INJECTION LINE OF THE SMALL ISOCHRONOUS RING*

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Abstract

The Small Isochronous Ring (SIR) under development at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) is a ring whose main purpose is the study of longitudinal space charge effects in the isochronous regime [1]-[3]. This paper describes de SIR injection line. Descriptions of the ion source, einzel lens, bending magnet, diagnostics, chopper, and ring injection inflector plates are given. Single particle beam dynamics simulations performed using COSY [4], SIMION [5] and TOSCA[6] are detailed.

1 INTRODUCTION

The purpose of SIR is the study of longitudinal space charge effects in isochronous regime [1] [3]. Bunches of different ions (H^+, H_2^+, Deuterons), energies (20keV-30keV), lengths (~10cm and up), and peak current (~25μA and up) will be injected into the ring. After several turns (~30), the bunch will be extracted and its longitudinal profile will be determined with a fast Faraday cup.

This paper describes the injection line of SIR. In Section 2 the different elements that form it are discussed. Section 3 focuses on the linear beam dynamics and particle tracking in 3D fields. The time structure of the injected bunches is covered in Section 4.

2 INJECTION LINE DESCRIPTION

The objective of SIR is to study the longitudinal space charge effects in an isochronous regime. In order to do this, matched to the close orbit solution bunches of different lengths need to be injected.

A multicusp ion source is used to produce H^+, H_2^+ and H_3^+. Preliminary experiments have already been performed where several hundred μA of total current have been extracted. The different charge states are separated by a 90° magnet similar to those used in the ring (See [2] for details of the magnet design). A triplet of electrical quadrupoles guarantees the matching to the close orbit solution at the injection point. An einzel lens immediately after the ion source focuses an, otherwise, very divergent beam. Bunches of different lengths are obtained using the chopper. An emittance measurement system immediately after the dipole and a Faraday cup characterize the injected beam.

The horizontal length of the injection line is about 3.5m and the ion source is located around 1.5m above the medium plane of the ring. (See Figure 1 for details)

3 TRANSVERSE BEAM DYNAMICS

3.1 Initial Ensemble

A number of experiments were performed to determine the properties of the beam extracted from the ion source. The emittance measurement system (consisting of two slits and a Faraday cup) was located 17cm away from the center of the einzel lens. The phase space was measured for different extraction energies and einzel lens voltages. Ions representing different points of the phase space, where a non-zero current was measured, were tracked back to point A (between ion source and einzel lens, see Figure 1).

The initial distributions of ions, as determined by two

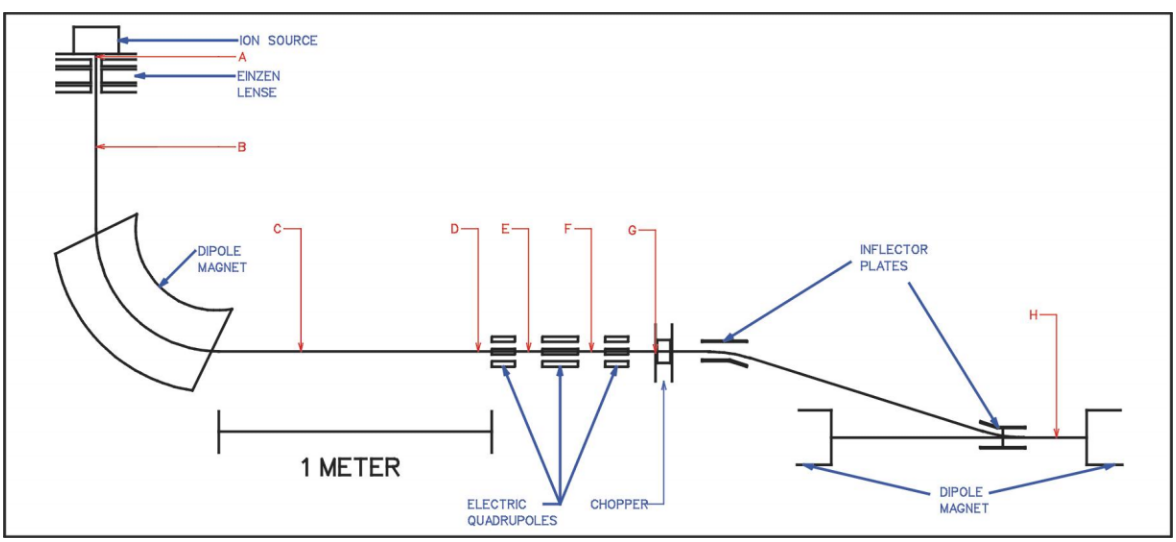

Figure 1: Injection Line of SIR.

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of these experiments, are shown in Figure 2 in blue squares and green circles. Both ensembles are roughly consistent.

The red (triangles) ellipse was chosen as the best representation of the experimental results (α=-4.8, β=0.12, ε=50π mm mrad). Different initial distributions (black) could be matched to the ring acceptance at the injection point by readjusting the voltages in the einzel lens and electrical quadrupoles, as well as using the quadrupole corrector in the dipole magnet.

This flexibility is needed since changes in the total extracted current have an effect in the initial ensemble due to transverse space charge effects.

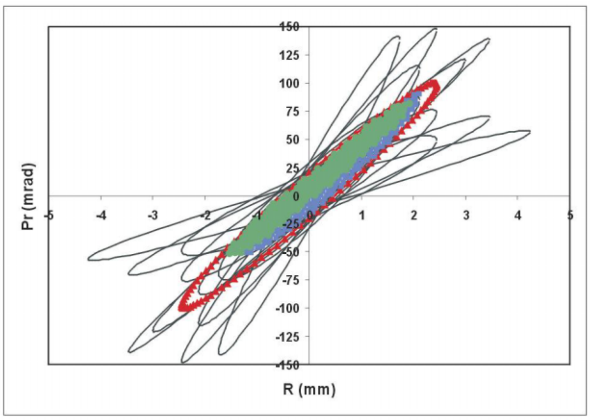

Figure 2: Initial ensemble

3.2 First order dynamics

COSY Infinity was used to calculate the first order dynamics. Figure 3 shows the envelope of the beam in the plane parallel to the medium plane of the ring (bottom) as well as in the perpendicular (top).

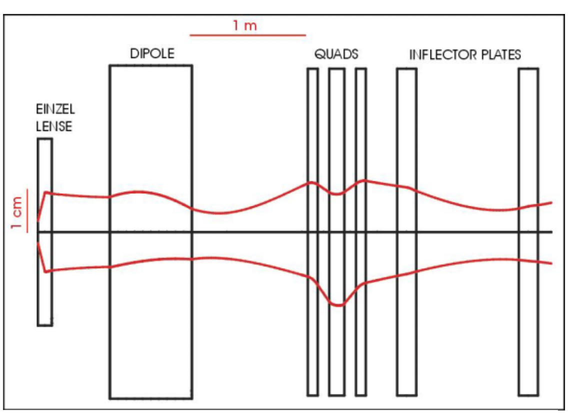

Figure 3: Envelopes

The size of beam stays around ~1cm. This is especially important inside the dipole, inside the chopper and in the inflector plates, since clearance between central ray and hardware is approximately 2 cm.

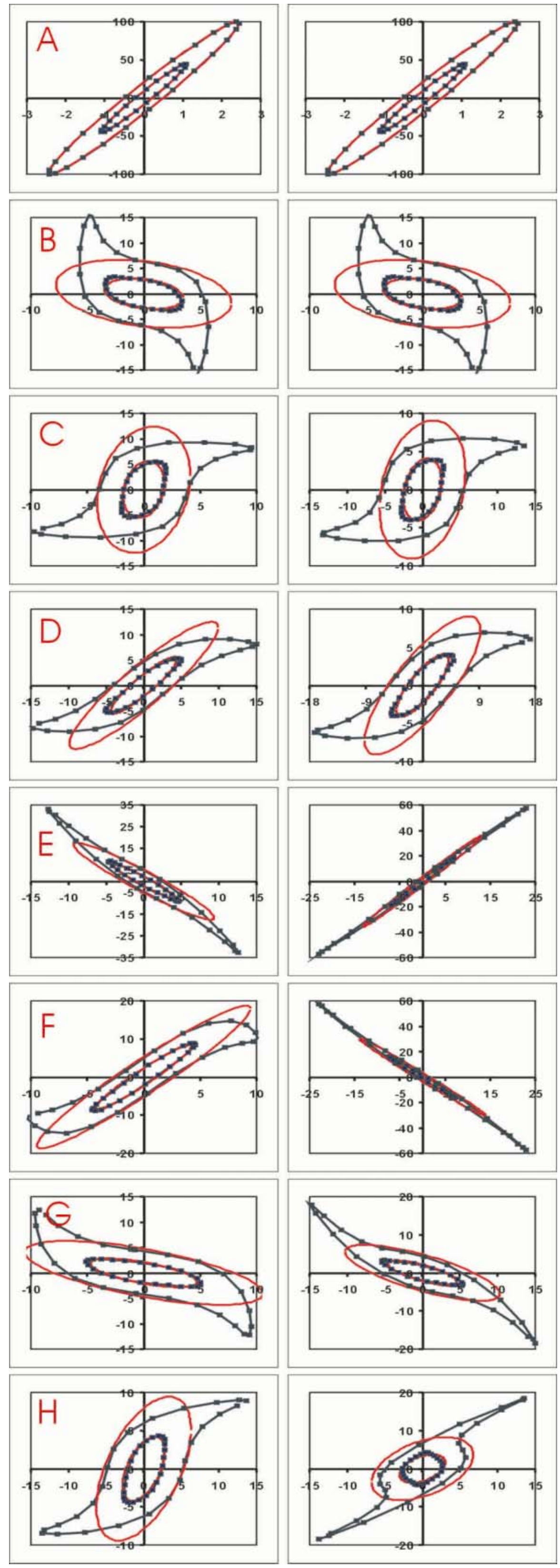

Figure 4: Particle tracking in 3D fields in black squares. Inner ellipse: ε=10π mm mrad. Outer: ε=50π mm mrad

3.3 Particle tracking in 3D fields

Ions were tracked in the 3D fields to study non-linear effects. TOSCA and SIMION 7.0 were used to track ions in the magnet and the electrostatic elements respectively. Figure 4 shows the shape of the ellipses without (red) and with (black squares) non-linear effects for different points (A, B…) in the injection line (See Figure 1 for the specific locations of these points). Particles were tracked trough each element individually as well. None of the elements, except for the einzel lens, produce important distortions. Simulations to try to modify the design of the lens to minimize these effects have been carried out but the constrains in space and maximum voltage in the lens limited the possible improvements. A diaphragm could be used to reduce the size of the wings.

4 TIME STRUCTURE OF BUNCHES

4.1 Chopper description

In order to inject bunches of different lengths into the ring a chopper will be used. It consists of a pair of deflector plates driven by two pulse generators. The PVX-4140 (Directed Energy Inc.) is capable of producing up to ±3500V pulses with a raise and fall time of 25ns. When the high voltage is off, the beam is injected into the ring. When the high voltage is on, the beam is deflected and stopped. Ions, which do not spend enough time inside the chopper with high voltage on to be completely deflected, form the head and tail of the bunch.

The length of the plates is 5cm and the gap between them is 4cm. Ground metallic grids, 0.5cm away from the plates, keep the electric field confined. This reduces the length of the head and tail of the bunch since ions, before they get to the first grid and once they pass the second grid, are not deflected by the decaying or raising electric field. (See Figure 5)

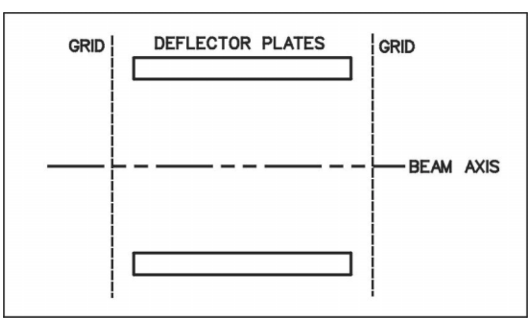

Figure 5: Chopper Schematics

4.2 Time Structure of Bunches

Simulations to determine the time structure of the bunches were performed using SIMION 7.0. The voltage in the deflector plates was changed as a 20keV H_2^+ beam was flying through the chopper.

The deflection angle acquire by central ray ions arriving at different times at the chopper were calculated. The results are shown in Figure 6 together with the electric field at the time the ions reached the middle of the chopper. The effect of the extension of the field can clearly be seen as the deflection angle is not proportional to the field but to the integral of the field. This, effectively, increases the length of the head and tail of the bunch.

It follows from the calculations that the length of head and tail is ~15ns (considering a >20mrad deflection angle enough to stop the beam). Therefore, bunches as short as 30ns (just head and tail) can be injected into the ring.

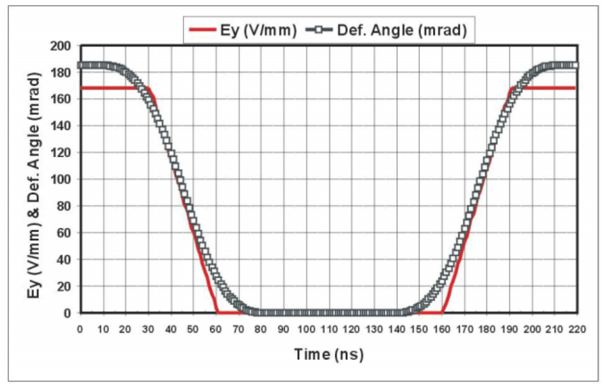

Figure 6: Deflection angle produced by the chopper

5 CONCLUSION

Transverse and longitudinal beam dynamics were studied and described. The proposed design is capable of injecting matched single charge state bunches into SIR.

Further studies, in which transverse space charge effects would be included, should be performed to minimize the effect of the non-linearities observed in the einzel lens.

6 ACKNOWLEDGMENT

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7 REFERENCES

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