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A PRECISE BEAM DYNAMICS MODEL OF THE PSI INJECTOR 2

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Abstract

The Injector 2 at Paul Scherrer Institut (PSI) is a 72 MeV separate sector cyclotron producing a high intensity proton beam up to 3 mA CW, which is subsequently injected to the 590 MeV Ring Cyclotron. The injection energy of the pre-bunched beam is 870 keV at an intensity of 10 to 11 mA. In this paper we describe initial conditions for the Injector 2 to obtain a matched beam with space charge that is coupled in the transverse-longitudinal plane. 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

The Injector 2 (see Figure 1) is a high intensity proton cyclotron producing high quality beam reaching 72 MeV that is then injected into the 590 MeV Ring cyclotron. It is composed of four sector magnets and accelerating cavities. The injection energy is 870 keV with 2π mm $\times$ mrad beam emittance and a dc current of 11 mA. The accelerator operates at a frequency of 50.63 MHz .

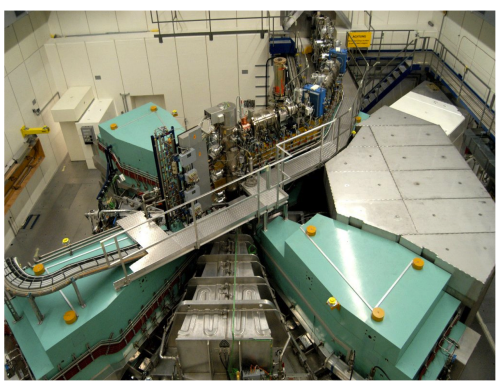

Figure 1: PSI Injector 2.

The better understanding of space charge effects in isochronous cyclotrons, such as the Injector 2, is still of great interest. 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. Currently, there is no self-consistent theory/model, to match a bunched beams with non-linear space charge in cyclotrons, hence we have to rely on numerical methods. For this purpose, we use open source code OPAL [1]. In the first stage of this research the stationary initial distribution with space charge based on theoretical model Baumgarten [2, 3] is found.

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INITIAL CONDITIONS

Tune Diagram and Accelerated Equilibrium Orbit

The calculations for the tunes ν_r and ν_z, as shown in Figure 2, matching well the Injector 2 design values. In this calculation we used measured mid-plane fields. The Accelerated Equilibrium Orbit (AEO) is shown in Figure 3.

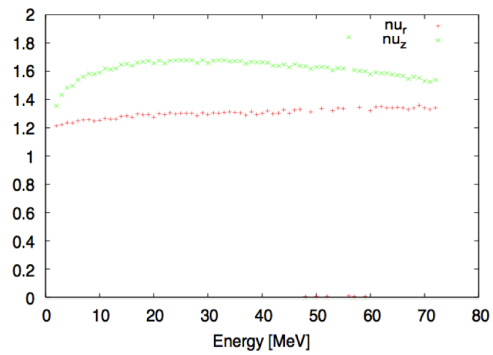

Figure 2: Tune diagram for Injector 2.

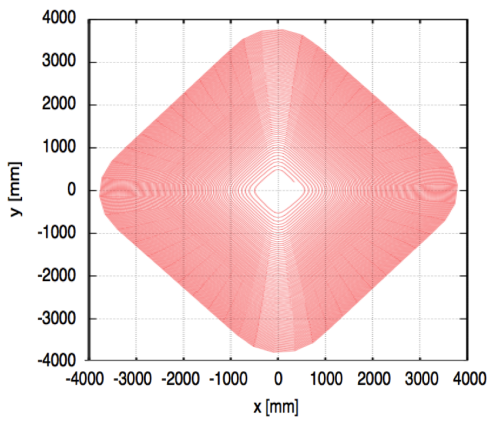

Figure 3: AEO of Injector 2.

Initial Matched Distribution with Linear Space Charge Forces

We obtained a matched sigma-matrix σ for given emittances iteratively using the linearized model as described in [2, 3].

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The decoupling transformation of the "symplex" (i.e. "Hamiltonian matrix") is $S = \sigma\gamma_0$, where γ_0 being the symplectic unit matrix [3].

The decoupling results are in $S' = RSR^{-1}$. N random vectors ψ_k are generated with independent variables of Gaussian distribution. We then scale with the corresponding variances given by the root of the diagonal elements of σ_0. The covariance matrix of the produced random vectors $\sigma_0 = -S'\gamma_0$ followed by inverse transformation $S = R^{-1}S'R$, gives the desired correlated distribution

$$\psi_k = R^{-1}\psi_k \,. \tag{1}$$

This theoretical model was already successfully used for the high intensity injector cyclotron in DAEδALUS project [4].

RESULTS

Simulations were performed, with matched initial distribution from Eq. (1) at 2 MeV. The beam current was set to 2.2 mA with 2π mm $\times$ mrad beam emittance. The closed orbit for a single particle is shown in Figure 4. The bunch was coasting at 2 MeV orbit for 20 turns to investigate the bunch size and phase space evolution (see Figure 5). As it can be seen in Figure 6, bunch size in horizontal and longitudinal plane and its phase space are nearly stationary. These results are satisfactory providing that we have used a linear space charge model to generate initial distribution, whereas subsequent tracking with OPAL includes the nonlinear effects.

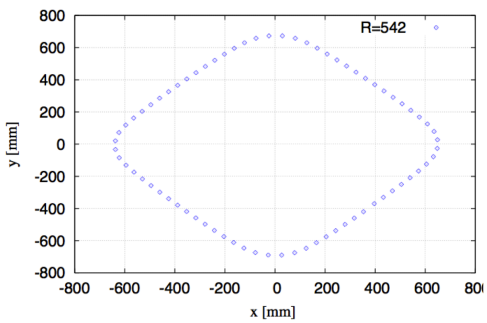

Figure 4: 2 MeV single particle turn.

CONCLUSION AND OUTLOOK

A sample Gaussian random distribution was successfully generated using linear space charge model. The results show that the distribution stays stationary after the beam is allowed to coast for a number of turns.

The next steps toward a full 3D model includes: acceleration, collimation and apertures which then has to be validated against the experimental data and the comparison to radial density profiles. The inclusion of the aperture will enable us to study uncontrolled losses observed during operation.

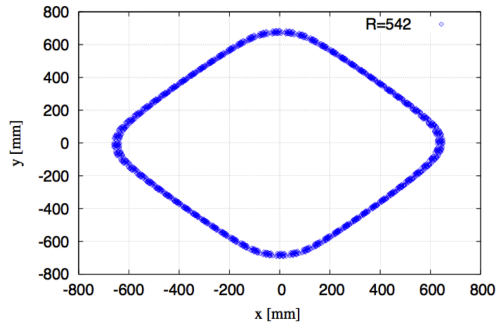

Figure 5: Coasting initial bunch at 2 MeV orbit.

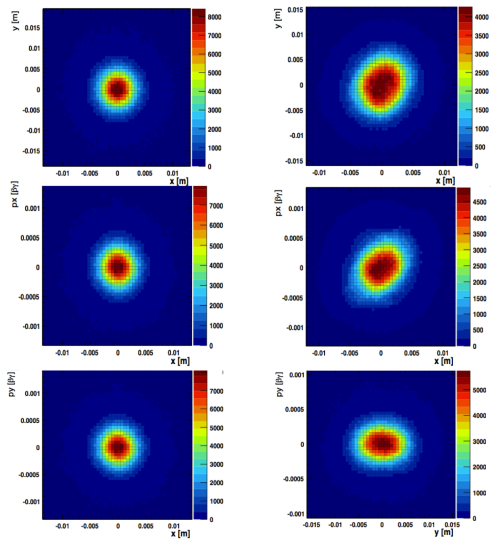

Figure 6: The mid-plane geometry and phase space of the initial bunch (left) and the distribution after 20 turns at 2 MeV orbit (right).

ACKNOWLEDGMENTS

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