RECENT DEVELOPMENT AT THE NSCL SMALL ISOCHRONOUS RING*

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Abstract

The Small Isochronous Ring (SIR) at the National Superconducting Cyclotron Lab (NSCL), Michigan State University (MSU) was built to study space charge effects in the isochronous regime. Results of experimental studies of the longitudinal beam dynamics in the ring showed a remarkable agreement with results of numerical simulations. Recently, we have designed, built and tested a compact retarding field energy analyzer to accurately measure the beam energy spread.

INTRODUCTION

The Small Isochronous Ring (SIR) [1] of National Superconducting Cyclotron (NSCL) at Michigan State University is a compact, low energy storage ring that is designed to simulate the beam physics of high power cyclotrons in the isochronous regime. After the Hydrogen ion beam produced by multicusp ion source is chopped and injected into the storage ring, the bunch can coast in the ring for up to 300 turns, it can be deflected by a deflector in the measurement ("extraction") box either to the phosphor screen above the median, or to the Multi-sector Fast Faraday Cup (four independent sensors spaced from inner to outer radius) under the median plane to get the longitudinal beam profile in each of the four sectors.

Our previous experiments and simulations showed that after injection, an initially mono-energetic, uniform beam was deformed and can break up into several small clusters [1][2]. E. Pozdeyev's recent work [3] explained the onset of the instability and predicted the initial growth rate of instability: the longitudinal charge density modulation can produce modulation of energy and radius of revolution, the wiggle of a bunch will enhance its transverse field then modify the dispersion function and slip factor, so the working point of an isochronous machine is raised above transition where negative mass instability will take place for a beam dominated by space charge impedance. For long term evolution of beam distribution and instability, the development of energy spread with time plays a key role and should be measured [4]. Recently, we have designed, built and tested a compact, high resolution retarding field energy analyzer with a large entrance slit to accurately measure the beam energy spread for SIR.

DESIGN, SIMULATION AND TEST OF ENERGY ANALYZER

The energy analyzer of SIR is an electrostatic retarding field analyzer which can scan across the beam to measure the energy spread of a bunch at a chosen number of turns after injection. It is installed under the median plane in the

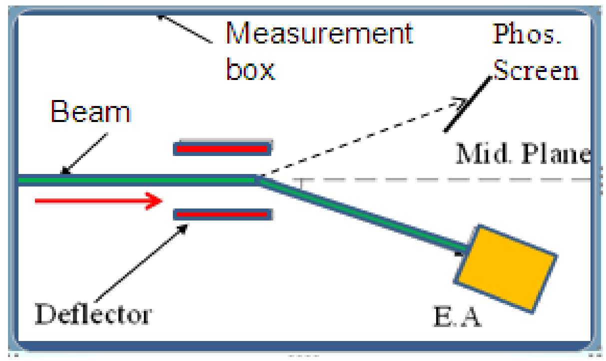

Figure 1: Measurement box.

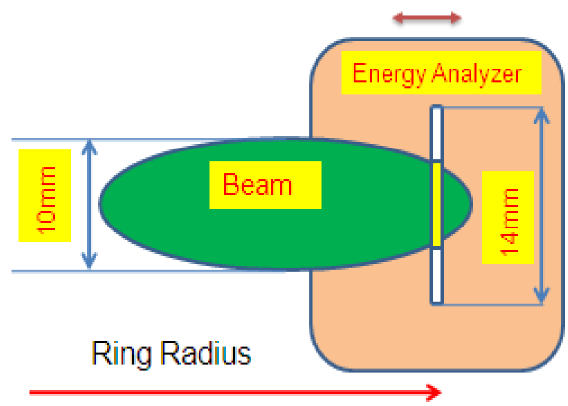

Figure 2: SIR energy analyzer and beam.

extraction box (Figure 1) to replace the Sector Fast Faraday Cup, its entrance plate is tilted at an angle with respect to vertical plane to align the analyzer axis parallel to that of deflected beam. The design parameters of SIR energy analyzer are shown in Table 1.

Table 1: Design Parameters of SIR Analyzer

Ions	H2+
Beam Energy	20 keV
Beam current	0-30μA
Beam Emittance	10π mm* mrad
Energy change (due to space charge)/turn	7-8 eV
Beam radius	5 mm

The analyzer should be able to scan across the beam transversely to measure the radial distribution of energy spread. Because the beam size of SIR is about 10 mm in diameter and the beam peak current is only at about 10 μA level (outside the analyzer for a DC beam), in order to

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sample as much beam as we can, we adopted a 14mm×1mm slit as the entrance aperture instead of a conventional small hole (Figure 2).This asymmetric, large entrance aperture makes design work more challenging. The University of Maryland has designed a compact, high resolution retarding field energy analyzer to measure the energy spread of the electron beam in UMER [5]. We used their design as our main design reference. The working principles of the two analyzers are simple and similar: if a beam enters the analyzer through the entrance aperture, it will be decelerated and focused by the retarding field produced by the retarding tube and mesh. Only those ions whose kinetic energy is higher than the retarding voltage can pass through the mesh to form current on the collector. By changing the retarding voltage on mesh and analyzing the change of collector current as a function of retarding voltage, we can get the energy spread of initial beam. Though the working principles of two analyzers are similar, they differ on many aspects as shown in Table 2.

Table 2: Comparison of UMER and SIR Analyzers

	UMER Analyzer	**SIR Analyzer**
Extraction	Single pass	Variable turn
Particles	e-	H_2+
Entrance	1 mm hole	14mm×1mm slit
Electrodes	Cylindrical tube	Rectangular tube
Extra focusing	Yes	No
Retarding point	Before mesh	On mesh
Working mode	Static	Scanning
Beam current	mA	nA

The SIR analyzer is a 60mm×60mm×50mm box, limited by the space available in the extraction box. The equipotential field lines calculated with the simulation code SIMION 8.0 [6] are shown in Figure 3 and Figure 4.

The SIR analyzer consists of: (1) a housing box with an entrance slit on the front plate (2) retarding tube and fine mesh (3) secondary electron suppressor (4) current collector (5) four ceramic insulators.

Unlike the UMER analyzer whose retarding point is designed several mm before mesh, the resolution of SIR analyzer depends on the wire density of fine mesh strongly. We choose a 1000 lines per inch (LPI=1000, 50% transparency rate) Nickel mesh in our design.

We use the code SIMION 8.0 to simulate the behavior of ions in the analyzer. In the simulation we take into account the effect of finite wire density of the mesh by setting up a small piece of real mesh model with high resolution. This small field model can be moved along the whole retarding plane back and forth when the ions are tracked one by one to simulate the whole real mesh.

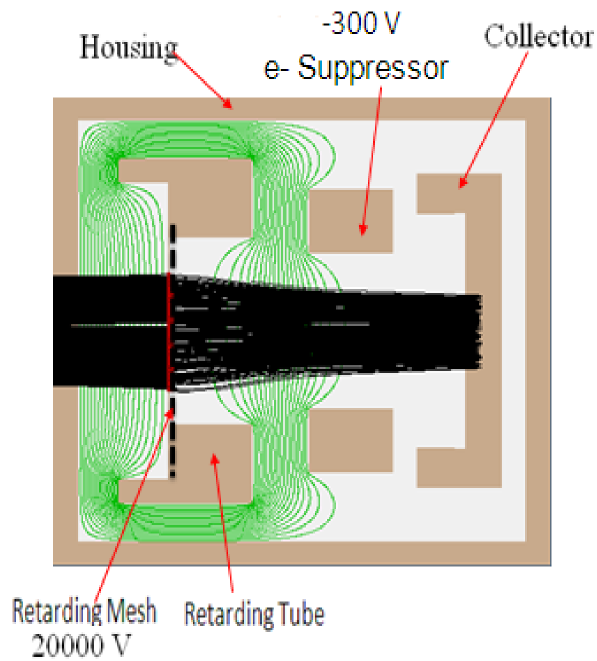

Figure 3: Energy Analyzer of SIR (E_k=20.01 keV, V_r=20kV, V_{sp}=-300V).

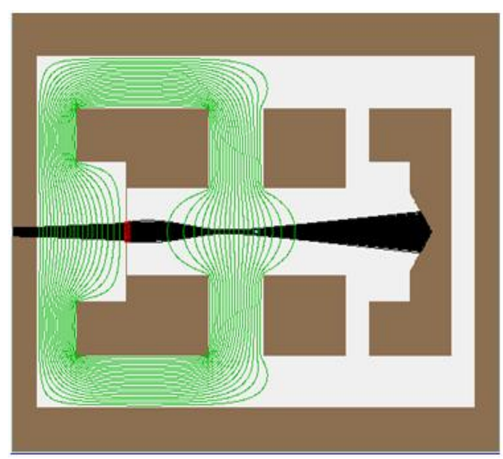

Figure 4: Another side view of SIR analyzer.

In the simulation, the retarding voltage on mesh is fixed to 20 kV, while the source voltage (or kinetic energy of beam) is changed. We also assume the beam has an uniform distribution at the entrance slit and the initial moving direction of each ion has a uniform cone distribution with half angle equals 10 mrad. The simulation results in Figure 5 demonstrate that the relative energy error or resolution is about 5e-4.

We also solve the sheet beam envelope equation [7] to study the resolution of analyzer further. The calculation shows that the change of beam current and emittance inside analyzer has little effects on the resolution of analyzer; this guarantees a constant resolution during the energy spread measurement.

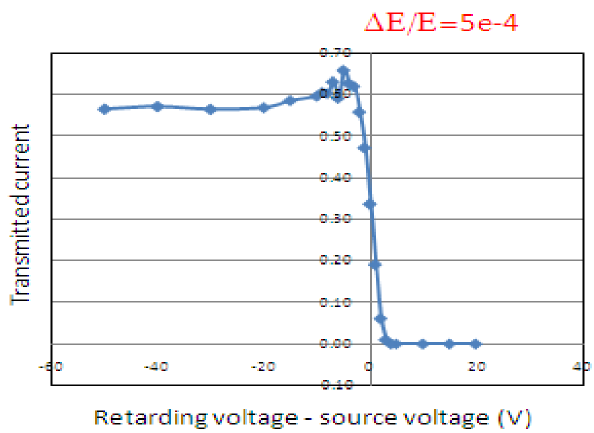

Figure 5: Performance of SIR Analyzer simulated by SIMION 8.0 for a 20 kV retarding potential.

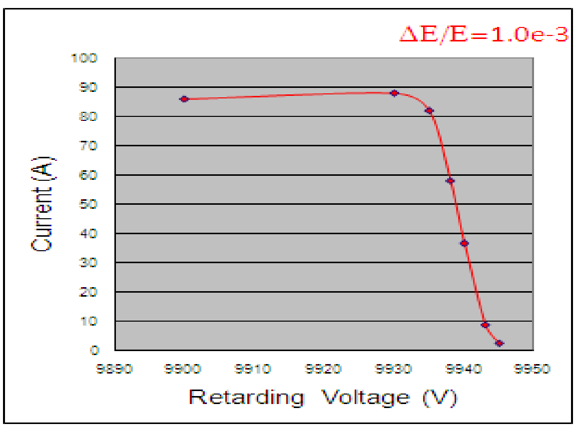

Figure 6: Performance of SIR Analyzer tested at Artemis B ECR ion source.

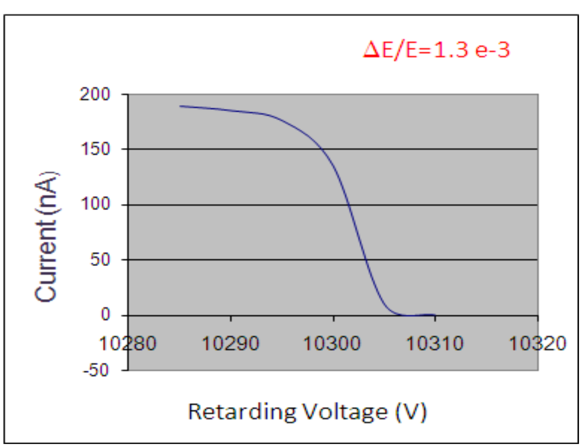

Figure 7: Performance of SIR Energy Analyzer tested at SIR by DC beam.

We tested the performance of analyzer by using it to measure the beam energy at the Artemis B ECR source [8] beam line and SIR (only use DC beam, half a turn from injection to extraction) at NSCL. The experimental results show the overall relative energy error including the alignment error, energy spread of beam and resolution of analyzer is 1.0e-3 and 1.3e-3 respectively (Figure 6 and Figure 7). The resolution is estimated as the spread in retarding potential to go from 95 % to 5 % transmission. The performance of analyzer meets our requirement for energy-spread measurement. When we tested the analyzer by using pulsed beam of SIR (necessary to follow the evolution of the energy spread as a function of turn number), we found the signal to noise ratio is too low and it should be improved in future experiments. The noise is produced by the high speed, high voltage switches used to control the different choppers, inflectors and deflectors.

FUTURE WORK

First, we will continue on improving the signal to noise ratio of the energy analyzer for the pulsed beam of SIR. Then the energy spread of pulsed beam will be measured for different number of circulating turns as a function of the radial position. Next, we will modify the slip factor by adding two terms introduced by space charge effects and energy spread respectively, solve the equations of development of energy spread and amplitude of collective instability derived from nonlinear Vlasov equation [4] numerically to get the beam distribution and energy spread. At last, by comparing the experiment results with the numerical solutions, we will try to explain the long term evolution of beam distribution and instability.

SUMMARY AND CONCLUSIONS

A compact, high resolution retarding field energy analyzer has been designed and tested for SIR of NSCL at MSU to further study the beam instability. Experiment results showed the performance of analyzer meets the requirement for future measurement and research work.

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