Optics studies at FLASH in 2016-2017. FEL-Seminar

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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: Optics engine ⇒ MAD8 + linac extension = LMAD
 Actual optics of FLASH ⇒ read out magnet currents and feed into LMAD ⇒ script do this.
 - **③** Matching engine \Rightarrow LMAD (SIMPLEX, MIGRAD, LMDIF)
 - Quality factors for comparison of actual and design optics:

mismatch parameter:
$$m_p = \frac{1}{2}(\beta\hat{\gamma} - 2\alpha\hat{\alpha} + \hat{\beta}\gamma)$$

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 pre-setups before measuring beam sizes

• check laser position on virtual cathode

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check laser position on virtual cathodedark current kicker timing scan(?)



- Check laser position on virtual cathode
- Ø dark current kicker timing scan(?)
- S choose right energy profile



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- Ø dark current kicker timing scan(?)
- $\textcircled{\textbf{$0$}} choose right energy profile$
- ${\ensuremath{\textcircled{}}}$ check machine optics fit to energy profile
- measuring on-crest phases
- setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
- $\boldsymbol{0}$ steering of the orbit in ACC1

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- Ø dark current kicker timing scan(?)
- $\textcircled{\textbf{$0$}} choose right energy profile$
- 4 check machine optics fit to energy profile
- 6 measuring on-crest phases
- setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
- $\boldsymbol{0}$ steering of the orbit in ACC1

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6DBC2

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TTF2.DIAG/CAM.BC2/6DB0

- ① check laser position on virtual cathode
- Ø dark current kicker timing scan(?)
- € choose right energy profile
- 4 check machine optics fit to energy profile
- 6 measuring on-crest phases
- setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
- $\boldsymbol{0}$ steering of the orbit in ACC1







308.9 A

Bucking Coil

-26.00

-26.0

-26.0 A

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- (3) setup minimum E-spread





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- measuring on-crest phases
- setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
- $\boldsymbol{0}$ steering of the orbit in ACC1
- (3) setup minimum E-spread
- optimizing beam spots on DBC2 screens using solenoid current

| Injector settings | | | | | | | B., | LOLA & Kick | er off |
|-----------------------------|-----------------|--|---------------------|-----------------------|--------------------------|---------------------|------------------|-----------------|--------------------------|
| Charge 0.29 nC | | | | | | | Camera xn | TTF2.DIAG/CAN | 1.BC2/3BC2/* |
| BSA Chos | KLY Co. Inc. | 3 KL | 12 | | KLY6 | 3BC2 None | | | TTF2.DIAG.YOAM.BC2/3BC2. |
| Common Flash | 1 Fla | sh 2 | | | | Shutter: +^^80.0 | Gain: + 602.0 | Brightness: | Print Mages |
| Laser 2 Bunches 000 | slow R | :F FB on/off | всм | BC | H 10802.1 corrected | Controls | image _ | Rate [Hz]: 10.0 | Frame: 12490659 |
| Flash 2 1 | FB | okay? | вам | -0.387 | \$8-900 L | | | | |
| 251 kHz block Flash 1 | | in the second seco | | 9.4636 | £008-38 🗆 | | | | |
| Flash2 blocked | Flash 2 | GUN 53.99 | 2 | ACC1 159.37 | ACC39 19.55 | | | | |
| 771.2 MV | SP | <u>5</u> 3.99 | â 🔳 | î\$9.20 H | 19.50 H | | | | |
| RBV Vector Sum 771.4 MeV | old RB | 53,992 1 53,991 1 | dVin Win | 159.7 MV 160.6 MV | 18.5 MV | | | | |
| Main Solenoid | Flash 2 | 0.00 | | 5.77 | -8.62 | | | | |
| Bucking Coll | Phase | £000.0 | iộ 🔳 | ÷000.54 🗏 | 0000.00 M | | | | |
| -26.0 A | old RB | 0.00 |) deg I deg | 0.50 deg -2.79 deg | -0.00 deg -151.04 deg | | | @ | |
| | an-creat: | 0.0 de 10-10-2016 | 9 ? 07:50 | 0.0 deg ? | 0.0 deg 🙎 | | | | |

- ① check laser position on virtual cathode
- Ø dark current kicker timing scan(?)
- $\textcircled{\textbf{$0$}} choose right energy profile$
- O check machine optics fit to energy profile
- B measuring on-crest phases
- setup charge right, BSA setting (a hint for me, because this is my main fault when setup this)
- $\boldsymbol{0}$ steering of the orbit in ACC1
- (3) setup minimum E-spread
- optimizing beam spots on DBC2 screens using solenoid current
- ${\rm (I)}$ close dispersion in dogleg and FL2EXTR



injector matching for different charges

charge: 0.29 nC, BSA: 1.2 mm

4DBC2 6DBC2 8DBC2 10DBC2

| $eta_T=$ 2.45 m | $eta_M=$ 2.68 +- 0.07 m |
|------------------------|--------------------------------|
| $\alpha_T = -1.18$ | $\alpha_M =$ -1.30 +- 0.04 |
| $arepsilon_T=$ 0.49 um | $arepsilon_M=$ 0.49 +- 0.01 um |
| | |
| $m_P = 1.00$ | $\lambda_P =$ 1.09 |

| $eta_T=$ 2.58 m | $eta_M =$ 2.73 +- 0.06 m |
|------------------------|--------------------------------|
| $lpha_T=$ 1.24 | $lpha_M=$ 1.34 +- 0.05 |
| $arepsilon_T=$ 0.49 um | $arepsilon_M=$ 0.49 +- 0.01 um |
| | |
| $m_P = 1.00$ | $\lambda_P = 1.06$ |







6DBC2 (68.3199um RMS hor)





10DBC2 (68.6649um RMS hor)



injector matching for different charges

charge: 0.41 nC, BSA: 1.2 mm

4DBC2 6DBC2 8DBC2 10DBC2

| $eta_T=$ 2.45 m | $eta_M=$ 2.55 +- 0.06 m |
|------------------------|--------------------------------|
| $\alpha_T = -1.18$ | $\alpha_M =$ -1.20 +- 0.03 |
| $arepsilon_T=$ 0.54 um | $arepsilon_M=$ 0.54 +- 0.01 um |
| | |
| $m_P = 1.00$ | $\lambda_P =$ 1.05 |

| $eta_T=$ 2.58 m | $\beta_M =$ 2.58 +- 0.07 m |
|------------------------|--------------------------------|
| $lpha_T=$ 1.24 | $lpha_M=$ 1.20 +- 0.05 |
| $arepsilon_T=$ 0.51 um | $arepsilon_M=$ 0.51 +- 0.02 un |
| | |
| $m_P = 1.00$ | $\lambda_P = 1.04$ |







6DBC2 (68.0799um RMS hor)





10DBC2 (70.5982um RMS hor)

(66.2722um RMS ver)

injector matching for different charges

charge: 0.47 nC, BSA: 1.3 mm

4DBC2 6DBC2 8DBC2 10DBC2

| $eta_T=$ 2.45 m | $eta_M=$ 2.63 +- 0.08 m |
|------------------------|--------------------------------|
| $\alpha_T = -1.18$ | $\alpha_M =$ -1.32 +- 0.04 |
| $arepsilon_T=$ 0.53 um | $arepsilon_M=$ 0.53 +- 0.01 um |
| | |
| $m_P = 1.00$ | $\lambda_P =$ 1.09 |

| $eta_T=$ 2.58 m | $eta_M =$ 2.80 +- 0.08 m |
|------------------------|--------------------------------|
| $\alpha_T = 1.24$ | $lpha_M=$ 1.31 +- 0.06 |
| $arepsilon_T=$ 0.52 um | $arepsilon_M=$ 0.52 +- 0.02 um |
| | |
| $m_P = 1.00$ | $\lambda_P = 1.10$ |







6DBC2 (71.0509um RMS hor)







J. Zemella, Μ. Vogt (DESΥ

injector matching for different charges

charge: 0.57 nC, BSA: 1.5 mm

4DBC2 6DBC2 8DBC2 10DBC2

| $eta_T=$ 2.45 m | $eta_M=$ 2.64 +- 0.09 m |
|------------------------|--------------------------------|
| $\alpha_T = -1.18$ | $\alpha_M =$ -1.31 +- 0.05 |
| $arepsilon_T=$ 0.57 um | $arepsilon_M=$ 0.57 +- 0.01 um |
| | |
| $m_P = 1.00$ | $\lambda_P =$ 1.09 |

| $eta_T=$ 2.58 m | $eta_M =$ 2.63 +- 0.07 m |
|------------------------|--------------------------------|
| $lpha_T=$ 1.24 | $lpha_M=$ 1.20 +- 0.05 |
| $arepsilon_T=$ 0.55 um | $arepsilon_M=$ 0.55 +- 0.01 um |
| | |
| $m_P = 1.00$ | $\lambda_P = 1.07$ |







GDBC2 (72.3392um RMS hor)





(68.2595um RMS ver)

Injector match of LASER 1 while LASER 2 is matched using free parameters









comparing different beam size estimations methods OTR8DBC2

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



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

ver/beamprofile server/MeasurementData/2016-10-11T140035-OTR.DBC2/Image-OTR.8DBC2-2(ver/beamprofile server/beamprofile server/beamprof



comparing different beam size estimations methods OTR5DBC3

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

BeamSize_ROI_0010.dat



asymsupergauss: $g(x) = A \exp^{-\frac{|x-x_0|^n}{2|s(1+sign(x-x_0)e)|^n}}$ BeamSize ROI 0010.dat



some measurements BC3 matching



J. Zemella, M. Vogt (DESY

FEL-Seminar.

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

| full data set: | | Q1DBC2 \rightarrow OTR5DBC3 | | Q2DBC2 \rightarrow OTR5DBC3 | | Q3DBC2→OTR5DBC3 | | symm. QS: Q3DBC2→OTR5DBC3 | |
|-------------------|-------------------|-------------------------------|-----------|-------------------------------|-----------|-----------------|-----------|---------------------------|-----------|
| | Design | Reconstructed | Measured | Reconstructed | Measured | Reconstructed | Measured | Reconstructed | Measured |
| Location | STARTACC2 | STARTACC2 | MQ1DBC3.U | STARTACC2 | MQ2DBC3.U | STARTACC2 | MQ3DBC3.U | STARTACC2 | MQ3DBC3.U |
| $Beta \times (m)$ | +7.237 | +8.394 | +12.537 | +6.731 | +7.742 | +7.280 | +4.593 | +16.233 | +2.456 |
| Alpha x | -0.178 | -0.925 | -1.927 | -0.281 | +0.915 | +0.025 | +2.076 | -1.965 | +1.891 |
| Beta y (m) | +6.046 | +7.907 | +4.149 | +9.379 | +3.983 | +12.441 | +4.902 | +3.042 | +1.985 |
| Alpha y | -0.093 | +1.576 | -0.041 | +2.082 | -0.967 | +2.798 | -1.875 | -0.690 | +1.124 |
| limited data | set: 11 points ar | ound the waist | _ | | _ | | | | |

| | Design | Reconstructed | Measured | Reconstructed | Measured | Reconstructed | Measured | Reconstructed | Measured |
|------------|-----------|---------------|-----------|---------------|-----------|---------------|-----------|---------------|-----------|
| Location | STARTACC2 | STARTACC2 | MQ1DBC3.U | STARTACC2 | MQ2DBC3.U | STARTACC2 | MQ3DBC3.U | STARTACC2 | MQ3DBC3.U |
| Beta x (m) | +7.237 | +8.222 | +12.088 | +8.019 | +9.625 | +8.700 | +6.917 | +16.450 | +2.872 |
| Alpha x | -0.178 | -0.860 | -1.822 | -0.477 | +1.123 | -0.426 | +2.897 | -2.182 | +2.326 |
| Beta y (m) | +6.046 | +8.786 | +5.013 | +9.223 | +5.138 | +10.068 | +7.669 | +3.164 | +2.072 |
| Alpha y | -0.093 | +1.540 | +0.087 | +1.772 | -1.124 | +1.905 | -2.906 | -0.681 | +1.141 |

some measurements SFUND matching

charge: 0.41 nC, BSA: 1.2 mm

1SFUND1 1SFUND2 1SFUND3 1SFUND4

| $eta_T=$ 4.20 m | $\beta_M =$ 3.98 +- 0.05 m |
|------------------------|--------------------------------|
| $\alpha_T = -0.36$ | $\alpha_M =$ -0.28 +- 0.03 |
| $arepsilon_T=$ 1.49 um | $arepsilon_M=$ 1.49 +- 0.04 um |

 $m_P = 1.00$ $\lambda_P = 1.09$



 $\lambda_P = 1.24$



1SFUND3





1SFUND2

1SFUND4





 $m_P = 1.02$

J. Zemella, M. Vogt (DESY

some measurements undulator match

charge: 0.41 nC, BSA: 1.2 mm

WIRE5UND1 WIRE5UND2 WIRE5UND3 WIRE5UND5 WIRE5UND6

| $eta_T=$ 13.06 m | $eta_M=$ 12.60 +- 0.57 m | $eta_T=$ 6.30 m | $eta_M=$ 7.40 +- 0.12 m |
|-------------------------|--------------------------------|------------------------|--------------------------------|
| $\alpha_T = 1.18$ | $lpha_{M} =$ 1.11 +- 0.09 | $\alpha_T = -0.66$ | α_M = -0.85 +- 0.03 |
| $arepsilon_T =$ 1.08 um | $arepsilon_M=$ 1.08 +- 0.06 um | $arepsilon_T=$ 1.28 um | $arepsilon_M=$ 1.28 +- 0.03 um |
| | | | |
| $m_P = 1.00$ | $\lambda_P = 1.05$ | $m_P = 1.02$ | $\lambda_P=$ 1.19 |







Bunch shape dependence on orbit in BC3.

Dispersion is not an explanation:

 $\begin{array}{l} \frac{\Delta E}{E} = \frac{200 \ \mathrm{keV}}{700 \ \mathrm{MeV}} \rightarrow D \sim 1 \ \mathrm{m \ or} \\ \frac{\Delta E}{E} = \frac{8.5 \ \mathrm{MeV}}{700 \ \mathrm{MeV}} \rightarrow D \sim 2.3 \ \mathrm{cm} \end{array}$









27.06.2017 12 / 16

Appendix.

Matching of the actual optics to design optics.

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

Reconstruct Twiss parameters at a start marker upstream of the matching quadrupoles. Ly This is done by 'matching' the initial Twiss parameter using LMAD.

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

4 Generate a current list of the new quadrupole strengths.



Emittance and optics measurement.



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

$$\begin{split} \mathbf{M}_{(n,l),1\cdots 3} &= \left(\left(\mathbf{R}_{l\leftarrow 0}^{(n)} \right)_{q,q}^{2}, 2 \left(\mathbf{R}_{l\leftarrow 0}^{(n)} \right)_{q,q} \left(\mathbf{R}_{l\leftarrow 0}^{(n)} \right)_{q,p}, \left(\mathbf{R}_{l\leftarrow 0}^{(n)} \right)_{q,p}^{2} \right) \\ \mathbf{M} & \left(\begin{array}{c} \sigma_{0}^{2} \\ \operatorname{Cov}(q,p)_{0} \\ \sigma_{p,0}^{2} \end{array} \right) = \left(\begin{array}{c} \sigma_{n=1,l=1}^{2} \\ \cdots \\ \sigma_{n,l}^{2} \\ \cdots \\ \sigma_{n=N,l=L}^{2} \end{array} \right) \\ \end{split}$$

Special cases:

- Single quad scan: L=1, N=1
- ❷ 4-screen method: L=0, N=4

Transfer matrix R
x-plane: (q,p) = (1,2)
y-plane: (q,p) = (3,4)



some more quad scans











some more quad scans

