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

2005

Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

STEERING AND FOCUSING EFFECTS IN TESLA CAVITY DUE TO HIGH ORDER MODE AND INPUT COUPLERS

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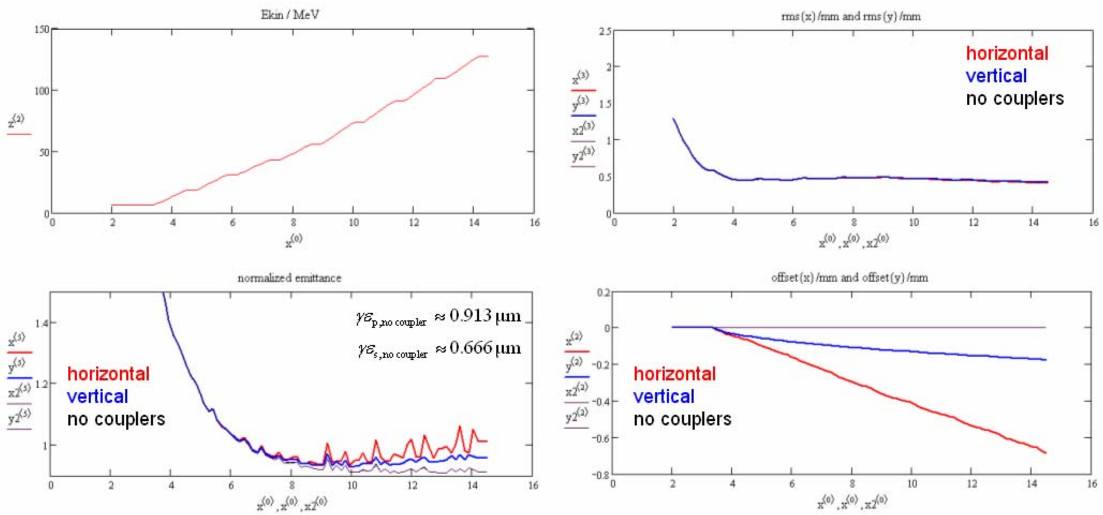
IMPACT ON THE XFEL PHOTOINJECTOR

We present a practical example of the coupler-ef on the beam dynamics by considering the x-ray FEL toinjector [5]. In the injector, the electron beam is toemitted in an L-band (f = 1.3 GHz) rf-gun and dire injected into a standard TESLA-type accelerating mo composed of eight cavities and accelerated to ~190 M The first two cavities of the accelerating module are erated with $\hat{E}_z$ = 23 MV/m and the remaining six c ties with $\hat{E}_z$ = 50 MV/m. Figure 7 compares the b parameter evolutions along the injector beamline from 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 gro respectively in the horizontal and vertical plane. The duced steering results in beam displacements at the ac erating module exit of $|\delta x|$ =680 μm and $|\delta y|$ =170 and no significant $x - y$ coupling is observed.

h=17%
v= 1%

ASTRA calculation for ACC1



projected emittance

$$\frac{\varepsilon_{p,x}}{\varepsilon_{p,\text{no coupler}}} \approx 1.11 \qquad \frac{\varepsilon_{p,y}}{\varepsilon_{p,\text{no coupler}}} \approx 1.051$$

slice emittance (center 10% charge)

$$\frac{\varepsilon_{s,x}}{\varepsilon_{s,\text{no coupler}}} \approx 1.028 \qquad \frac{\varepsilon_{s,y}}{\varepsilon_{s,\text{no coupler}}} \approx 1.021$$

conclusions, questions

similar results as Philippe

growth of horizontal emittance in ACC1: projected 11%, slice 3%

1st order effect = offset independent field (centroid shift) 5.5%

2nd order effect = offset dependent field 5.7%, 2.8%

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

s2e-meeting 21.May 2007: Beam Dynamics in Low Energy Part of XFEL Acc.
V. Tsakanov

Summary

- Coupler RF Field effects

ACCEL1 – 5-100 MeV
Emittance growth - 14 %

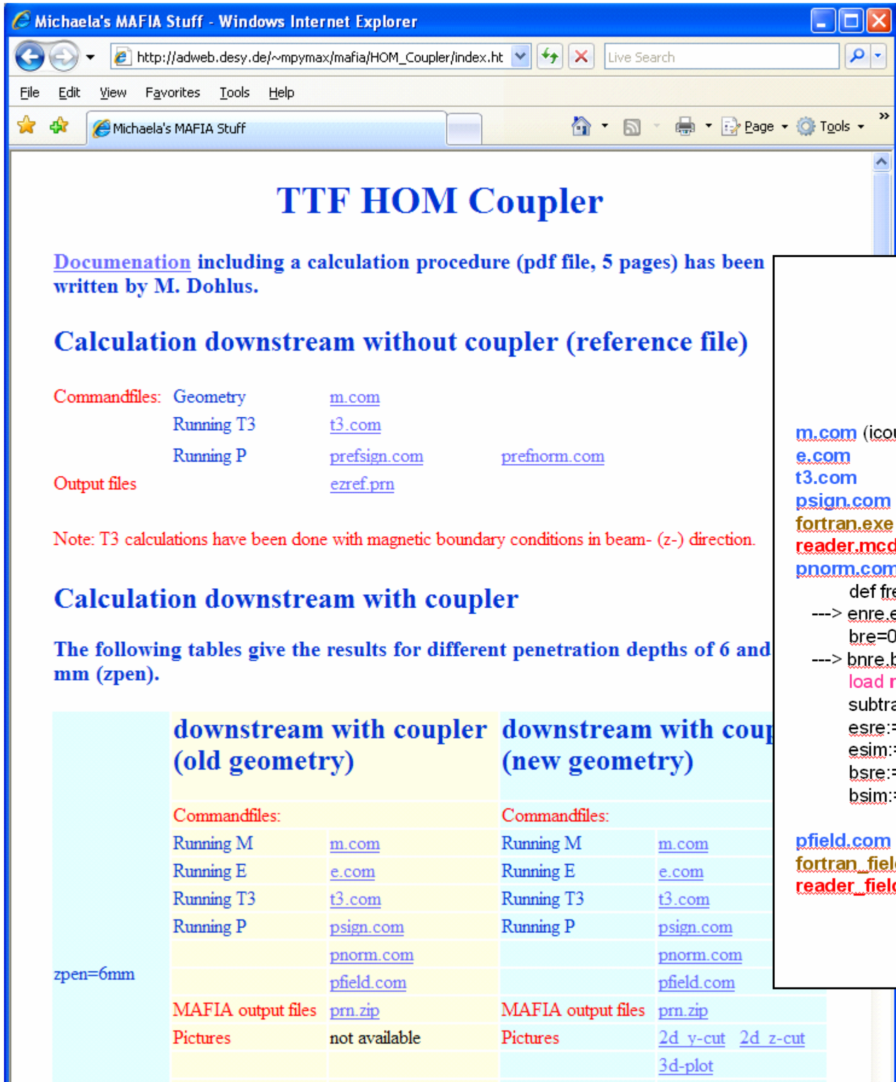
Linac 1 – 100-500 MeV
Emittance growth – 5%

- Other effects - below 1%

calculation of coupler kicks

the old MAFIA method

see: http://adweb.desy.de/~mpymax/mafia/HOM_Coupler/index.html



a lengthy procedure:

about 10 MAFIA runs

intermediate processing with fortran program

final post processing with mathcad

calculation downstream with coupler

m.com (icoup=1,idown=1)
e.com
t3.com
psign.com
fortran.exe
reader.mcd check power and envelope
pnorm.com
def fref=... (from fresult.dat)
---> enre.enim (nomalized to enor=50MV/m)
bre=0.5*(brea+breb), bim=...
---> bnre.bnim
load reference solution (erefre.erefim.brefre.brefim)
subtract reference field, invert time
esre:=(enre-erefre)
esim:=-(enim-erefim)
bsre:=-(bnre-brefre)
bsim:=(bnim-brefim)

pfield.com
fortran_fields.exe
reader_fields.mcd calculate kick ...

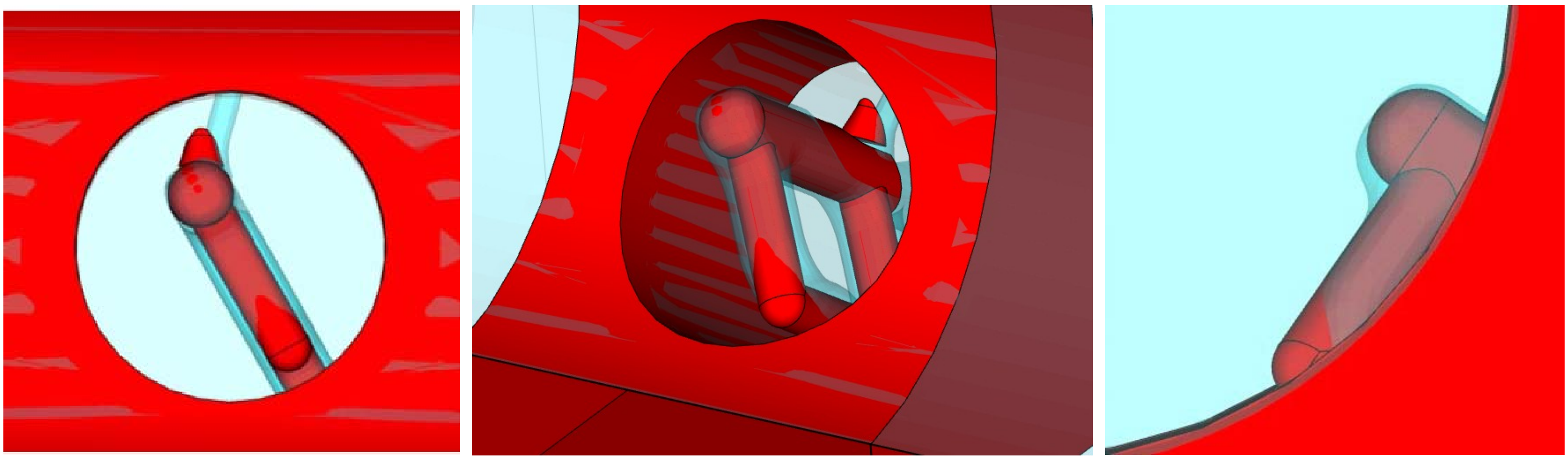
calculation downstream without coupler

m.com (icoup=0,idown=1)
t3.com ($ material=3, $ #waveguide section)
prefsign.com
fortran.exe
reader.mcd check power and envelope
prefnorm.com
def fref=... (from fresult.dat)
---> enre.enim (nomalized to enor=50MV/m)
bre=0.5*(brea+breb), bim=...
---> bnre.bnim

calculation of coupler kicks

mode of operation: steady state, pure forward wave, zpen=6mm $\rightarrow$ Qe $\approx$ 3.5E6
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

old / FNAL

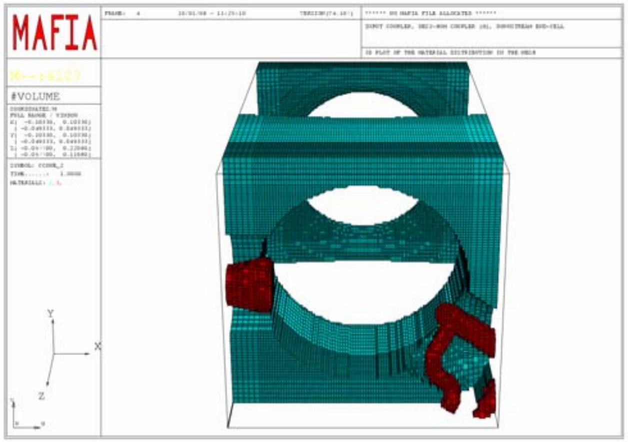
everything could be done better

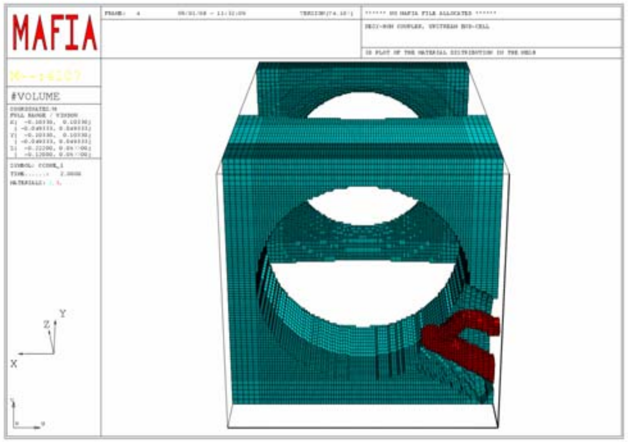
discretization
field calculation

but more time consuming!

calculation of coupler kicks

existing version



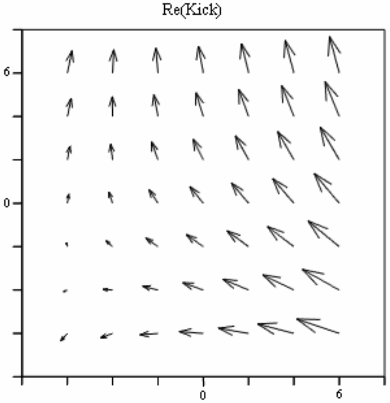


TTF coupler, downstream, new geometry, zpen=6mm

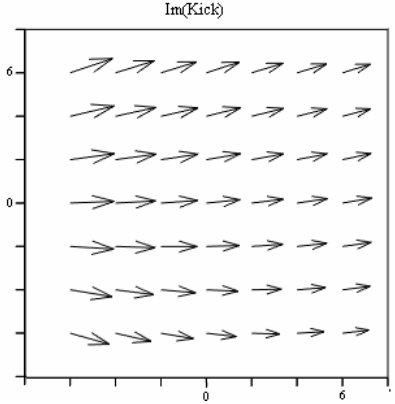
center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -24.258 + 53.968i$

$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = 31.301 + 5.483i$

Re(Kick)



Im(Kick)

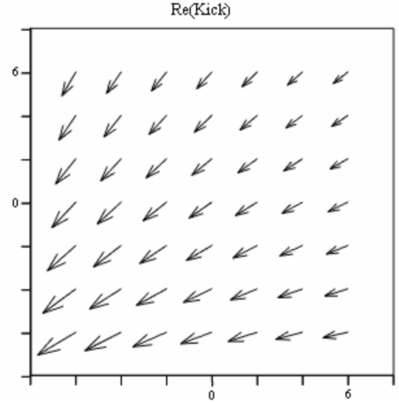


TTF coupler, upstream

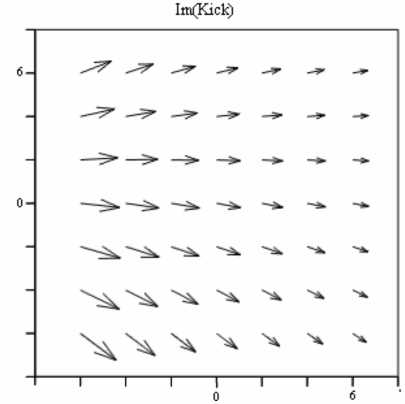
center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -59.399 + 9.412i$

$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = -43.459 - 1.833i$

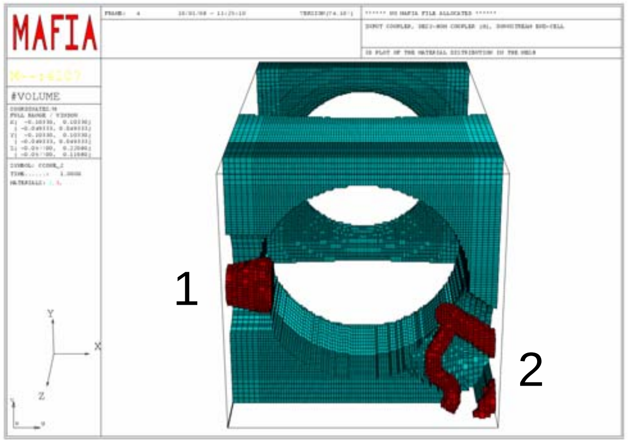
Re(Kick)

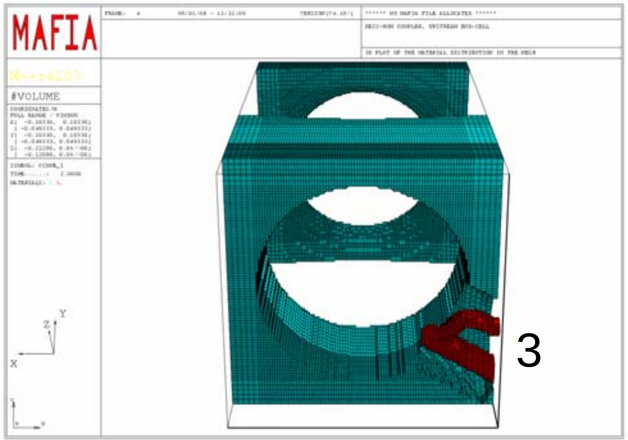


Im(Kick)

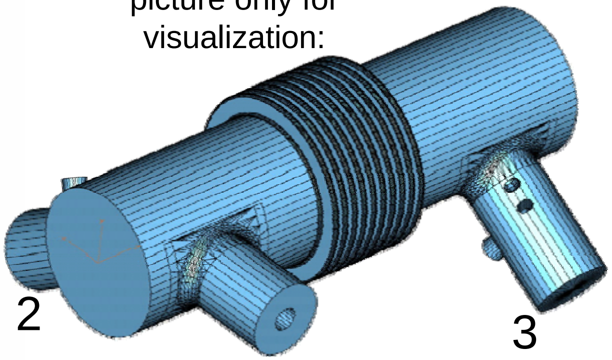


existing version (all couplers together)





picture only for visualization:



new geometry, zpen=6mm

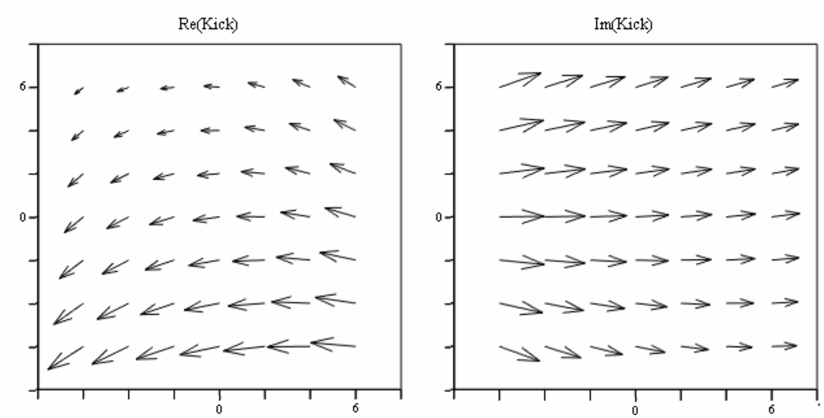
center: (both)

$vx_{ii,jj} \cdot 10^6 = -83.657 + 63.38i$

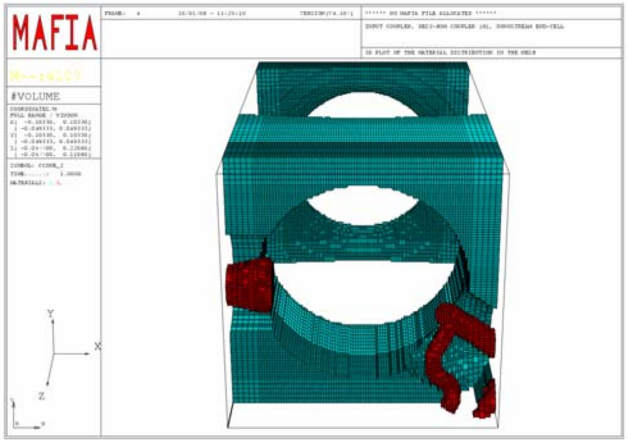
$vy_{ii,jj} \cdot 10^6 = -12.158 + 3.65i$

name1 = "kick_upstream_kick.dat"

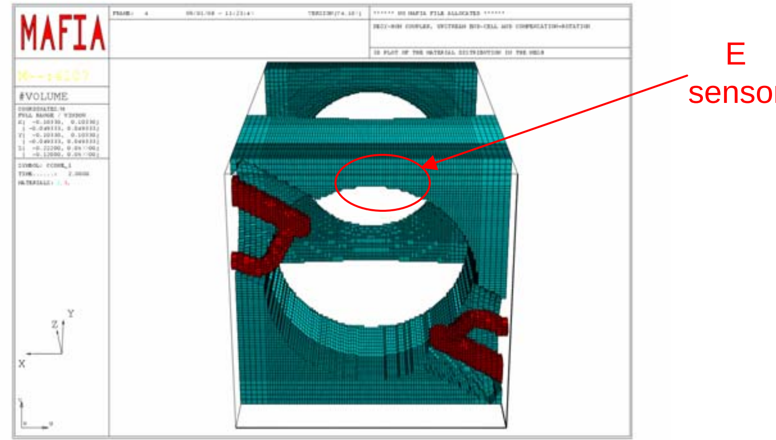
name2 = "kick_downstream_kick.dat"



(downstream = unchanged)



(upstream with compensation)

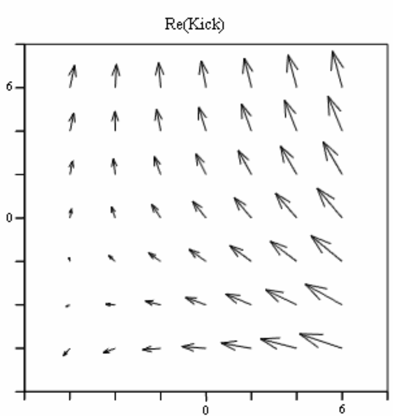


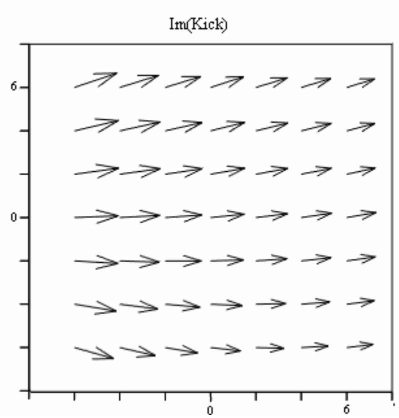
real or virtual
2nd HOM coupler

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

center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -24.258 + 53.968i$

$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = 31.301 + 5.483i$



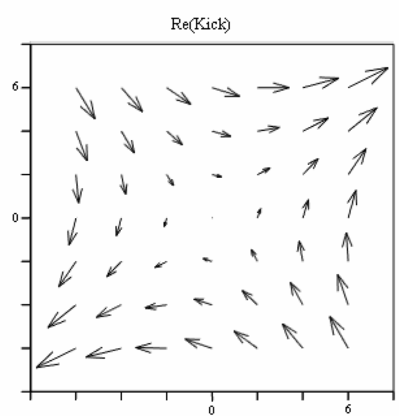


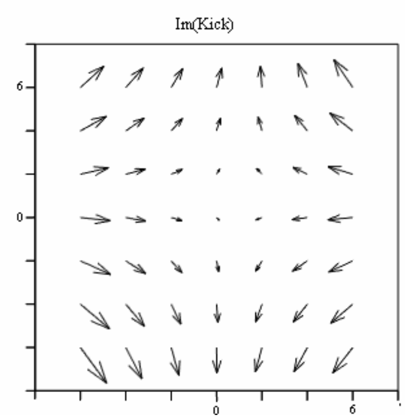
TTF coupler, upstream

center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = 0.482 + 0.852i$

$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = 0.569 - 0.997i$

not perfect due to
numerical errors!

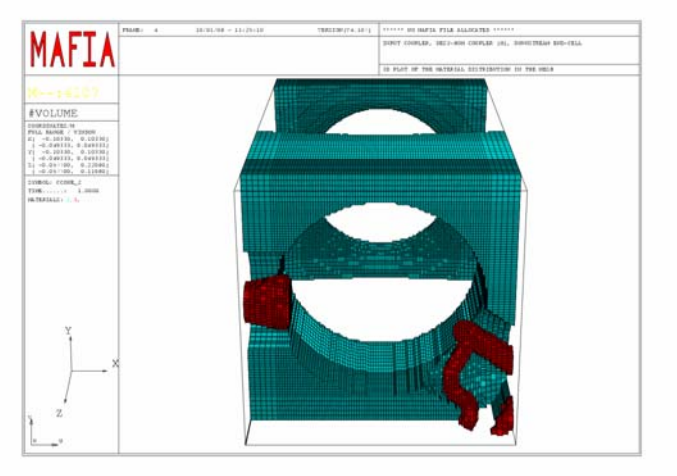


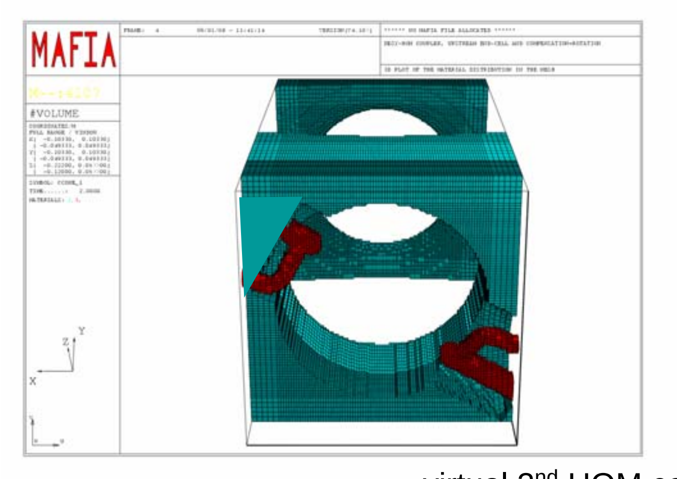


local compensation version u2

(downstream = unchanged)

(upstream with compensation)



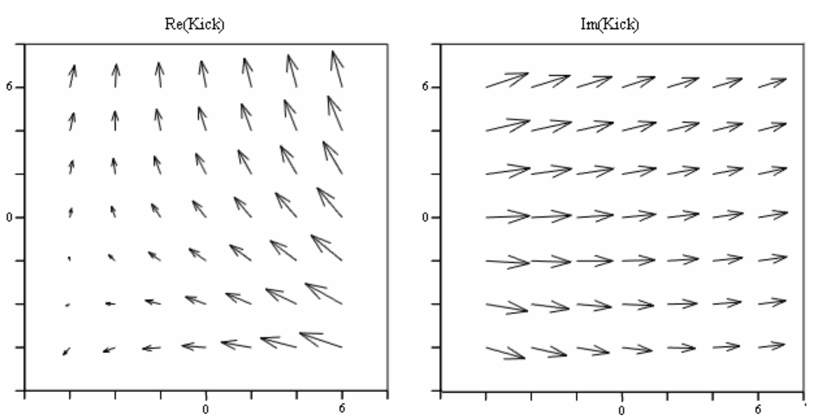


virtual 2nd HOM coupler
reduced length

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

center: $\frac{Vx_{ii,jj}}{Vz}\cdot 10^{6} = -24.258 + 53.968i$

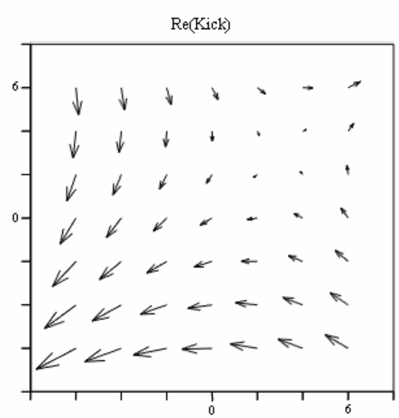
$\frac{Vy_{ii,jj}}{Vz}\cdot 10^{6} = 31.301 + 5.483i$

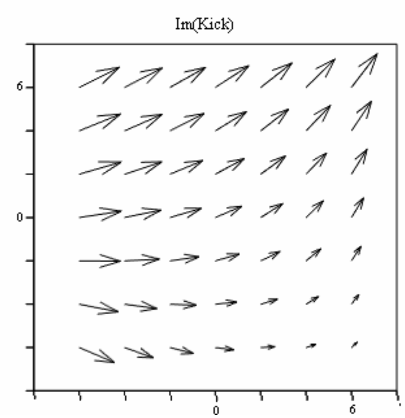


TTF coupler, upstream

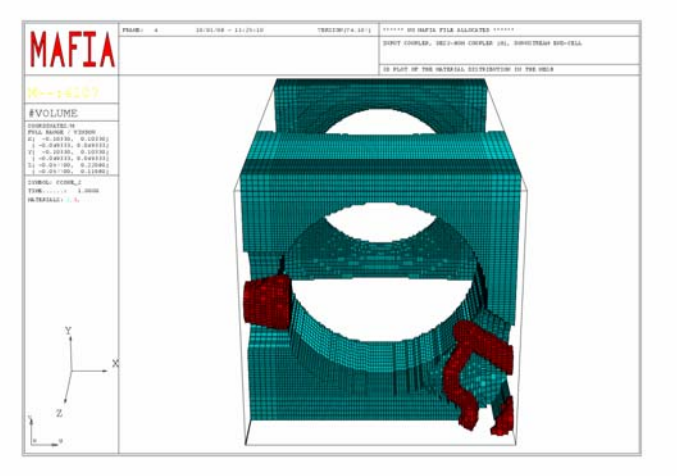
center: $\frac{Vx_{ii,jj}}{Vz}\cdot 10^{6} = -22.521 + 11.54i$

$\frac{Vy_{ii,jj}}{Vz}\cdot 10^{6} = -14.089 + 5.138i$

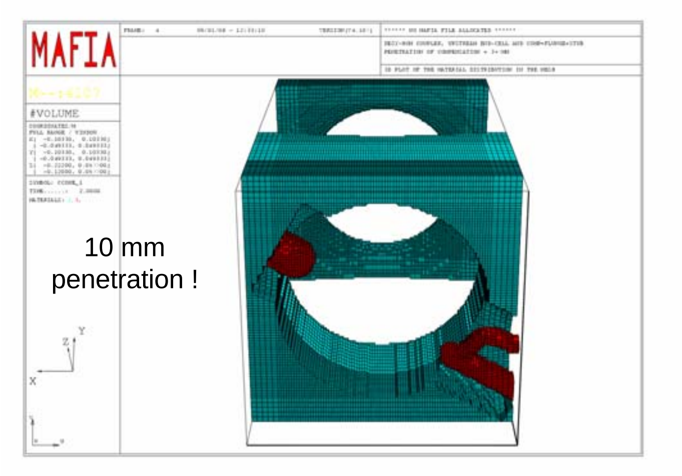




(downstream = unchanged)



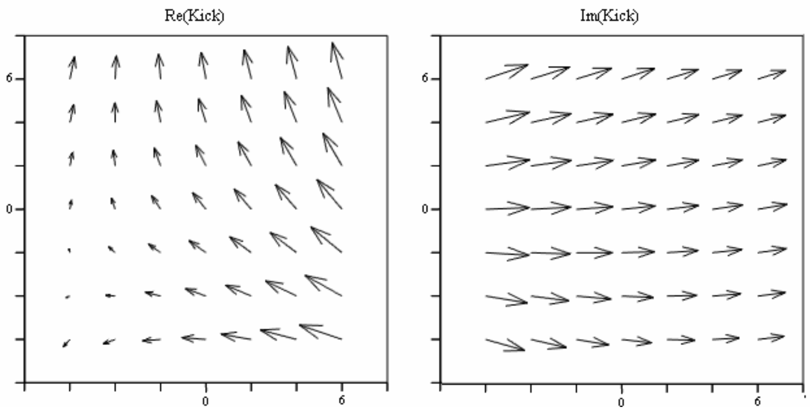
(upstream with compensation)



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

center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -24.258 + 53.968i$

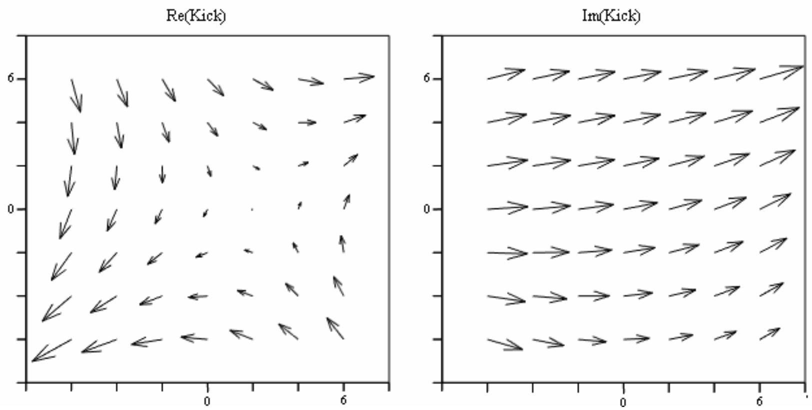
$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = 31.301 + 5.483i$



TTF coupler, upstream

center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -6.925 + 19.794i$

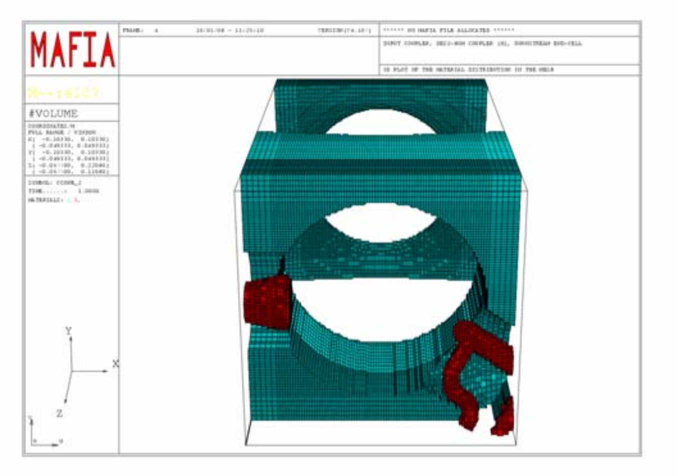
$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = -13.043 + 3.994i$



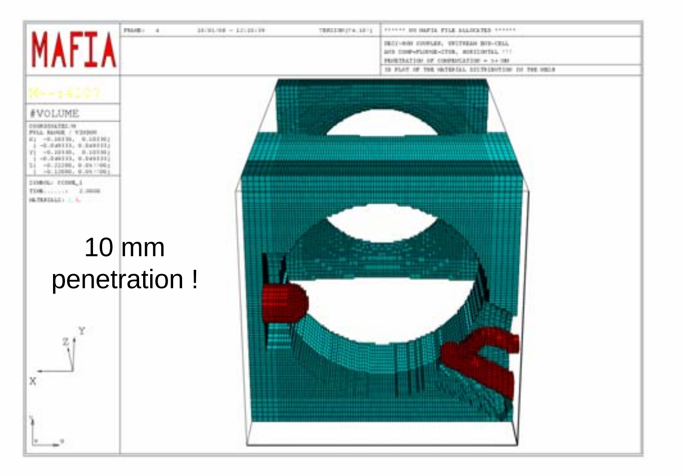
not quite local compensation version 1

reduce real part of sum

(downstream = unchanged)



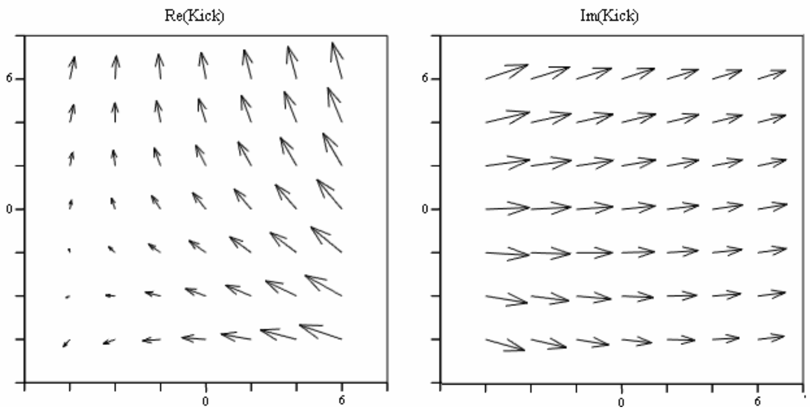
(upstream with compensation)



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

center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -24.258 + 53.968i$

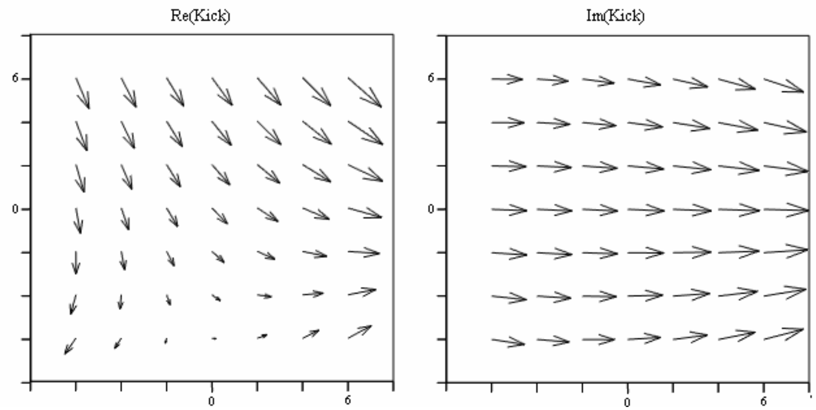
$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = 31.301 + 5.483i$



TTF coupler, upstream

center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = 39.961 + 37.917i$

$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = -42.745 - 1.84i$

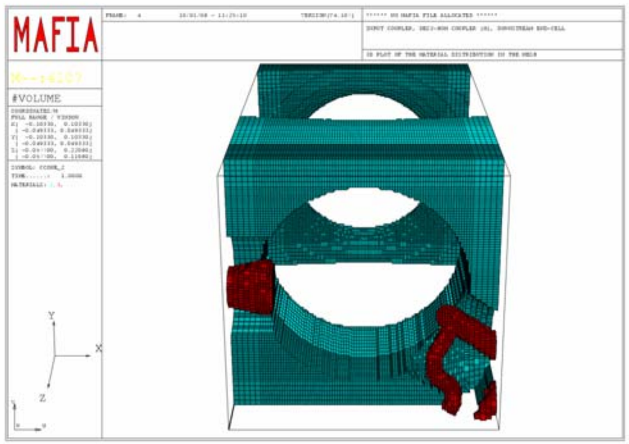


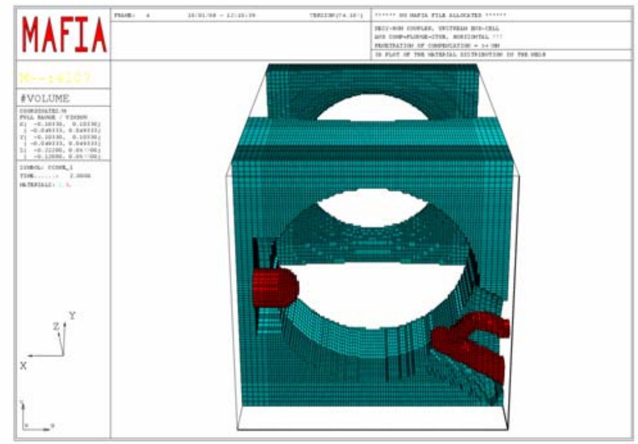
not quite local compensation

version 1

reduce real part of sum

(downstream = unchanged) (upstream with compensation)





new geometry, zpen=6mm

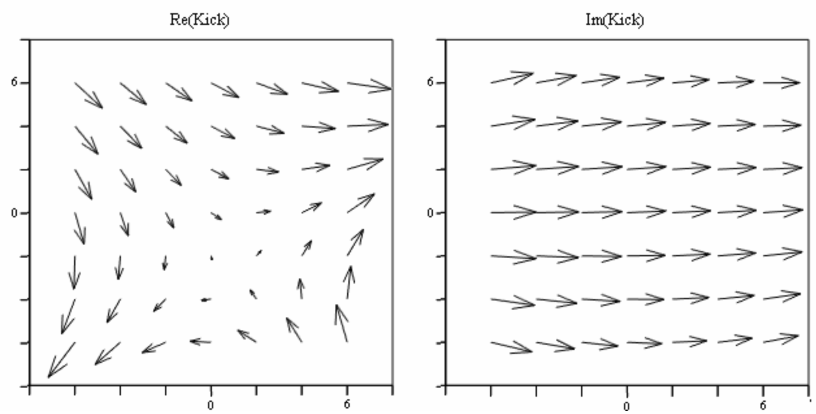
center: (both)

$vx_{ii,jj} \cdot 10^6 = 15.703 + 91.885i$

$vy_{ii,jj} \cdot 10^6 = -11.444 + 3.644i$

name1 = "kick_upstream_comp8.dat"

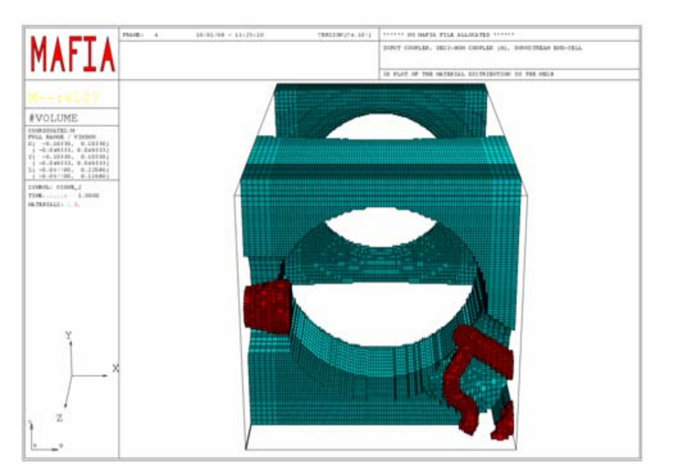
name2 = "kick_downstream_kick.dat"



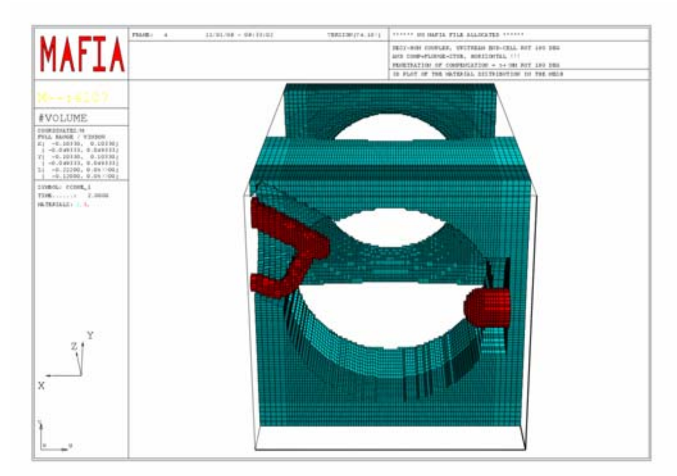
not quite local compensation version 2

reduce imaginary part of sum

(downstream = unchanged)



(upstream with compensation)

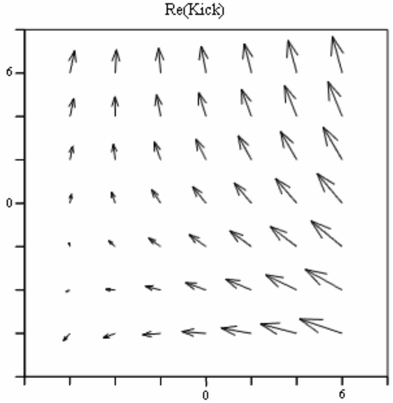


TTF coupler, downstream, new geometry, zpen=6mm

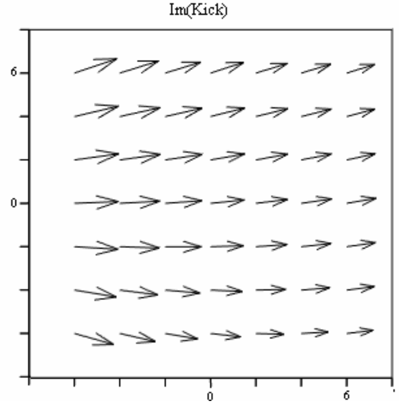
center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -24.258 + 53.968i$

$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = 31.301 + 5.483i$

Re(Kick)



Im(Kick)

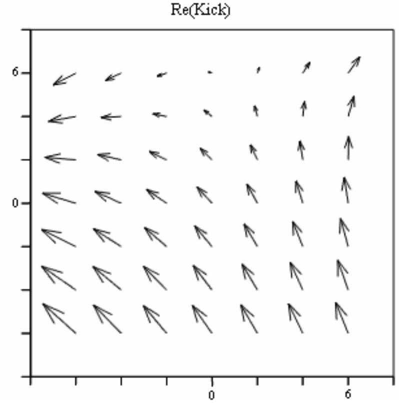


TTF coupler, upstream

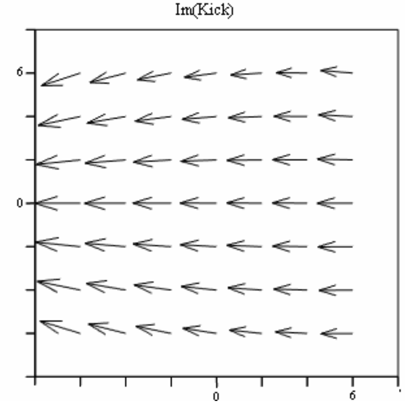
center: $\frac{Vx_{ii,jj}}{Vz} \cdot 10^6 = -38.587 - 36.233i$

$\frac{Vy_{ii,jj}}{Vz} \cdot 10^6 = 43.788 + 0.351i$

Re(Kick)



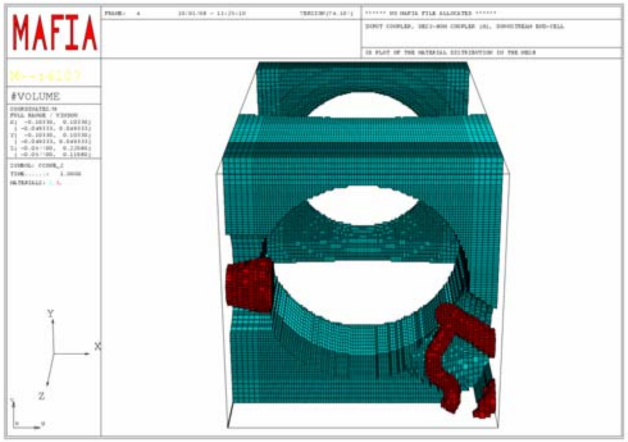
Im(Kick)

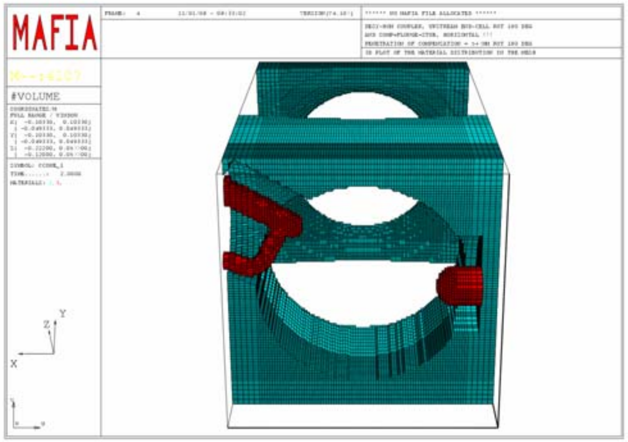


not quite local compensation version 2

reduce imaginary part of sum

(downstream = unchanged) (upstream with compensation)





new geometry, zpen=6mm

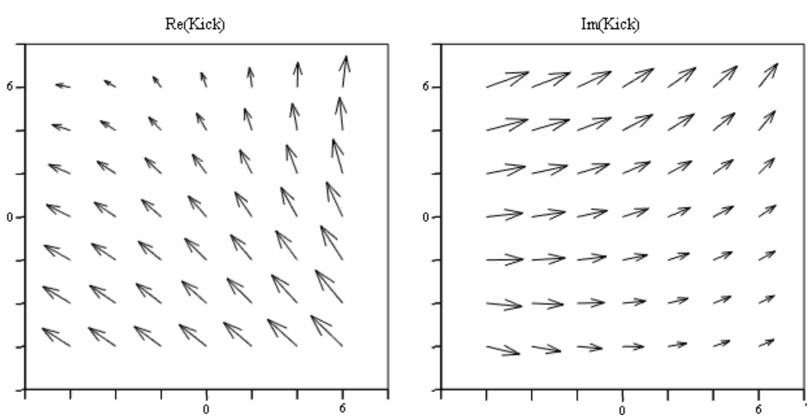
center: (both)

$vx_{ii,jj} \cdot 10^6 = -62.845 + 17.735i$

$vy_{ii,jj} \cdot 10^6 = 75.089 + 5.835i$

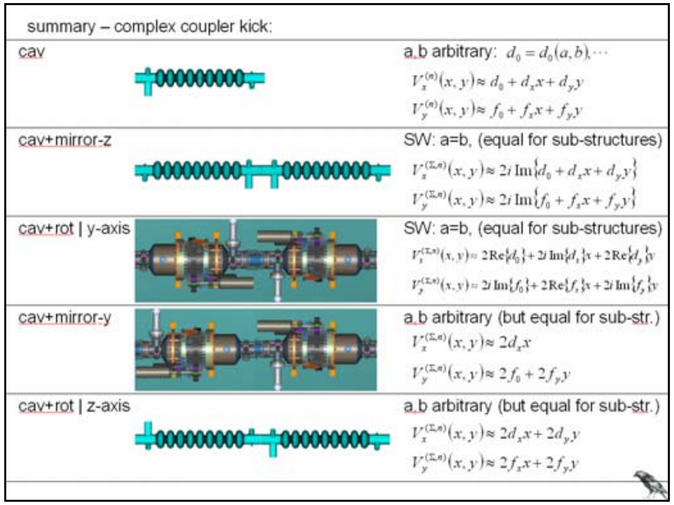
name1 = "kick_upstream_comp9.dat"

name2 = "kick_downstream_kick.dat"



simple geometry transformations: rotation- or mirror-transformation

general discussion in: http://www.desy.de/~dohlus/2007/2007.07.ckick/



summary – complex coupler kick:

cav	a,b arbitrary: $d_0 = d_0(a,b), \cdots$ $V_x^{(n)}(x,y) \approx d_0 + d_x x + d_y y$ $V_y^{(n)}(x,y) \approx f_0 + f_x x + f_y y$
cav+mirror-z	SW: a=b, (equal for sub-structures) $V_x^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{d_0 + d_x x + d_y y\}$ $V_y^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{f_0 + f_x x + f_y y\}$
cav+rot | y-axis	SW: a=b, (equal for sub-structures) $V_x^{(\Sigma,n)}(x,y) \approx 2\mathrm{Re}\{d_0\} + 2i\,\mathrm{Im}\{d_x\}x + 2\mathrm{Re}\{d_y\}y$ $V_y^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{f_0\} + 2\mathrm{Re}\{f_x\}x + 2i\,\mathrm{Im}\{f_y\}y$
cav+mirror-y	a,b arbitrary (but equal for sub-str.) $V_x^{(\Sigma,n)}(x,y) \approx 2d_x x$ $V_y^{(\Sigma,n)}(x,y) \approx 2f_0 + 2f_y y$
cav+rot | z-axis	a,b arbitrary (but equal for sub-str.) $V_x^{(\Sigma,n)}(x,y) \approx 2d_x x + 2d_y y$ $V_y^{(\Sigma,n)}(x,y) \approx 2f_x x + 2f_y y$

redesign of distribution network and cryostat

one side distribution network

two side distribution network

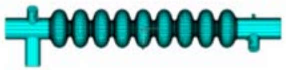
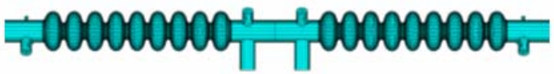
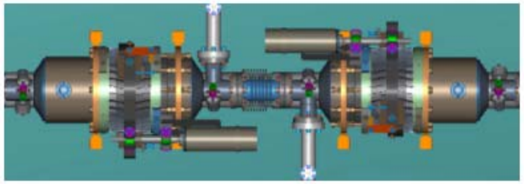
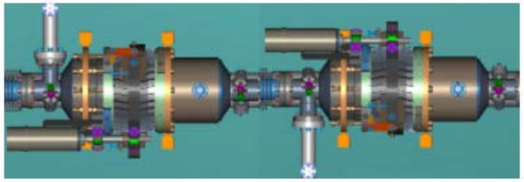
same or similar arguments for rf-fields and wake-fields

different energy at kick and compensating kick

$\rightarrow$ is global compensation possible at the very low energy of ACC1?

general discussion (standard modules / 3rd harm. modules)

see: http://www.desy.de/~dohlus/2007/2007.07.ckick/

summary – complex coupler kick:			
cav		a,b arbitrary: $d_0 = d_0(a,b), \cdots$ $V_x^{(n)}(x,y) \approx d_0 + d_x x + d_y y$ $V_y^{(n)}(x,y) \approx f_0 + f_x x + f_y y$	
cav+mirror-z		SW: a=b, (equal for sub-structures) $V_x^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{d_0 + d_x x + d_y y\}$ $V_y^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{f_0 + f_x x + f_y y\}$	no on crest kick phase dep. kick, position dep.
cav+rot | y-axis		SW: a=b, (equal for sub-structures) $V_x^{(\Sigma,n)}(x,y) \approx 2\mathrm{Re}\{d_0\} + 2i\,\mathrm{Im}\{d_x\}x + 2\mathrm{Re}\{d_y\}y$ $V_y^{(\Sigma,n)}(x,y) \approx 2i\,\mathrm{Im}\{f_0\} + 2\mathrm{Re}\{f_x\}x + 2i\,\mathrm{Im}\{f_y\}y$	systematic kick no phase dep. kick position dep.
cav+mirror-y		a,b arbitrary (but equal for sub-str.) $V_x^{(\Sigma,n)}(x,y) \approx 2d_x x$ $V_y^{(\Sigma,n)}(x,y) \approx 2f_0 + 2f_y y$	
cav+rot | z-axis		a,b arbitrary (but equal for sub-str.) $V_x^{(\Sigma,n)}(x,y) \approx 2d_x x + 2d_y y$ $V_y^{(\Sigma,n)}(x,y) \approx 2f_x x + 2f_y y$	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

$$V_x^{(n)}(x,y) \approx d_0 + d_x x + d_y y \rightarrow \Delta p_{x,\nu} \approx \mathrm{Re}\left\{V_x^{(n)}(x_\nu, y_\nu)\cdot \exp(i\omega t_\nu)\right\}$$

$$V_y^{(n)}(x,y) \approx f_0 + f_x x + f_y y \rightarrow \Delta p_{y,\nu} \approx \mathrm{Re}\left\{V_y^{(n)}(x_\nu, y_\nu)\cdot \exp(i\omega t_\nu)\right\}$$

- 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

- 1st order Taylor expansion of kick parameter → analytic theory
- 1st order Taylor expansion of kick parameter → generic coupler field → efficient BD simulation

use of glue-track?

summary and remarks

local- or quasi-local compensation: fixed (not tunable) reactive element
partial 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