FEL-Seminar

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DESY
Hamburg

27.06.2017
Matching of the actual optics to design optics.

Task: Change quadrupoles upstream of the reference point in a way that Twiss parameters of measurement are equal to design Twiss parameters.

Need:

1. Optics engine \(\Rightarrow\) MAD8 + linac extension = LMAD
2. Actual optics of FLASH \(\Rightarrow\) read out magnet currents and feed into LMAD
   \(\Rightarrow\) script do this.
3. Matching engine \(\Rightarrow\) LMAD (SIMPLEX, MIGRAD, LMDIF)

- Quality factors for comparison of actual and design optics:
  
  mismatch parameter: \( m_p = \frac{1}{2}(\beta\gamma - 2\alpha\hat{\alpha} + \hat{\beta}\gamma) \)

  mismatch amplitude: \( \lambda_p = m_p + \sqrt{m_p^2 - 1} \)

\(\Rightarrow\) The matching is done in a general way.

User can decide which point he wants to match in the beam line (FLASH1/2)
some measurements
some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
some measurements
some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
2. dark current kicker timing scan (?)

![Graph of dark current kicker timing scan](image.png)

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some measurements
some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
2. dark current kicker timing scan (?)
3. choose right energy profile
some measurements
some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
2. dark current kicker timing scan (?)
3. choose right energy profile
4. check machine optics fit to energy profile
some measurements
some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
2. dark current kicker timing scan(?)
3. choose right energy profile
4. check machine optics fit to energy profile
5. measuring on-crest phases
some measurements
some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
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4. check machine optics fit to energy profile
5. measuring on-crest phases
6. setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
some measurements
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7. steering of the orbit in ACC1
some measurements

some pre-setups before measuring beam sizes

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7. steering of the orbit in ACC1
8. setup minimum E-spread
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some pre-setups before measuring beam sizes

① check laser position on virtual cathode
② dark current kicker timing scan(?)
③ choose right energy profile
④ check machine optics fit to energy profile
⑤ measuring on-crest phases
⑥ setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
⑦ steering of the orbit in ACC1
⑧ setup minimum E-spread
⑨ optimizing beam spots on DBC2 screens using solenoid current
some measurements

some pre-setups before measuring beam sizes

1. check laser position on virtual cathode
2. dark current kicker timing scan (?)
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4. check machine optics fit to energy profile
5. measuring on-crest phases
6. setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
7. steering of the orbit in ACC1
8. setup minimum E-spread
9. optimizing beam spots on DBC2 screens using solenoid current
10. close dispersion in dogleg and FL2EXTR
some measurements
injector matching for different charges

charge: 0.29 nC, BSA: 1.2 mm

$\beta_T = 2.45 \text{ m}$  $\beta_M = 2.68 \pm 0.07 \text{ m}$
$\alpha_T = -1.18$  $\alpha_M = -1.30 \pm 0.04$
$\varepsilon_T = 0.49 \text{ um}$  $\varepsilon_M = 0.49 \pm 0.01 \text{ um}$

$m_P = 1.00$  $\lambda_P = 1.09$

$m_P = 1.00$  $\lambda_P = 1.06$
some measurements
injector matching for different charges

charge: 0.41 nC, BSA: 1.2 mm

$4\text{DBC2} \\ 6\text{DBC2} \\ 8\text{DBC2} \\ 10\text{DBC2}$

\[\begin{align*}
\beta_T &= 2.45 \text{ m} & \beta_M &= 2.55 \pm 0.06 \text{ m} \\
\alpha_T &= -1.18 & \alpha_M &= -1.20 \pm 0.03 \\
\varepsilon_T &= 0.54 \text{ um} & \varepsilon_M &= 0.54 \pm 0.01 \text{ um} \\
m_f &= 1.00 & \lambda_f &= 1.05
\end{align*}\]

\[\begin{align*}
\beta_T &= 2.58 \text{ m} & \beta_M &= 2.58 \pm 0.07 \text{ m} \\
\alpha_T &= 1.24 & \alpha_M &= 1.20 \pm 0.05 \\
\varepsilon_T &= 0.51 \text{ um} & \varepsilon_M &= 0.51 \pm 0.02 \text{ um} \\
m_f &= 1.00 & \lambda_f &= 1.04
\end{align*}\]
some measurements
injector matching for different charges

charge: 0.47 nC, BSA: 1.3 mm

\[ \beta_T = 2.45 \text{ m} \quad \beta_M = 2.63 \pm 0.08 \text{ m} \]
\[ \alpha_T = -1.18 \quad \alpha_M = -1.32 \pm 0.04 \]
\[ \varepsilon_T = 0.53 \text{ um} \quad \varepsilon_M = 0.53 \pm 0.01 \text{ um} \]
\[ m_p = 1.00 \quad \lambda_p = 1.09 \]

\[ \beta_T = 2.58 \text{ m} \quad \beta_M = 2.80 \pm 0.08 \text{ m} \]
\[ \alpha_T = 1.24 \quad \alpha_M = 1.31 \pm 0.06 \]
\[ \varepsilon_T = 0.52 \text{ um} \quad \varepsilon_M = 0.52 \pm 0.02 \text{ um} \]
\[ m_p = 1.00 \quad \lambda_p = 1.10 \]
some measurements
injector matching for different charges

charge: 0.57 nC, BSA: 1.5 mm

4DBC2 6DBC2 8DBC2 10DBC2

$\beta_T = 2.45 \text{ m}$  $\beta_M = 2.64 \pm 0.09 \text{ m}$
$\alpha_T = -1.18$  $\alpha_M = -1.31 \pm 0.05$
$\varepsilon_T = 0.57 \text{ um}$  $\varepsilon_M = 0.57 \pm 0.01 \text{ um}$

$m_T = 1.00$  $\lambda_T = 1.09$

$m_M = 1.00$  $\lambda_M = 1.07$
some measurements
Injector match of LASER 1 while LASER 2 is matched using free parameters
some measurements
comparing different beam size estimations methods

OTR8DBC2

\text{gauss: } f(x) = A \exp \left( \frac{(x-x_0)^2}{2s^2} \right)

\text{asymsupergauss: } g(x) = A \exp \left( -\frac{|x-x_0|^n}{2|x-\text{sign}(x-x_0)c|^n} \right)

\begin{array}{c|c|c}
\text{value} & \text{error} & \text{value} & \text{error} \\
\hline
\mu_x (px) & -1.11 & 4.40 & 0.53 & 0.00 \\
\mu_y (px) & -0.91 & 1.69 & 0.36 & 0.00 \\
\sigma_x (px) & 8.00 & 0.23 & 6.77 & 0.04 \\
\sigma_y (px) & 7.97 & 0.11 & 6.54 & 0.09 \\
\mu_{3,x}/\sigma_x & -0.70 & 0.20 & -0.00 & 0.00 \\
\mu_{3,y}/\sigma_y & -0.20 & 0.06 & -0.00 & 0.00 \\
\mu_{4,x}/\sigma_x & 8.64 & 1.10 & 3.00 & 0.00 \\
\mu_{4,y}/\sigma_y & 4.13 & 0.12 & 3.00 & 0.00 \\
\end{array}
some measurements comparing different beam size estimations methods

OTR5DBC3

gauss: \( f(x) = A \exp \left( -\frac{(x-x_0)^2}{2s^2} \right) \)

asymsupergauss: \( g(x) = A \exp \left( -\frac{|x-x_0|^n}{2s(1+\text{sign}(x-x_0)e)^n} \right) \)

file mode

Moments gauss
BeamSize_ROI_0010.dat

file mode

Moments asymsupergauss
BeamSize_ROI_0010.dat

<table>
<thead>
<tr>
<th></th>
<th>gauss</th>
<th>asymsupergauss</th>
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<tbody>
<tr>
<td>value</td>
<td>error</td>
<td>value</td>
</tr>
<tr>
<td>( \mu_x ) (px)</td>
<td>-1.15</td>
<td>0.00</td>
</tr>
<tr>
<td>( \mu_y ) (px)</td>
<td>-0.59</td>
<td>0.00</td>
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<tr>
<td>( \sigma_x ) (px)</td>
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<td>0.32</td>
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<td>( \sigma_y ) (px)</td>
<td>15.05</td>
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<td>( \mu_3 / \sigma_3 )</td>
<td>0.32</td>
<td>0.00</td>
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<tr>
<td>( \mu_3 / \sigma_3 )</td>
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<tr>
<td>( \mu_4 / \sigma_4 )</td>
<td>3.19</td>
<td>0.00</td>
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</table>
some measurements

**BC3 matching**

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**theory optics**

- **Q1DBC3 → OTR5DBC3**

- **Q2DBC3 → OTR5DBC3**

- **Q3DBC3 → OTR5DBC3**

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**symmetrized QS**

- **Q3DBC3 → OTR5DBC3**
some measurements

BC3 matching, back-tracking measurements to STARTACC2 to compare reconstruction results

<table>
<thead>
<tr>
<th>Design</th>
<th>Reconstructed</th>
<th>Measured</th>
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<tbody>
<tr>
<td>Location</td>
<td>STARTACC2</td>
<td>MQ1DBC3.U</td>
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<tr>
<td>Beta x</td>
<td>+7.237</td>
<td>+8.394</td>
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<tr>
<td>Alpha x</td>
<td>-0.178</td>
<td>-0.925</td>
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<tr>
<td>Beta y</td>
<td>+6.046</td>
<td>+7.907</td>
</tr>
<tr>
<td>Alpha y</td>
<td>-0.093</td>
<td>+1.576</td>
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<tr>
<td>Location</td>
<td>MQ1DBC3.U</td>
<td>STARTACC2</td>
</tr>
<tr>
<td>Beta x</td>
<td>+12.537</td>
<td>+6.731</td>
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<tr>
<td>Alpha x</td>
<td>-1.927</td>
<td>-0.281</td>
</tr>
<tr>
<td>Beta y</td>
<td>+4.149</td>
<td>+9.379</td>
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<tr>
<td>Alpha y</td>
<td>-0.041</td>
<td>+2.082</td>
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<tbody>
<tr>
<td>Location</td>
<td>STARTACC2</td>
<td>MQ2DBC3.U</td>
</tr>
<tr>
<td>Beta x</td>
<td>+7.742</td>
<td>+7.280</td>
</tr>
<tr>
<td>Alpha x</td>
<td>+0.915</td>
<td>+0.025</td>
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<tr>
<td>Beta y</td>
<td>+4.902</td>
<td>-12.441</td>
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<tr>
<td>Alpha y</td>
<td>-1.875</td>
<td>-2.798</td>
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<tr>
<td>Location</td>
<td>MQ2DBC3.U</td>
<td>STARTACC2</td>
</tr>
<tr>
<td>Beta x</td>
<td>+16.233</td>
<td>+2.870</td>
</tr>
<tr>
<td>Alpha x</td>
<td>-1.965</td>
<td>+2.735</td>
</tr>
<tr>
<td>Beta y</td>
<td>+3.042</td>
<td>+2.413</td>
</tr>
<tr>
<td>Alpha y</td>
<td>+1.985</td>
<td>+2.456</td>
</tr>
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<tr>
<td>Location</td>
<td>MQ3DBC3.U</td>
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</tr>
<tr>
<td>Beta x</td>
<td>+16.450</td>
<td>+2.872</td>
</tr>
<tr>
<td>Alpha x</td>
<td>-2.182</td>
<td>-2.072</td>
</tr>
<tr>
<td>Beta y</td>
<td>+3.164</td>
<td>+2.326</td>
</tr>
<tr>
<td>Alpha y</td>
<td>+1.141</td>
<td>+2.072</td>
</tr>
</tbody>
</table>

limited data set: 11 points around the waist
some measurements

SFUND matching

charge: 0.41 nC, BSA: 1.2 mm

$\beta_T = 4.20 \, m \quad \beta_M = 3.98 \pm 0.05 \, m$

$\alpha_T = -0.36 \quad \alpha_M = -0.28 \pm 0.03$

$\varepsilon_T = 1.49 \, um \quad \varepsilon_M = 1.49 \pm 0.04 \, um$

$\gamma = 1.00 \quad \lambda_T = 1.09$

$\gamma = 1.02 \quad \lambda_M = 1.24$

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some measurements
undulator match

charge: 0.41 nC, BSA: 1.2 mm

\[\beta_T = 13.06 \text{ m}, \quad \beta_M = 12.60 \pm 0.57 \text{ m}\]
\[\alpha_T = 1.18, \quad \alpha_M = 1.11 \pm 0.09\]
\[\varepsilon_T = 1.08 \text{ um}, \quad \varepsilon_M = 1.08 \pm 0.06 \text{ um}\]
\[m_p = 1.00, \quad \lambda_p = 1.05\]

\[\beta_T = 6.30 \text{ m}, \quad \beta_M = 7.40 \pm 0.12 \text{ m}\]
\[\alpha_T = 0.66, \quad \alpha_M = 0.85 \pm 0.03\]
\[\varepsilon_T = 1.28 \text{ um}, \quad \varepsilon_M = 1.28 \pm 0.03 \text{ um}\]
\[m_p = 1.02, \quad \lambda_p = 1.19\]

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Bunch shape dependence on orbit in BC3.

Dispersion is not an explanation:

\[ \Delta E = \begin{cases} 200 \text{ keV} & \rightarrow D \sim 1 \text{ m} \\ 700 \text{ MeV} & \rightarrow D \sim 2.3 \text{ cm} \end{cases} \]

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Appendix.
Matching of the actual optics to design optics.

Procedure:

1. Measurement of the current Twiss parameters at a reference point.

2. Reconstruct Twiss parameters at a start marker upstream of the matching quadrupoles.
   - This is done by ‘matching’ the initial Twiss parameter using LMAD.

3. Match the actual optics to design optics at reference point by user defined quadrupoles.
   - This is done by LMAD.

4. Generate a current list of the new quadrupole strengths.

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Emittance and optics measurement.

Special cases:
1. Single quad scan: L=1, N=1
2. 4-screen method: L=0, N=4

Set of equations has to be solved: (with \((n,l)\)-th measured beam size \(\sigma_{n,l}\))

\[
M_{(n,l),1\cdots3} = \left( \left( R_{l\leftarrow0}^{(n)} \right)_{q,q}^2, 2 \left( R_{l\leftarrow0}^{(n)} \right)_{q,q} \left( R_{l\leftarrow0}^{(n)} \right)_{q,p}, \left( R_{l\leftarrow0}^{(n)} \right)_{q,p}^2 \right) \right)
\]

\[
\begin{bmatrix}
\sigma_0^2 \\
\text{Cov}(q,p)_0 \\
\sigma_{p,0}^2 \\
\end{bmatrix}
= 
\begin{bmatrix}
\sigma_{n=1,l=1}^2 \\
\vdots \\
\sigma_{n,l}^2 \\
\sigma_{n=N,l=L}^2 \\
\end{bmatrix}
\]

- Transfer matrix \(R\)
- \(x\)-plane: \((q,p) = (1,2)\)
- \(y\)-plane: \((q,p) = (3,4)\)
some more quad scans

in theory
some more quad scans
in theory
some more quad scans

in theory

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some more quad scans

in theory
some more quad scans

in theory
some more quad scans
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some more quad scans

in theory