compensation of rf coupler kicks
1st attempt

previous investigations

calculation of coupler kicks

local compensation

not quite local compensation

global compensation

beam dynamics

summary and remarks
s2e-meeting 21.May 2007: Emittance Growth by RF Coupler Kicks

IMPACT ON THE XFEL PHOTOINJECTOR

We present a practical example of the coupler effect on the beam dynamics by considering the x-ray FEL photoinjector [5]. In the injector, the electron beam is emittances with $E_x = 23$ MV/m and $E_y = 50$ MV/m. Figure 7 compares the $x$ and $y$ parameter evolutions along the injector beamline from the photocathode surface ($z = 0$) up to the end of the accelerating module. The field disturbances caused by coupler result in a 16% and 1% relative emittance growth, respectively, in the horizontal and vertical planes. The induced steering results in beams displacements at the accelerating module exit of $|\Delta z| = 500 \mu$m and $|\Delta y| = 170 \mu$m and no significant $x-y$ coupling is observed.

$h = 17\%$
$v = 1\%$

ASTRA calculation for ACC1

- horizontal vertical no couplers
- horizontal vertical no couplers
- projected emittance

\[
\begin{align*}
\frac{E_{p,x}}{E_{p,\text{no coupler}}} & \approx 1.11 \\
\frac{E_{p,y}}{E_{p,\text{no coupler}}} & \approx 1.051
\end{align*}
\]

- slice emittance (center 10% charge)

\[
\begin{align*}
\frac{E_{x,x}}{E_{x,\text{no coupler}}} & \approx 1.028 \\
\frac{E_{y,y}}{E_{y,\text{no coupler}}} & \approx 1.021
\end{align*}
\]
conclusions, questions

similar results as Philippe

growth of horizontal emittance in ACC1: projected 11%, slice 3%  
1st order effect = offset independent field (centroid shift)  
2nd order effect = offset dependent field  
5.5%, 2.8%

horiz. emittance growth to end of ACC2: projected 16%, slice 3%

V. Tsakanov

Summary

• Coupler RF Field effects

ACCEL1 – 5-100 MeV  
Emittance growth - 14 %

Linac 1 – 100-500 MeV  
Emittance growth – 5%

• Other effects - below 1%
calculation of coupler kicks

the old MAFIA method
see: http://adweb.desy.de/~mpymax/mafia/HOM_Coupler/index.html

TTF HOM Coupler

Documentation including a calculation procedure (pdf file, 5 pages) has been written by M. Dohlus.

Calculation downstream without coupler (reference file)

Command files:
- Geometry: m.com
- Running T: t3.com
- Running P: psign.com
- Output files: outfiles

Note: T3 calculations have been done with magnetic boundary conditions in beam (z-) direction.

Calculation downstream with coupler

The following tables give the results for different penetration depths of 6 and mm (zpen).

<table>
<thead>
<tr>
<th>zpen=6mm</th>
<th>downstream with coupler</th>
<th>downstream with coupler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command files:</td>
<td>m.com (ic=1,ic=1)</td>
<td>m.com (ic=0,ic=1)</td>
</tr>
<tr>
<td>T3</td>
<td>t3.com (t3 materials=3, t3 waveguide section)</td>
<td>t3.com</td>
</tr>
<tr>
<td>e.com</td>
<td>e.com</td>
<td></td>
</tr>
<tr>
<td>psign.com</td>
<td>psign.com</td>
<td></td>
</tr>
<tr>
<td>fortran.exe</td>
<td>fortran.exe</td>
<td></td>
</tr>
<tr>
<td>reader.mcd</td>
<td>reader.mcd</td>
<td></td>
</tr>
<tr>
<td>prenorm.com</td>
<td>prenorm.com</td>
<td></td>
</tr>
<tr>
<td>def bref=... (from fresult.dat)</td>
<td>def bref=... (from fresult.dat)</td>
<td></td>
</tr>
<tr>
<td>--&gt; e=1 (normalized to e=10MV/m)</td>
<td>--&gt; enez (normalized to enez=10MV/m)</td>
<td></td>
</tr>
<tr>
<td>bre=0.5 (transverse, bterm)</td>
<td>bre=0.5 (transverse, bterm)</td>
<td></td>
</tr>
<tr>
<td>bterm= (bterm=bre)</td>
<td>bterm= (bterm=bre)</td>
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<tr>
<td>bterm= (bterm=bre)</td>
<td>bterm= (bterm=bre)</td>
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</tr>
<tr>
<td>pfield.com</td>
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<td>fortran_fields.exe</td>
<td>fortran_fields.exe</td>
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</tr>
<tr>
<td>reader_fields.mcd</td>
<td>reader_fields.mcd</td>
<td></td>
</tr>
<tr>
<td>calculate kick ...</td>
<td>calculate kick ...</td>
<td></td>
</tr>
</tbody>
</table>

a lengthy procedure:
- about 10 MAFIA runs
- intermediate processing with fortran program
- final post processing with mathcad
calculation of coupler kicks

**mode of operation:** steady state, pure forward wave, $z_{pen}=6\text{mm}$ $\rightarrow Q_e \approx 3.5\times 10^6$

kick from input coupler depends on forward and backward waves!

the old main and HOM coupler geometry

comparison with FNAL geometry (report Lunin, Solyak, Yakolev)
the actual DESY geometry is probably similar

**everything could be done better**

discretization
field calculation $\quad$ but more time consuming!
calculation of coupler kicks

existing version

TTF coupler, downstream, new geometry, zpen=6mm

center: \[
\frac{\gamma_{B,1}}{\gamma_z} L' | \{l_{11}\} = -34.258 + 53.881i
\]

\[
\frac{\gamma_{B,1}}{\gamma_z} L' | \{l_{12}\} = 21.201 + 5.483i
\]

TTF coupler, upstream

center: \[
\frac{\gamma_{B,1}}{\gamma_z} L' | \{l_{(21)}\} = -39.339 + 9.412i
\]

\[
\frac{\gamma_{B,1}}{\gamma_z} L' | \{l_{(22)}\} = -43.439 - 1.833i
\]
calculation of coupler kicks

existing version (all couplers together)

picture only for visualization:

new geometry, zpen=6mm

center: (both)
$\psi_{a,b}^{1.0} = -0.6367 + 0.336i$
$\psi_{a,b}^{3.0} = -12.158 + 3.65i$

name1 = "kick_upstream_kick.dat"
nname2 = "kick_downstream_kick.dat"
local compensation

(downstream = unchanged)

(upstream with compensation)

not perfect due to numerical errors!

real or virtual 2nd HOM coupler

TTF coupler, downstream, new geometry, zpen=6mm

center: \[ \frac{V_{h,1}}{V_h} \times 10^6 = 34.25 \times 10^6 \] 

\[ \frac{V_{h,2}}{V_h} \times 10^6 = 21.301 \times 10^6 \]

sensor

E

TTF coupler, upstream

center: \[ \frac{V_{h,1}}{V_h} \times 10^6 = 0.933 + 0.352i \] 

\[ \frac{V_{h,2}}{V_h} \times 10^6 = 0.969 - 0.997i \]
local compensation  version u2

(downstream = unchanged)  (upstream with compensation)

virtual 2nd HOM coupler
reduced length

TTF coupler, downstream, new geometry, zpen=6mm

center: \[
\frac{V_{h,1}}{V_h} \cdot 10^6 = -34.238 + 53.98i
\]
\[
\frac{V_{h,2}}{V_h} \cdot 10^6 = 21.201 + 3.48i
\]

TTF coupler, upstream

center: \[
\frac{V_{h,1}}{V_h} \cdot 10^6 = -22.521 + 11.54i
\]
\[
\frac{V_{h,2}}{V_h} \cdot 10^6 = -140.09 + 9.13i
\]
local compensation  version u3

(downstream = unchanged)  

(upstream with compensation)

TTF coupler, downstream, new geometry, zpen=6mm

\[
\begin{align*}
\text{center:} & \quad \frac{\nu_{y,1} - \nu_{y,2}}{\nu_2} = -34.25 + 53.84 \text{i} \\
& \quad \frac{\nu_{y,1} + \nu_{y,2}}{\nu_2} = 21.301 + 5.481 \text{i}
\end{align*}
\]

TTF coupler, upstream

\[
\begin{align*}
\text{center:} & \quad \frac{\nu_{y,1} - \nu_{y,2}}{\nu_2} = -6.923 + 35.784 \text{i} \\
& \quad \frac{\nu_{y,1} + \nu_{y,2}}{\nu_2} = -13.643 + 3.394 \text{i}
\end{align*}
\]

10 mm penetration!
not quite local compensation

version 1

reduce real part of sum

(downstream = unchanged)

(upstream with compensation)

TTF coupler, downstream, new geometry, zpen=6mm

\[
\begin{align*}
\text{center: } & \frac{V_{h,b,3}}{V_{a}} \cdot 10^6 = -342.28 + 53.90 i \\
& \frac{V_{h,4,3,6}}{V_{a}} \cdot 10^6 = 21.301 + 1.453 i
\end{align*}
\]

TTF coupler, upstream

\[
\begin{align*}
\text{center: } & \frac{V_{h,b,3}}{V_{a}} \cdot 10^6 = 39.961 + 37.917 i \\
& \frac{V_{h,4,3,6}}{V_{a}} \cdot 10^6 = -42.745 - 1.84 i
\end{align*}
\]
not quite local compensation

version 1

reduce real part of sum

(downstream = unchanged)

(upstream with compensation)

new geometry, zpen=6mm

center:
  (both)

\begin{align*}
  \omega_{u,y}^{(1)} &= 15.703 + 91.885 i \\
  \omega_{u,y}^{(2)} &= -11.444 + 3.648 i
\end{align*}

case1 = "lack_upstream_comp@dit"
case2 = "lack_downstream_lack.dat"
not quite local compensation

version 2

reduce imaginary part of sum

(downstream = unchanged)

(upstream with compensation)

TTF coupler, downstream, new geometry, zpen=6mm

\[
\frac{V_{b,i}}{V_{k}} i L^6 = -34.238 + 53.838i
\]

\[
\frac{V_{y,b,i}}{V_{c}} y L^6 = 31.301 + 3.482i
\]

TTF coupler, upstream

\[
\frac{V_{b,i}}{V_{k}} i L^6 = -39.207 - 34.325i
\]

\[
\frac{V_{y,b,i}}{V_{c}} y L^6 = 43.298 + 0.311i
\]
not quite local compensation

(new geometry, $z_{pen}=6\text{mm}$)

(downstream = unchanged)

(1) not quite local compensation

(2) reduce imaginary part of sum

(3) upstream with compensation

[Diagram showing new geometry with $z_{pen}=6\text{mm}$ and corresponding flow field plots]

**center:**

- $\psi_{B_{y}}$: $10^6 = -62.045 + 17.735i$
- $\psi_{B_{y1}}$: $10^3 = 7.9349 + 3.8353i$

name = "back_upstream_comp.dat"

name2 = "back_downstream_comp.dat"
global compensation

simple geometry transformations: rotation- or mirror-transformation


redesign of distribution network and cryostat

one side distribution network

two side distribution network

same or similar arguments for rf-fields and wake-fields

different energy at kick and compensating kick

→ is global compensation possible at the very low energy of ACC1?
## Global Compensation

### General Discussion (Standard Modules / 3rd Harm. Modules)


### Summary – Complex Coupler Kick:

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>cav</strong></td>
<td>a, b arbitrary: ( d_0 = d_0(a, b) ), ...</td>
</tr>
<tr>
<td></td>
<td>( V_x^{(n)}(x, y) \approx d_0 + d_x x + d_y y )</td>
</tr>
<tr>
<td></td>
<td>( V_y^{(n)}(x, y) \approx f_0 + f_x x + f_y y )</td>
</tr>
<tr>
<td><strong>cav+mirror-z</strong></td>
<td>SW: a = b, (equal for sub-structures)</td>
</tr>
<tr>
<td></td>
<td>( V_x^{(n)}(x, y) \approx 2i \text{Im}{d_0 + d_x x + d_y y} )</td>
</tr>
<tr>
<td></td>
<td>( V_y^{(n)}(x, y) \approx 2i \text{Im}{f_0 + f_x x + f_y y} )</td>
</tr>
<tr>
<td>**cav+rot</td>
<td>y-axis**</td>
</tr>
<tr>
<td></td>
<td>( V_x^{(n)}(x, y) \approx 2\text{Re}{d_0} + 2i\text{Im}{d_x x} + 2\text{Re}{d_y y} )</td>
</tr>
<tr>
<td></td>
<td>( V_y^{(n)}(x, y) \approx 2i\text{Im}{f_0} + 2\text{Re}{f_x x} + 2i\text{Im}{f_y y} )</td>
</tr>
<tr>
<td><strong>cav+mirror-y</strong></td>
<td>a, b arbitrary (but equal for sub-str.)</td>
</tr>
<tr>
<td></td>
<td>( V_x^{(n)}(x, y) \approx 2d_x x )</td>
</tr>
<tr>
<td></td>
<td>( V_y^{(n)}(x, y) \approx 2f_0 + 2f_y y )</td>
</tr>
<tr>
<td>**cav+rot</td>
<td>z-axis**</td>
</tr>
<tr>
<td></td>
<td>( V_x^{(n)}(x, y) \approx 2d_x x + 2d_y y )</td>
</tr>
<tr>
<td></td>
<td>( V_y^{(n)}(x, y) \approx 2f_x x + 2f_y y )</td>
</tr>
</tbody>
</table>

### Notes:
- No kick on crest kick
  - Phase dep. kick, position dep.
- Systematic kick
  - No phase dep. kick, position dep.
- No kick on axis
  - Position dep.
beam dynamics

complicated mechanism of emittance growth
emittance compensation schema
strong variation of energy and transverse beam size
spatial and temporal dependency of coupler fields

\[
V_x^{(n)}(x, y) \approx d_0 + d_x x + d_y y \rightarrow \Delta p_{x,v} \approx \text{Re}\{V_x^{(n)}(x_v, y_v) \cdot \exp(i \omega t_v)\}
\]

\[
V_y^{(n)}(x, y) \approx f_0 + f_x x + f_y y \rightarrow \Delta p_{y,v} \approx \text{Re}\{V_y^{(n)}(x_v, y_v) \cdot \exp(i \omega t_v)\}
\]

steering effects of coupler fields

it is not clear what type of compensation is needed
is the emittance growth driven by spatial or temporal dependency? …

further ASTRA calculations are required
procedure is lengthy, the risk of mistakes is considerable
simplified and/or standardized procedure desirable

1\text{st} order Taylor expansion of kick parameter \rightarrow \text{analytic theory}

1\text{st} order Taylor expansion of kick parameter \rightarrow \text{generic coupler field} \rightarrow \text{efficient BD simulation}

use of glue-track?
local- or quasi-local compensation: fixed (not tunable) reactive element
partially compensation of some effects

clarify operational conditions, limitation of tuning ranges bunch currents
and bunch charges

optimal geometry for rf induced kicks is not necessarily identical
with geometry for minimal wake field effects $\rightarrow$ simultaneous investigation

global compensation: does it work in principle?

**strong geometrical constraints**: tuner (local)
cryostat (in general)
E sensor

**further BD simulations required**: lengthy
improved or simplified method
driving terms of emittance growth