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Small Isochronous Ring (SIR) project at NSCL, MSU: first experimental results
Outline

- Introduction
  - Specifics of Space Charge effects in isochronous cyclotrons
- Small Isochronous Ring (SIR)
  - Beam parameters and Design
- First Experimental Results
- Future plans
Isochronous regime in accelerators

\( \frac{\partial \omega}{\partial E} = 0 \quad \iff \quad \frac{p}{T} \frac{dT}{dp} = \alpha_p - \frac{1}{\gamma^2} = 0 \)

No synchronous phase
No longitudinal focusing
No synchrotron motion

Applications:

- Synchrotrons at \( \gamma_{tr} \)
- Isochronous Cyclotrons
High power isochronous cyclotrons

PSI Main Ring Cyclotron:

\[ E = 600 \text{ MeV} \]
\[ I = 2 \text{ mA} \]
\[ P = 1.2 \text{ MW} \]

1 GeV, 10 mA (10 MW) cyclotron was proposed for:

- Waste transmutation
- Accelerator-driven nuclear reactors
- Neutron and other particle production
Specifics of Space Charge effects in isochronous regime

Simulated beam dynamics in PSI Inj. 2, \( I_b = 2 \) mA, \( E = 5 \) MeV

CYCO: \( N_p = 10^5 \), \( N_{sc} = 180 \) calc./turn
Small Isochronous Ring: scaling down with energy

**BEAM PARAMETERS:**
- Low energy (tens of keV)
- Light ions: $\text{H}_2^+, \text{D}$

- SC effects scale with energy => low intensity beam
- Relaxed requirements on diagnostics and Inj./Extr.
- Simple, low-field magnets
- Magnetic Field is strong enough to avoid stray field problem

- Small-scale, inexpensive project
- Opportunity to do precise experiments
Schematic view and main parameters

Beams: $H_2^+$ or D
Energy: 0-30 keV
$\nu_x, \nu_y$: 1.14, 1.11
$\alpha_p$: 1.0
$T$: 4.5 $\mu$sec
$C$: 6.57 m
$N_{\text{turns}}$: 30
$I_{\text{peak}}$: 0-100 $\mu$A
Comparison to large-scale accelerators

Space charge effects in the isochronous regime scale as

\[ \frac{Q}{A^5 \gamma^5 \omega^3} \]

- SIR: \( I_p = 20 \mu A \),
- Equiv. to
- PSI Inj.2: 2 mA
- PSI Ring Cyc: 8.5 mA
Bunch break-up in SIR (simulations)

\[ I_p = 20 \ \mu\text{A} \]
\[ E = 23.5 \ \text{keV} \]
\[ t_b = 200 \ \text{nsec} \]
\[ \varepsilon = 50 \ \pi \cdot \text{mm} \cdot \text{mrad} \]

CYCO: \( N_p = 3 \cdot 10^5 \)

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Dipole magnets

- B: 1000 G
- R: 450mm
- Bend: 90deg
- Edge: 26deg
- Gap: 71mm
- Weight: 250kg
- Power: 750W

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Other subsystems

- Steering and Quadrupole Correctors
- Injection-Extraction
  - Pulsed electrostatic deflectors
- Vacuum system
  - Al vacuum chamber in the dipoles
  - $P = 10^{-8} - 10^{-7}$ Torr
- Diagnostics
  - Wire scanners
  - 2 Phosphor screens
  - Fast Faraday Cup ($Z = 50 \, \Omega$)
First beam in the ring
Betatron tunes

\[ \nu_x = 1.142 \ (1.140, 1.143) \]
\[ \nu_y = 1.110 \ (1.110, 1.128) \]

Measured
Calculated in the measured magnetic field
Calculated in the TOSCA-generated field
Beam life-time in the ring

Equivalent average pressure 2.5e-7 Torr.

Measured pressure 1.2e-7 Torr.

$I(N) \propto e^{-\frac{N}{120}}$
First **indication** of space charge effects

Radial beam profile

**MEASURED**

**SIMULATED (CYCO)**

- $I = 20 \mu A$
- $E = 17$ keV
- $T = 1 \mu sec$

$E=17$ keV $T=1 \mu sec$
First **indication** of space charge effects (cont’d)

\[ \theta \approx -2 \frac{y_0}{\eta} = 7.1^\circ \]

\[ \frac{\delta E}{E} = 2 \frac{x - x_\beta}{\eta} = 5\% \]

**CYCO:**
\[ \frac{\delta E}{E_{\text{rms}}} = 1.2\% \]
\[ \frac{\delta E}{E_{\text{max}}} = 11.5\% \]
Longitudinal bunch distribution measured by the Fast Faraday Cup (01/09/2004)

**I_{arc}=1.1 \, A (? \, I_{beam}=15-20 \, \mu A ?), \, E=24.6 \, \text{keV}, \, H_2^+**

![Graphs showing longitudinal bunch distribution for I_{arc}=1.1 A.](image)

**I_{arc}=0.25 \, A (? \, I_{beam}=6-8 \, \mu A ?)**

![Graphs showing longitudinal bunch distribution for I_{arc}=0.25 A.](image)
Time-line

- Fall 2000 – Proposal to build SIR
- Sep 2001 - Ion source tested
- Nov 2002 - First magnet assembled, mapped
- Apr 2003 – Beam through injection line, ¼ of ring
- Oct 30, 2003 – One turn in the ring
- Nov 2003 – More than 200 turns in the ring
Future plans

- **Phase I: Winter-Spring 2004**
  Isochronous regime, longitudinal beam dynamics, $I_p = 20 \, \mu A$ ($\delta \nu_L = 0.05$)

- **Phase II: (?)**
  Non-isochronous regime, transverse and longitudinal beam dynamics, $I = 100 \, \mu A$ ($\delta \nu_L = 0.25$), will include simple RF system
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