High-Intensity Beam simulation for IFMIF / like Accelerator

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Intense Beam and Accelerator Laboratory
Ulsan National Institute of Science and Technology
Contents

• Introduction

• Low Energy Beam Transport (LEBT)

• Medium Energy Beam Transport (MEBT)

• Summary & Future plan
IFMIF

Particle Type : $D^+$
Beam Current : 125 mA
Operation Type : CW

Perveance $K = \frac{I}{I_0} \cdot \frac{2}{\beta^3 \gamma^3} \cdot (1 - \gamma^2 f_e)$

$f_e$: neutralization factor

IFMIF/EVEDA, 2018, What is IFMIF, [http://www.ifmif.org/?page_id=6], Accessed May 24, 2018
Phu Anh Phi Nghiem et al, The IFMIF – EVEDA challenges in beam dynamics and their treatment (2011)
TRACEWIN & WARP

< TRACEWIN >

Developer: Researchers of CEA

Warp is an extensively developed open-source particle-in-cell Python package designed for simulation of plasmas and high current particle beams in a range of applications. The name "Warp" stems from the code's ability to simulate Warped (bent) Cartesian meshes. This bent-mesh capability allows the code to efficiently simulate space-charge effects in bent accelerator lattices (resonation can be placed where needed) associated with rings and beam transfer lines with dipole bends.

Warp has a broad variety of integrated physics models and extensive diagnostics — most of which work in multiple dimensions to allow examination of modeling idealizations within a common framework.

History

Warp was first developed by Alex Friedman in the 1980s at LLNL following a Livermore Lab model of the same name. The model is continuously used and has been extensively extended by David Grote (LLNL, SNL) from the late 1990s to the present with key contributions from others in the SNL team to achieve its present highly developed state.


Second order momentum / Macroparticle

http://warp.lbl.gov/home

Full PIC
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Neutralization time: \[ \tau_n = \frac{1}{n_g \sigma_i v_b} \]

Atomic Processes

1. Ionization by beam
\[ D^+ + Kr \rightarrow D^+ + Kr^+ + e^- \]

2. Ionization by electron
\[ e^- + Kr \rightarrow e^- + Kr^+ + e^- \]

3. Recombination
\[ Kr^+ + e^- \rightarrow Kr \]
Schematic of LEBT & Parameter

### Schematic of IFMIF LEBT

- **ECR**
- **Sol 1**
- **Sol 2**
- **RFQ**


### Initial Beam Parameter

- **Particle Type**: $D^+$
- **Beam Current**: 125mA
- **Initial Energy**: 100keV
- **Emittance**: 0.064 $\pi$ mm mrad
- **Twiss Parameter**: $\alpha = 0.8, \beta = 2.0$

### Lattice parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Pipe Radius</td>
<td>80mm</td>
</tr>
<tr>
<td>Cone Radius</td>
<td>35mm, 12mm</td>
</tr>
<tr>
<td>B-field of Solenoid</td>
<td>Sol1: 0.37T, Sol2: 0.47T</td>
</tr>
</tbody>
</table>

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Without SCC

**TRACEWIN**

At exit

\[ \varepsilon_{n,rms_x} = 0.2796 \pi \text{ mm mrad} \]

\[ \varepsilon_{n,rms_y} = 0.2794 \pi \text{ mm mrad} \]

Target value: \( \varepsilon_{n,rms} = 0.233 \pi \text{ mm mrad} \)

**WARP**

At exit

\[ \varepsilon_{n,rms_x} = 0.3697 \pi \text{ mm mrad} \]

\[ \varepsilon_{n,rms_y} = 0.3778 \pi \text{ mm mrad} \]
Without SCC

TRACEWIN

WARP
With SCC

**TRACEWIN**

**WARP**

**Rms X**

At exit

\[
\varepsilon_{n,rms_x} = 0.1228\pi \text{ mm mrad} \\
\varepsilon_{n,rms_y} = 0.1189\pi \text{ mm mrad}
\]

Target value: \( \varepsilon_{n,rms} = 0.233\pi \text{ mm mrad} \)
With SCC

TRACEWIN

WARP
Result Comparison

Without SCC

\[
\begin{align*}
\varepsilon_{n,rms \ x} &= 0.2796 \pi \text{ mm.mrad} \\
\varepsilon_{n,rms \ y} &= 0.2794 \pi \text{ mm.mrad}
\end{align*}
\]

Target value: \( \varepsilon_{n, rms} = 0.233 \pi \text{ mm.mrad} \)

With SCC

\[
\begin{align*}
\varepsilon_{n,rms \ x} &= 0.1228 \pi \text{ mm.mrad} \\
\varepsilon_{n,rms \ y} &= 0.1189 \pi \text{ mm.mrad}
\end{align*}
\]

\[
\begin{align*}
\varepsilon_{n,rms \ x} &= 0.1763 \pi \text{ mm.mrad} \\
\varepsilon_{n,rms \ y} &= 0.1957 \pi \text{ mm.mrad}
\end{align*}
\]
Instability Issue

Two stream instability: \( F(k, \omega) = \frac{\omega_p^2}{\omega^2} + \frac{\omega_i^2}{(\omega - kv_0)^2} \) (unstable when \( F(k, \omega) > 1 \))

\[
X - Y
\]

\[
X - X' \quad Y - Y'
\]

2\(\mu s\)

4\(\mu s\)

6\(\mu s\)
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Schematic of MEBT & Parameter

### Schematic of IFMIF MEBT

![Schematic of IFMIF MEBT](image)


#### Initial Beam Parameter

<table>
<thead>
<tr>
<th>Beam Parameter</th>
<th>Initial Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle Type</td>
<td>$D^+$</td>
</tr>
<tr>
<td>Beam Peak Current</td>
<td>125mA</td>
</tr>
<tr>
<td>Initial Energy</td>
<td>4.98MeV</td>
</tr>
<tr>
<td>Longitudinal Emittance</td>
<td>0.3 π. mm. mrad</td>
</tr>
<tr>
<td>Twiss Parameter</td>
<td>$\alpha_x = -1.95, \beta_x = 0.37$&lt;br&gt;$\alpha_y = 1.5, \beta_y = 0.355$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lattice Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradient of Quadrupole</td>
<td>Quad1,2,3:25T/m&lt;br&gt;Quad4: 20.5T/m&lt;br&gt;Quad5: 20T/m</td>
</tr>
<tr>
<td>Buncher Frequency</td>
<td>175MHz</td>
</tr>
<tr>
<td>Maximum $E_0LT$</td>
<td>350kV</td>
</tr>
</tbody>
</table>
Simulation Result

TRACEWIN

WARP
Simulation Result

TRACEWIN

WARP

X(mm) - Y(mm)

Z(mm) - ΔW(MeV)

tail

head

tail

head
Longitudinal space charge: \( F_z = -\frac{q^2 g}{4\pi \varepsilon_0 \gamma^2} \frac{d\lambda}{dz} \) \((\gamma: \text{kinematic factor}, g: 1 + \ln\left(\frac{b}{a}\right))\)
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Future Plan & Summary

- SCC (Space – Charge – Compensation) is essential for achieving required emittance.

- Instability in LEBT, WARP simulation for MEBT will be optimized.

- RFQ, HWR(SRF) simulation can’t be done in warp simulation. Therefore RFQ, HWR(SRF) simulation will be done by TRACEWIN, IMPACT – Z. Results from those two simulation codes will be cross checked.
Thank you!

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