The Design of Beam Collimation System for CSNS/RCS

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Outline

• Introduction

• Two-stage collimation system design

• Compare among different schemes

• Dependence of collimation efficiency on apertures

• Summary
RCS – 4 Fold Structure

- Four straight sections - beam injection, collimation, extraction, RF systems

- Injection (chicane & bumps)
- RF Cavity
- Instruments and Others
- Collimation (transverse & longitudinal)
- Extraction (kickers & septum)
- Instrumentation

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**Inj./Ext. energy** 0.08/1.6 GeV

**Power** 100 kW

**Beam current** 62.5 μA

**Beam population** $1.56 \times 10^{13}$

**Hamonic number** 2

**Repetition frequency** 25 Hz

**Circumference** 228 m

**Betatron tune** 4.86/4.78

**Ring acceptance** 540 $\pi$ μm
Motivation

• **Localization of beam loss**
  - High collimation efficiency

• **Minimize uncontrolled beam losses**
  - <1 Watt/meter for hands-on maintenance

• **Beam halo cleaning**
  - Small beam loss -> larger beam loss
Beam Loss Distribution (No Collimation)

- The beam loss distribution (ORBIT)

- Total loss $2 \times 10^{-4}$, beam loss per component < 0.2 W/m

- The beam loss looks fine for an unperturbed machine, but worse performance are expected with errors or accidental cases
Two-stage Collimation System

- **Optics**
  - Separate straight section for transverse collimation
  - Similar phase advance in $x$ & $y$ planes
  - One 11 meter and two 3.8 meter dispersion free drift space
  - $\Delta\phi < 180^\circ$ (150 °, middle drift <90°)

- **One primary collimators**
  - 4 movable scrappers
  - Thin tungsten, $t = 0.17$ mm
  - 350 $\mu$m$\cdot$mrad (first restrictive apert.)

- **Four secondary collimators**
  - Adjustable or fixed
  - Thick, $t = 0.4$ m, 400 $\mu$m$\cdot$mrad
Comparison Among Collimation Schemes

- Collimation with up-right collimator jaws

- Collimation with DC bump

- Collimation with fixed elliptical apertures
1. Collimation with Up-right Collimator Jaws

- Primary → four movable scrappers with 90° apart
- Secondary → four movable vertical or horizontal jaws

**Beam halo cleaning**

- The emittance is depressed by the collimation, and the extract beam emittance decreased about 25% in both planes.
1. Collimation with Up-right Collimator Jaws

- **Collimation efficiency**

  - Total beam loss: 0.8%
  - Collimation efficiency: 93.5%
  - The beam losses mostly occur in the first three milliseconds
  - Average energy is 100 MeV

- The collimation efficiency varies with time as the impact parameter changes along with the expected emittance blow-up.
1. Collimation with Up-right Collimator Jaws

- Beam loss distribution

- The uncontrolled beam losses < 1 W/m.

- Over 96% of the beam lost within the collimation section.
2. Collimation with DC Bump

- **Principle**
  - In RCS, emittance shrinks during beam acceleration
  - DC bump → halo collimation in the early acceleration stage
  
  → smaller beam emittance at the extraction

\[ \Delta: \text{Clearance space} \]
\[ y_i: \text{Orbit bump at injection} \]
\[ y_e: \text{Orbit bump at extraction} \]

\[ y_{\text{bump},e} = y_{\text{bump},i} \frac{(B\rho)_i}{(B\rho)_e}. \]

2. Collimation with DC Bump

• **Simulation**
  - Vertical bump at primary collimator
  - Reduced bump factor $f = 0.8$

• **Emittance**
  - vertical $\rightarrow$ 20 % ↓
  - horizontal $\rightarrow$ 16 % ↑

(compare to the
case without bump)
2. Collimation with DC Bump

- Collimation efficiency

  - Total beam loss 1.7% with collimation efficiency of 90%

  - Larger number of beam loss locations

  - Exceed 1W/m at some position
3. Collimation with Fixed Elliptical Aperture

- **Primary**: four scrappers placed 45° apart to approximate the elliptical aperture
- **Secondary**: fixed elliptical aperture
- **Total beam loss 1.6% with resulting efficiency of 95.2%**
- **Similar loss pattern as the scheme with up-right collimator jaws**

![Graph showing loss distribution](image-url)
### Comparison Among Collimation Schemes

<table>
<thead>
<tr>
<th>Schemes</th>
<th>Up-right jaws</th>
<th>DC bump</th>
<th>Fixed aperture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collimation efficiency</td>
<td>93.5%</td>
<td>90%</td>
<td>95.2%</td>
</tr>
<tr>
<td>Total beam loss</td>
<td>0.8%</td>
<td>1.7%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Loss in collimation section</td>
<td>96.2%</td>
<td>94.5%</td>
<td>97.7%</td>
</tr>
<tr>
<td>Uncontrolled loss</td>
<td>5.2E-4</td>
<td>1.7E-3</td>
<td>7.7E-4</td>
</tr>
<tr>
<td>Flexibility</td>
<td>flexible</td>
<td>flexible</td>
<td>less flexible</td>
</tr>
<tr>
<td>Extraction emittance, 99.9%</td>
<td>↓26% in x</td>
<td>↓22% in x</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>↓24% in y</td>
<td>↓31% in y</td>
<td></td>
</tr>
<tr>
<td>&lt;1 W/m</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

- Collimation efficiency better than 90%.
- Scheme 1 has moderate collimation efficiency and smallest beam loss.
- Scheme 2 shows lowest collimation efficiency and highest beam loss, enables halo collimation at early acceleration stage and results in smaller beam emittance.
- Scheme 3 shows best collimation efficiency, and main drawback is less flexibility.
Dependence of Collimation Efficiency on Primary Acceptance

- The primary acceptance varies with a constant ratio between the acceptance of the primary and secondary collimators.
- The collimation performance is strongly dependent on the acceptance of the primary collimators.

- The collimation efficiency decreases when $\varepsilon_{\text{primary}} > 350\pi$.
- Higher efficiency at 320 $\pi$ with larger impact parameter and larger fraction of beam loss.

![Graph showing the dependence of collimation efficiency on primary acceptance](attachment:image.png)
Dependence of Collimation Efficiency on Physical Aperture

- A large enough acceptance gap between the collimator and the ring physical aperture is necessary in order to ensure good collimation efficiency.

- The collimation efficiency increases with the aperture ratio.
- The design value is moderate for the performance of the collimation system.
Summary

- Beam cleaning and collimation are necessary for beam loss localization for overall maintenance.

- A collimation system has been designed and studied for the CSNS RCS. The collimation efficiency is larger than 93%, and the maximum uncontrolled beam losses are less than 1 W/m along RCS.

- All results obtained so far refer to an unperturbed machine, works need to be done to include the magnetic errors, misalignments, COD, collective instabilities, et al…

- Accidental case should be studied in the future work.
Thanks for your attention!