Specifications and Performance of a Chicane Magnet for the cERL IR-FEL

High Energy Accelerator Research Organization (KEK)
Yao Lu, The Graduate University for Advanced Studies (Sokendai)

This presentation is supported by a NEDO project "Development of advanced laser processing with intelligence based on high-brightness and high-efficiency laser technologies (TACMI project)."
cERL IR-FEL Project

Project funded by a government organization NEDO:

Beam parameter (Target)
- Energy: 17.5 MeV
- Bunch charge: 60 pC
- Repetition frequency: 81.25 MHz
- Bunch length: 0.5 - 2 ps (FWHM)
- Energy spread: 0.1%
- Norm. emittance: 3 mm mrad

R. Kato et. al., this conference, TUPAB099.

Undulator parameter
- Type: Planar (APU)
- Total length: 2.976 m
- No. of Undulator: 2
- Period: 24 mm
- Gap: 10 mm (fixed)
- $K_u$: 1.42 (max)
- FEL wavelength: 10 – 20 um
Role of the Chicane Magnet

The chicane magnet increases the FEL pulse energy by converting energy to density modulation (microbunching).

The chicane magnet is placed between the two 3-m undulators in the cERL and used to increase the FEL pulse energy.
### Specifications of the Chicane Magnet

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yoke</strong></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>0.1mm-thick permalloy lamination (low hysteresis and eddy currents)</td>
</tr>
<tr>
<td>Permeability</td>
<td>400000 (max.)</td>
</tr>
<tr>
<td>Saturation field</td>
<td>0.75 T</td>
</tr>
<tr>
<td>Adhesive insulation</td>
<td>Varnish</td>
</tr>
<tr>
<td><strong>Coil</strong></td>
<td></td>
</tr>
<tr>
<td>Turn number</td>
<td>168</td>
</tr>
<tr>
<td>Material</td>
<td>Rectangular copper wire (2 x 3 mm)</td>
</tr>
<tr>
<td>Adhesive</td>
<td>Epoxy resin</td>
</tr>
<tr>
<td>Current per turn</td>
<td>10 A (max.)</td>
</tr>
</tbody>
</table>

The chicane magnet was originally produced as the phase shifter prototype of a polarization-controlled undulator and reused for the cERL IR-FEL. N. Nakamura et al., Proc. of PAC09, Vancouver, Canada, pp.342-344 (2009).
Field Distribution and Bump Orbits

Field distribution on the central axis of the chicane magnet

Bump orbit by the chicane magnet

Transverse field distribution at the BMIS02 center

The chicane magnet center is horizontally displaced from the beam orbit center by 5 mm to improve the field uniformity for bump orbits at $I_{BMIS02} > 5A$. 

$$x'(z) = \frac{e}{m c \gamma^2} \int_{-\infty}^{z} B_y(z') dz'_1$$

$$x'(z) = \frac{e}{m c \gamma^2} \int_{-\infty}^{z} B_y(z') dz'_1$$

$$R_{56} = -\int_{-\infty}^{\Delta z} x'(z)^2 dz = -2\Delta L_z \quad \Delta L_z: \text{change of path length}$$

$I_{BMIS02} = 10 A, E = 17.5 MeV \rightarrow \Delta L_z = 3.0 \text{ mm}, R_{56} = -6.0 \text{ mm}$
Tuning of Bump Orbits

Current ratio for closed bump orbit \( R = \frac{I_{BMIS01,03}}{I_{BMIS02}} \):
Result of fitting measured data to a sixth order polynomial
\[
R = a_6 I^6 + a_5 I^5 + a_4 I^4 + a_3 I^3 + a_2 I^2 + a_1 I + a_0 \quad (I = I_{BMIS02})
\]
\[
a_0 = 0.83399, a_1 = 6.8774\times10^{-5},
\]
\[
a_2 = -5.2135\times10^{-4}, a_3 = -5.2346\times10^{-5},
\]
\[
a_4 = 2.4306\times10^{-5}, a_5 = -3.4936\times10^{-6},
\]
\[
a_6 = 1.3889\times10^{-7}.
\]

\( I_{BMIS01,03} / I_{BMIS02} \approx 0.834 @ I_{BMIS02} = 0 - 6 \) A
(Calculated current ration : 0.8357)

Measured current ratio of \( I_{BMIS01,03} \) to \( I_{BMIS02} \) for making bump orbits closed

Beam profiles at the scree monitor cam23C in the Undulator #2

Current ratio of \( R = \frac{I_{BMIS01,03}}{I_{BMIS02}} \) for closed bump orbit by the chicane magnet is kept constant for \( I_{BMIS02} = 0-6 \) A, but the current ratio and beam profile are significantly changed for \( I_{BMIS02} > 6 \) A, because the field uniformity is degraded.

IPACJ2021 TUPAB064, N. Nakamura – 6/8
Operational Performance

Beam commissioning of June to July 2020: \( E/E_{inj} = 17.6/5\text{MeV} \), FEL wavelength \( \lambda \sim 20 \mu\text{m} \)

The FEL output was differently enhanced by using the chicane magnet for different operation conditions.

Beam commissioning of February to March 2021: \( E/E_{inj} = 17.6/5\text{MeV} \), FEL wavelength \( \lambda \sim 20 \mu\text{m} \)

Time variation of the FEL output by an MCT detector (left) and dependence of the FEL output on the chicane current (right)

Dependence of the FEL output on the chicane current for three different dates and conditions
Summary

1. A chicane magnet is placed between the two undulators in order to increase the FEL pulse energy of the cERL IR-FEL.

2. The chicane magnet consists of three dipole magnets, each of which has laminated yokes made of 0.1-mm-thick permalloy sheets and coils exciting the magnetic field with the maximum current of 10 A.

3. The current ratio of the three dipole magnets for making the bump orbit closed is almost the same at $I_{BMIS02} < 6$ A, but it changes with the beam profile at $I_{BMIS02} > 6$ A, because the field uniformity on the bump orbit is degraded.

4. The FEL output at 20 µm was increased in most cases by making use of the chicane magnet. However more systematic study and analysis on effects of the chicane magnet should be performed including different wavelengths.