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Barlow, Roger and Kolano, Anna

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A precise beam dynamics model of the PSI Injector 2 to estimate the intensity limit

A.M. Kolano*, University of Huddersfield, HD1 3DH Huddersfield, United Kingdom
A. Adelmann, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
R. Barlow, University of Huddersfield, HD1 3DH Huddersfield, United Kingdom
C. Baumgarten, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

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 OP AL (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 of 870 keV, emittance of $2\pi \, \text{mm} \times \text{mrad}$ and DC current of 11 mA. The accelerator operates at a frequency of 50.63 MHz.

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.

Figure 1: PSI Injector 2.

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

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* anna.kolano@psi.ch
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.

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.

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References