BEAM DIAGNOSTICS OF THE SMALL ISOCHRONOUS RING*

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Abstract

The purpose of this paper is to describe the beam diagnostic systems in the Small Isochronous Ring (SIR) developed and built at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU). SIR is a small-scale experiment that simulates the dynamics of intense beams in large accelerators. Some of the diagnostic tools available in SIR include an emittance measurement system in the injection line, a Faraday Cup at the end of the injection line, scanning wires in different sections of the ring, phosphor screens at the injection and extraction points and a fast Faraday cup in the extraction line. The design of these systems and the kind of beam information they provide are discussed in the paper.

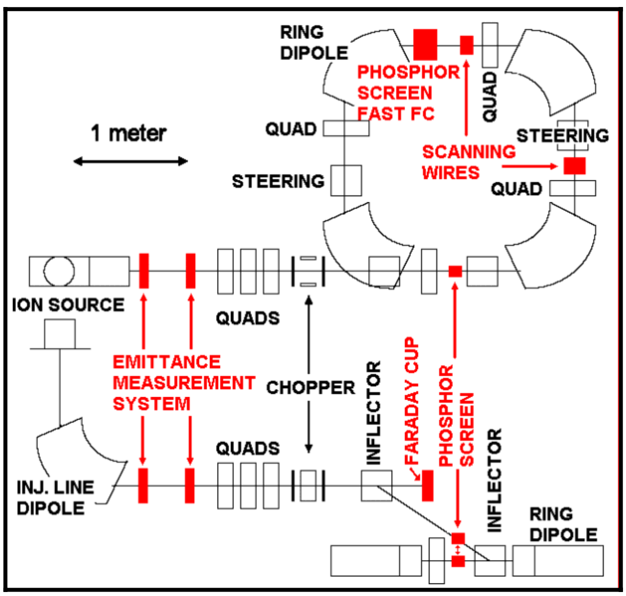

Figure 1: Top and side view of SIR. (Diagnostics in red)

INTRODUCTION

Figure 1 shows a simplified schematic top and side view of SIR. A 20 to 30 keV hydrogen or deuterium ion beam is produced by a multi-cusp ion source, injected in the ring through an injection line, and extracted from the ring after a variable number of turns. The longitudinal and the transverse beam profiles of the extracted beam are measured by the fast faraday cup and a phosphor screen respectively and studied later offline. The different diagnostic elements are marked in red. Refer to [1], [2], [3] and [4] for additional details on the project. Results of simulations of the beam dynamics in the injection line and in the ring can be found in [5] and [6] respectively. Details about the electronics and the control system are described in [7] and latest experimental results in [8].

BEAM DIAGNOSTICS

Emittance Measurement System

The Emittance Measurement System consists of a couple of movable slits followed by a shielded Faraday cup. This system is duplicated in the vertical and horizontal plane.

The portion of the beam that goes through the first slit (with a defined x) and the second slit (with a defined x') is collected in the Faraday cup. The result is a 2D histogram of beam density as a function of position and angle. This information can be used to calculate the α_x, β_x, α_y, β_y as well as the emittance of the beam. These parameters are later used to adjust the triplet of quadrupoles (see figure 1) and the Einzel lens to match the injected beam to the close orbit solution of the ring.

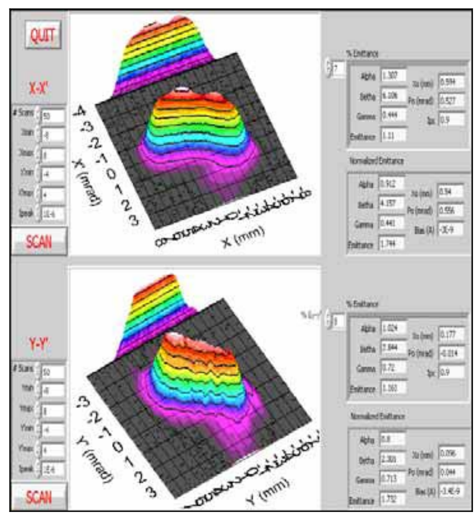

Figure 2: User interface of the emittance measurement system control program.

As an alternative, after retracting the first slit, the second slit and the attached Faraday cup can be used to quickly get information about the beam position and size.

Injection Line Faraday Cup

A shielded Faraday cup located at the end of the injection line (see figure 1) is used to accurately measure the peak beam current injected in the ring. The chopper and the inflector that sends the beam into the ring are turned off and a picoammeter is used to determine the dc beam current identical, in our case, to the peak beam current.

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Phosphor Screens

Two phosphor screens provide visual information about the position and transverse profile of the beam. The first one is movable and is located in the injection section of the ring. It can be used to observe at the beam either coming from the injection line or in the median plane after a single turn. The second one is permanently located above the medium plane of the ring, opposite to the Fast Faraday Cup. A pulsed electrostatic deflector is used to extract the beam and direct it to the screen that can also be used as a non-shielded Faraday Cup.

Because of the instant response of the phosphor screens, they have become one of the most useful means of diagnostic when operating SIR.

Figure 3: Pictures of the phosphor screen in the injection section (left) and in the extraction section (right).

Figure 4 shows precession of the beam spot on the phosphor screen for the beam extracted after the first eight turns. The figure was obtained by a superposition of eight video frames corresponding to different turns. The frequency of the precession provides the values of the betatron tunes, while the amplitude of the beam spot trajectory can be used as a measure of the injection errors.

The energy spread induced by the space charge effects manifests itself as a widening and a tilt of the beam spot on the phosphor screen. The tilt of the beam spot specific to the beam energy spread is due to a dependence of the deflection angle produced by the deflector on the particle energy.

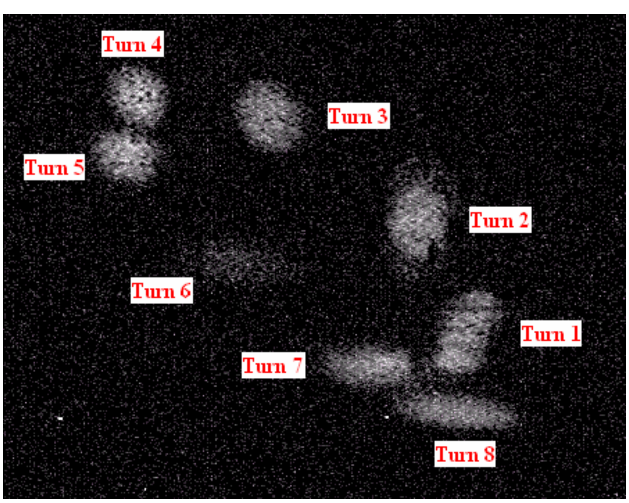

Figure 4: Superposition of pictures of the extracted beam after a variable number of turns before matching.

Fast Faraday Cup

A movable coaxial type Fast Faraday Cup (CFCC) [9] [10] is used to measure the longitudinal profile of the extracted bunches. Fig. 5 shows a picture of the CFFC before the shield grid is added.

A copper cone is attached to the central pin of a 50Ω type N Ceramaseal 18066-01-W feedthrough and a stainless steel cone is attached to the outer shield.

Reflection of the high frequency components of the beam signal is avoided by keeping the ratio between the inner radius of the shield and the outer radius of the central cone constant and equal to 2.3 (i.e. the impedance is 50Ω).

An 80% transparency molybdenum grid shields the CFFC from the incoming beam. This grid can also be biased to suppress secondary electrons.

Figure 5: Fast Faraday Cup

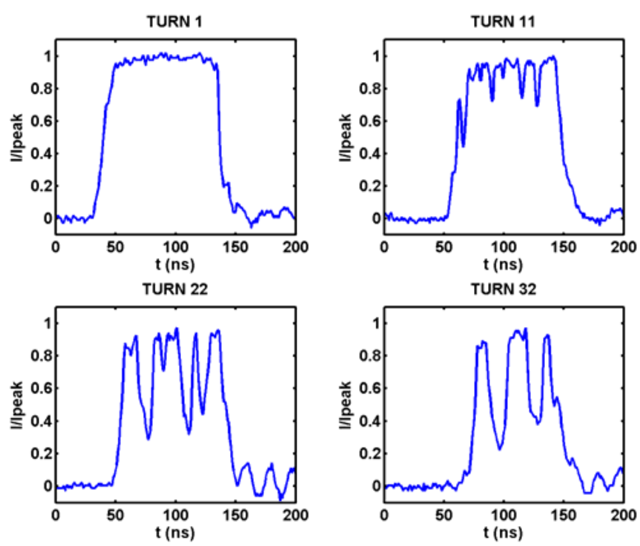

Figure 6: Longitudinal beam profiles measured with the Fast Faraday Cup when the beam is extracted after a variable number or turns.

Scanning Wires

Two pairs of scanning wires can be used to measure transverse beam profiles in the ring. They are located in the vertical and horizontal plane of the ring after ¼ and after ½ a revolution (fig. 1). They consist of a 1mm diameter tungsten wire held by an aluminum frame moved by a motorized linear motion feedthrough (fig. 7).

The scanning wires can be used with a dc beam to get information about the position and transverse profile of the beam during its first revolution.

In the pulsed mode, the scanning wires can be used to monitor the amplitude of the betatron oscillations when non-matched bunches are injected. When a beam profile is measured in this mode a number of peaks will appear. One of them will correspond to the profile of the beam during its first turn. Another will correspond to the profile of what is left of the beam during its second turn and so on.

Figure 7: Picture of a horizontal scanning wire on the left and a vertical scanning wire on the right.

The injection coordinates and angles are readjusted until all the peaks overlap (i.e. amplitude of betatron oscillations is minimized). If the beam is injected with the right α's and β's, the width of all the peaks will be the same and equal to the measured combined width. If it is not injected with the right α's and β's, the measured combined width will be larger. By readjusting the triplet of quadrupoles and the Einzel lens in the injection line a complete matching can be achieved.

The picture gets more complicated because the energy spread of the beam also increases the apparent width.

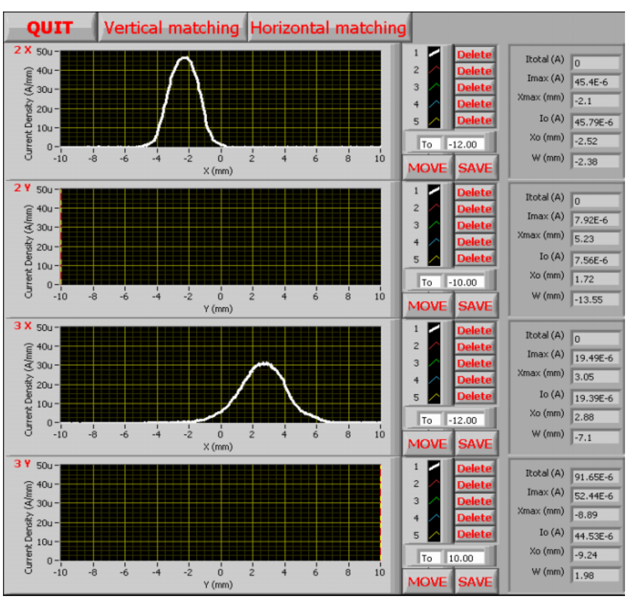

Figure 8: Front panel of the LabVIEW program used to move the two pairs of scanning wires.

FUTURE PLANS

Due to shortage of available space in the extraction region, the size of the central electrode of the 50Ω coaxial fast Faraday cup was limited to 1.5 cm. This size is a factor of two smaller than the final beam size which is mostly due to the energy spread induced by longitudinal space charge effects. This causes a part of the extracted beam to miss the Faraday cup. To capture a complete longitudinal beam profile the horizontal size of the Faraday cup must be increased.

A new FFC may be designed in the near future. A couple of options are being studied at this time:

- A wider coaxial type FFC capable of capturing the whole bunch at the same time. In this case, due to space restrictions, the 50Ω matching condition would have to be relaxed.
- A stripline type FFC. The main advantage of this option is the size. No compromise in the 50Ω matching would be needed. The main disadvantage is the difficulties of making it high vacuum compatible.

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