the OPAL (Object Oriented Parallel Accelerator Library) simulation code, a tool for charged-particle optics calculations in large accelerator structures and beam lines including 3D space charge.

INTRODUCTION

A better understanding of space charge effects in isochronous cyclotrons, such as the Injector 2, is of great interest. The Injector 2, shown in Figure 1, is a pre-accelerator delivering a high intensity 72 MeV proton beam into the 590 MeV Ring cyclotron. The cyclotron is composed of four sector magnets and four accelerating cavities with an injection energy is 870 keV, emittance of 2π mm $\times$ mrad and DC current of 11 mA. The accelerator operates at a frequency of 50.63 MHz.

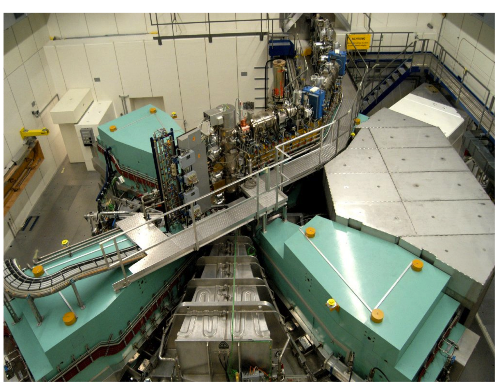

Figure 1: PSI Injector 2.

Due to space charge forces combined with radial and longitudinal coupled motion, a stationary compact beam is developed within the first several turns of the injector and remains quasi-stationary until extraction [1]. There is currently no self-consistent theory/model to match bunched beams with non-linear space charge in cyclotrons we therefore rely on numerical methods to simulate these effects. For this study we use a precise beam dynamics model based on the Object Oriented Parallel Accelerator Library (OPAL) simulation code. Opal is a tool for charged-particle optics calculations in large accelerator structures and beam lines and includes 3D space charge [2].

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3D BEAM DYNAMICS MODEL OF INJECTOR 2

The Injector 2 currently operates with two double gap resonators located 180 degrees apart and two single gap 3rd harmonic flat top cavities used as additional accelerating cavities. The machine accelerates from 870 keV to 72 MeV in 80 ± 1 turn with peak accelerating voltages of 0.36 MV and 0.12MV.

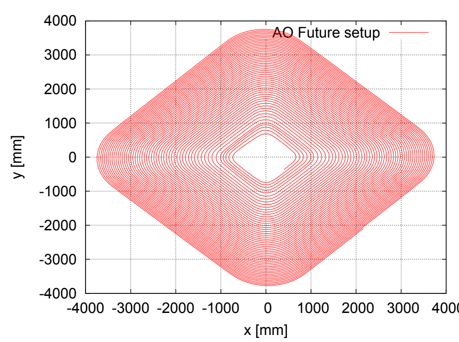
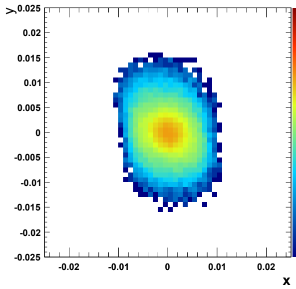


Figure 2: Accelerated Orbit of PSI Injector 2 future set up.

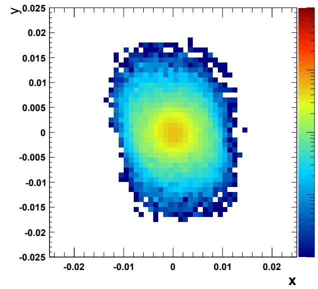
A 3D space charge model of that set up reaches the desired energy in 76 turns, with initial energy of 2 MeV (from 870 keV approx. 79 turns) and accelerating voltage matching the operating one. In this case, the injection radius is 541.191 mm, with RF of 82.9 degrees and azimuthal angle of -47.5.

Planned upgrade of the Injector 2 will involve replacing the 3rd harmonic cavities with single gap resonators, similar to those already installed, allowing higher acceleration voltages. In this set up all cavities run at the same voltage, for the 3D simulations voltage was chosen to be 0.365 MV. A bunch is injected at 542.892 mm radius at RF 24.1 degrees .

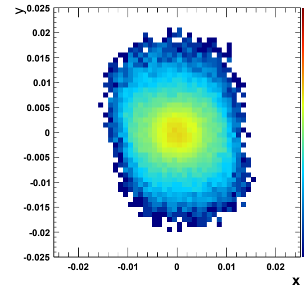
To find the best initial conditions an optimising python script embedded into OPAL was used allowing a range of values for the injection parameters and calculates a set of solutions that gives the best turn separation and accelerated orbit. The optimisation is performed using single particle tracking. Figure 2, depicts Accelerated Orbit (AO) of the future set up.



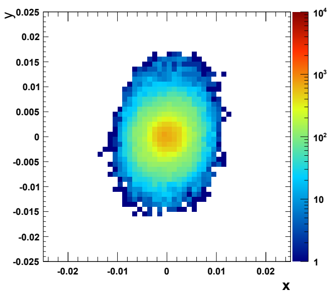
(a) 2mA PS



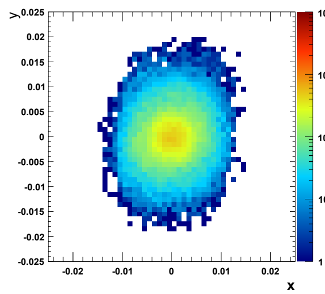
(b) 4mA PS



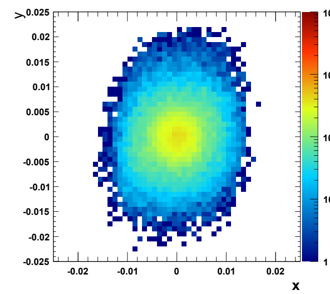
(c) 6mA PS



(d) 2mA (NS)



(e) 4mA NS



(f) 6mA NS

Figure 3: Spacial distribution of the bunch in the x-y plane (in meters). (a-c) shows it for production setup (PS) and (d-e) for future set up for 2, 4 and 6mA beam currents.

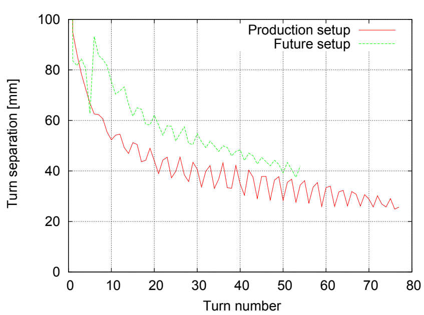


Figure 4: Comparison of turn separation.

Introducing two single gap resonators significantly reduces the number of turns from 76 to 56 at the same time increasing the final turn separation by approximately 50 % as shown in Figure 4.

RESULTS

The simulations were performed using 50k particle bunch with 4σ cut to temporarily recreate the collimation system. In this paper we present results for currents ranging from 0.5 mA to 6 mA. Matched distributions with linear space charge used in simulations were obtained using a theoretical model by Baumgarten [3, 4] and is described in more detail in past proceedings [5].

Figure 3 shows the particle distribution in the x y plane of the bunch after full acceleration for both present and future set ups with 2, 4 and 6 mA currents. Both models give comparable results but the future setup has significantly decreased turn number and increased turn separation which will play a key role in extraction, here omitted.

CONCLUSIONS AND FUTURE WORK

Initial matched distribution works well for 76 turn operation and future set up looks promising with nearly double increase in turn separation.

The presented model will be validated with data from radial profile measurements and loss rates from the collimators and the electrostatic septum in the Injector. Based on the 3D model we will estimate true intensity limit of this machine and comment on future operation modes.

ACKNOWLEDGMENTS

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