Current status of HEL beam dynamics and open points of the magnetic system

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HEL – New configuration @ flat top

1.13 T
~9.2 mm

0.79 T 1.28 T
~11 mm  ~8.6 mm

Cathode 0.37 T
HEL – New configuration @ Injection

Cathode 3.45 T

0.69 T
~36 mm

0.67 T  1.45 T
~36.5 mm  ~24.8 mm
Magnetic fields in CST for new configuration

Injection mode: Injection energy and with proton beta=280 m at 450GeV => HEL e-beam 8.58 – 17.15 mm which correspond 3.45 T for gun and 3 T for main solenoid

Flat top mode: Top energy and with proton beta=280 m at 7 TeV => HEL e-beam 2.17 – 4.34 mm which correspond 0.37 T for gun and 5 T for main solenoid
For all beam dynamics simulations the real gun profile is used.
Beam dynamic: Injection mode

$\phi \approx 35.5 \text{ mm}$
Beam dynamic: Flat top mode
Beam dynamic: Flat top mode

The residual field inside hollow is no more than 30 kV/m (5A) and no more than 4 kV/m (3A) in the end of main solenoid (which correspond previous simulations).
Fields inside hollow

The max. residual field inside hollow (marker 2) is no more than 30 kV/m (5A). Max. field on outer beam boundary (marker 1) – 0.65 MV/m.

5A

The max. residual field inside hollow (marker 1) is no more than 3.6 kV/m (3A). Max. field on outer beam boundary (marker 2) – 0.35 MV/m.

3A
HEL magnetic system (without collector part)

E-lens OPERA model with correctors. 1 – gun corrector, 2, 4 – short main solenoid correctors, 3, 5 – long main solenoid correctors

Notes:

1) Requirements for the maximum current of the corrector - 120 A (existing power supply)
2) All corrector calculations was performed for the superconductor wire with diameter \( d = 0.92 \text{ mm} \)
3) All calculations was performed for flat top mode
Residual fields due to the bend solenoid

Maximum residual field amplitude $\sim 300$ Gs $\rightarrow$ beam deflection in the entrance and exit of main solenoid $\sim 1.5$ mm
Trajectories of the beam center of mass

Behavior of E beam centroids in the entrance of the main solenoid for different currents in the gun corrector

Beginning of main solenoid

Y, mm

Z, mm

dy~1.1 mm

dy~2 mm

120 A (-y)

120 A (+y)
Correctors model (gun corrector)

### Gun corrector

<table>
<thead>
<tr>
<th>Current</th>
<th>By</th>
<th>Layers/wires (per layer)</th>
<th>Inductance</th>
<th>+y deflection</th>
<th>-y deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 A</td>
<td>1570 Gs</td>
<td>2/70</td>
<td>0.0112 H</td>
<td>6.1 mm</td>
<td>9.5 mm</td>
</tr>
<tr>
<td>120 A</td>
<td>950 Gs</td>
<td>2/70</td>
<td>--/--</td>
<td>3.1 mm</td>
<td>6.5 mm</td>
</tr>
</tbody>
</table>

Maximum deflection of the e–beam trajectories in the entrance of the main solenoid vs. gun corrector current.
Correctors model (Short main corrector)

**Short main solenoid corrector.**

<table>
<thead>
<tr>
<th>Current</th>
<th>By</th>
<th>Layers/wires (per layer)</th>
<th>Inductance</th>
<th>+y deflection</th>
<th>-y deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 A</td>
<td>1030 Gs</td>
<td>3/50</td>
<td>0.0144 H</td>
<td>4.7 mm</td>
<td>3 mm</td>
</tr>
<tr>
<td>120 A</td>
<td>620 Gs</td>
<td>3/50</td>
<td>--/--</td>
<td>3.8</td>
<td>1.7 mm</td>
</tr>
</tbody>
</table>

Maximum deflection of the $e^{-}$-beam trajectories in the entrance of the main solenoid vs. short main solenoid corrector current.
Correctors model (long main corrector)

Long main solenoid corrector

<table>
<thead>
<tr>
<th>Current</th>
<th>By</th>
<th>Layers/wires(per layer)</th>
<th>Inductance</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 A</td>
<td>410 Gs</td>
<td>3/30</td>
<td>0.029 H</td>
</tr>
<tr>
<td>120 A</td>
<td>136 Gs</td>
<td>1/30</td>
<td>0.0032 H</td>
</tr>
</tbody>
</table>

Notes:
1) Requirements for the maximum deflection angle of the corrector - 200 urad
2) 120A and one layer (30 wires) provides ~3 mrad
3) 120A and three layers (90 wires) provides ~9 mrad
Due to magnetic field lines distortion in the middle gap, the full uncentered beam deflection was observed.

\[ \Delta Y = 370 \text{ um} \]

\[ \Delta Y = 230 \text{ um} \]
Blue line correspond deflected e beam centroid due to second main solenoid shifting along Y axis.
Red line corresponds corrected e beam centroid. (Current for short main corrector – 30 A)
Proposal for residual field correction

Step corrector with current $\sim 15$ A and raised bending solenoid along Y axis (10 mm)

Just for proposal! Need to be optimized!
nine laps of nervous tension
PIC and TRK solvers give the same results for the beam after the bend, but here non-optimal grid is used due to PIC solver. In result the errors in the potential distribution and amplitude are arisen.
The comparison of the simulation for the same solvers gives the following result. The beam behavior is the same, but there is the difference between the amplitude and the distribution of the potential (kinetic energy). This is due to precision of the field simulation.
Potential asymmetry at the outer radius

\[ \Delta U_b \approx \frac{I}{2\pi v_b \varepsilon_0} \ln \frac{r_b}{a} - \frac{I}{2\pi v_b \varepsilon_0} \ln \frac{r_b}{2a + \sqrt{3}/2a} = \]

\[ \frac{I}{2\pi v_b \varepsilon_0} \ln \frac{2a + \sqrt{3}/2a}{a} \]

If the beam was solid with parameters \( U_0 = 15 \text{ keV} \), \( v_b = 0.2 \text{ c} \)

\( I = 5 \text{ A}, \ a = 30 \text{ mm}, \ r_b = 1.8 \text{ mm} \), potential difference is

\[ \Delta U_b \approx 1.3 \text{ kV} \]
Potential asymmetry and beam shape perturbation

Particles starting from different azimuthal angles have different rotation velocity

Perturbation of the azimuthally uniform electron density

Non-zero electric field in the hollow increasing with the beam motion through the vacuum chamber