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CTF3 Note 063 (Tech.)
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Are Beam Position Corrector Coils in Quadrupole Magnets Helpful?

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Sometimes the question arises whether corrector coils in quadrupole magnets may avoid corrector magnets in a beam transport line to save room and money. This note tries to give help to find an answer. For the case of the CTF3-QG quadrupoles, field errors introduced by corrector coils are calculated and put into relation to the quadrupole field.

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1 Calculation Principle

Sometimes the question arises whether corrector coils in quadrupole magnets may avoid corrector magnets in a beam transport line to save room and money. This note tries to give help to find an answer. For the case of the CTF3-QG quadrupoles, field errors introduced by corrector coils are calculated and put into relation to the quadrupole field.

To calculate the field distribution of corrector coils in a quadrupole magnet, the 2D software OPERA-2d of Vector-Fields Ltd. has been used. The model developed for the design of the QTF3-QG magnets is described in Note EDMS 452014. It had to be supplemented here to represent one half of the quadrupole geometry because the combined quadrupole and dipole field has only one symmetry plane, see Fig.1. The figure shows also field lines for a pure dipolar excitation. We number the coil cross-sections 1, 2, 3, and 4 starting at the rhs end and proceeding in the mathematicaly posetive angular direction. The current densities are set for two South-Poles: -0.11 A/mm^2, +0.11 A/mm^2, -0.11 A/mm^2, and +0.11 A/mm^2, respectively. The resulting field on the axis is B_y = +10 mT. The coil cross-sections are 88 mm $\times$ 37 mm. The correctors effective full gap height is g = 90 mm. The aperture diameter of the quadrupole is 100 mm.

Fig.2 shows field lines when adding the current densities for a field gradient of 6.4 T/m (for a magnetic South Pole rhs): -1.9656 A/mm^2, +1.9656 A/mm^2, +1.9656 A/mm^2, and -1.9656 A/mm^2, respectively.

2 Results

The field harmonis have been determined for a field gradient of 6.4 T/m and corrector fields of 5 mT and 10 mT. According to the field espansion (z = x + i·y):

$$B_y + i \cdot B_x = \Sigma(B_n + i \cdot A_n) \cdot (z/R)^{n-1}$$

we get, with $A_n = 0$ (no skew components), R = 30 mm (reference radius), and $b_n = B_n/B_2$:

	B_1 = 10 mT		B_1 = 5 mT	
b_1	5.25	%	2.63	%
b_2	1.00		1.00	
b_3	1.50	%	0.75	%
b_4	0.71	10^{-4}	0.71	10^{-4}
b_5	6.6	10^{-4}	3.3	10^{-4}
b_6	1.8	10^{-4}	1.8	10^{-4}
b_7	-1.8	10^{-4}	-0.9	10^{-4}
b_8	1.2	10^{-5}	1.2	10^{-5}

$$|b_n| \leq 10^{-5} \text{ for } n \geq 9.$$

Components b_3, b_5, and b_7 are due to a pole profile improper for a dipole. They are proportinal to the corrector field B_1 and reciprocaly proportional to the field gradient. b_6 is a typical quadrupole component. The cause for the small final value of b_4 is probably a geometrical error of the model. For the model of EDMS 452014, using full quadrupole geometry, we got $b_6 = 1.59 \cdot 10^{-4}$ and $b_4 = 0$.

Fig.3 and Fig.4 show the gradient inhomogeneity and field inhomogeneity along the 'good-field' radius 30 mm for field gradient 6.4 T/m and corrector fields 5 mT and 10 mT.

Fig.5 and Fig.6 show the B_y component of the pure corrector field along the x- and y-axes.

The following tables summarize some results of the design report EDMS 452014 of the CTF3-QG quadrupole magnet.

Data Survey:

Aperture radius	50.000	mm
Nominal field gradientR	8.000	T/m
Nominal current	200.000	A
Yoke length l_{fe}	253.000	mm
Magnetic length l_{eff}	300.000	mm
Construction length	333.000	mm
Yoke weight (sheets)	161.500	kg
Copper weight	45.880	kg
Stored energy, 200 A	350.400	J
Number of coils	4	
Number of turns per coil	40	

Operational Data, 200 A dc:

Nominal current	200.000	A
Total resistivity, 34.9^0C	75.040	mΩ
Total resistivity, 20^0C	70.200	mΩ
Total inductivity	17.520	mH
Total voltage, dc	15.010	V
Total dissipated power	3.002	kW
Total cooling water	2.734	ℓ/min
Pressure drop per circuit	3.500	bar
Water temperature rise	15.810	^{0}C

Operational Data, 384 A dc:

Field gradient	12.244	T/m
Total resistivity, 43.5^0C	77.343	mΩ
Total inductivity	17.520	mH
Total voltage, dc	29.713	V
Total dissipated power	11.415	kW
Total cooling water	4.981	ℓ/min
Pressure drop per circuit	10.000	bar
Water temperature rise	33.000	^{0}C
Water outlet	60.000	^{0}C

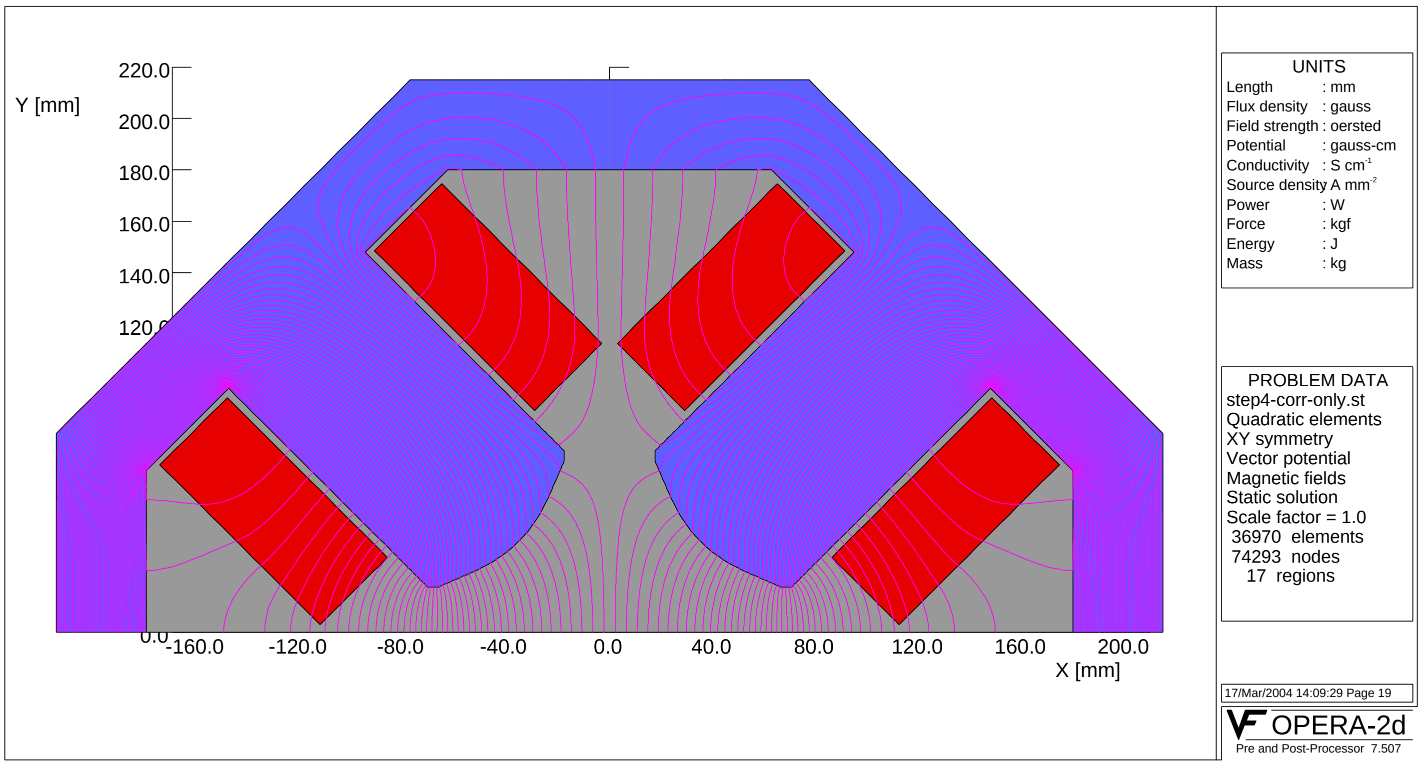

Figure 1: Field lines for excitation of a pure corrector field

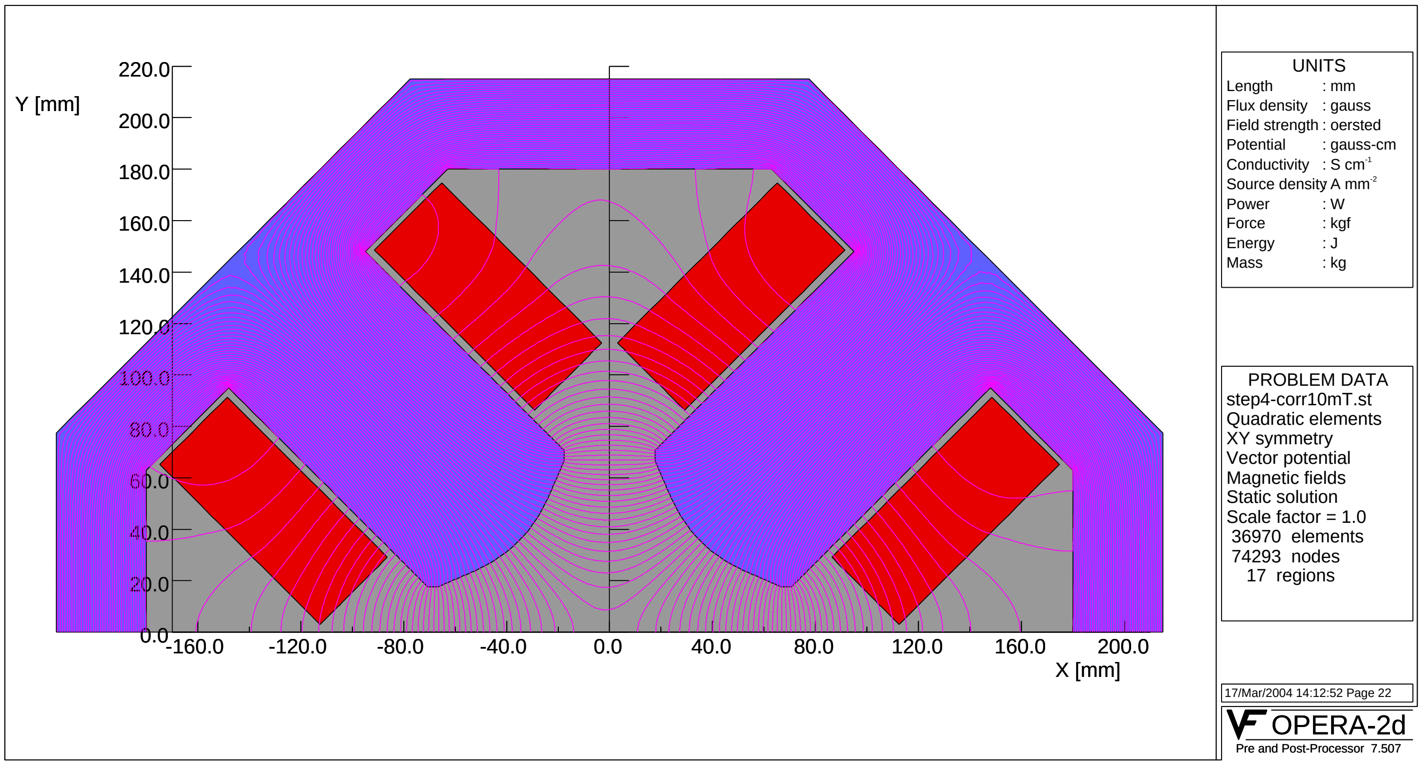

Figure 2: Field lines for field gradient 6.4 T/m and corrector field 10 mT

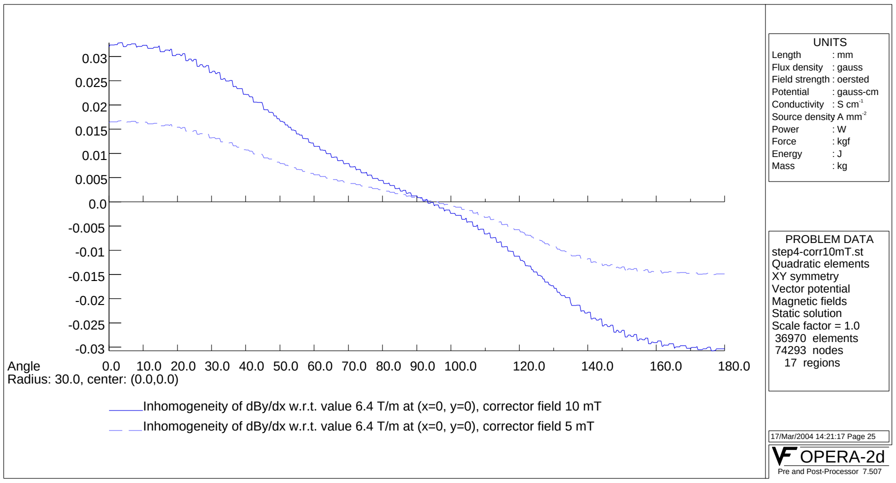

Figure 3: Inhomogeneity of of the field gradient along radius 30 mm

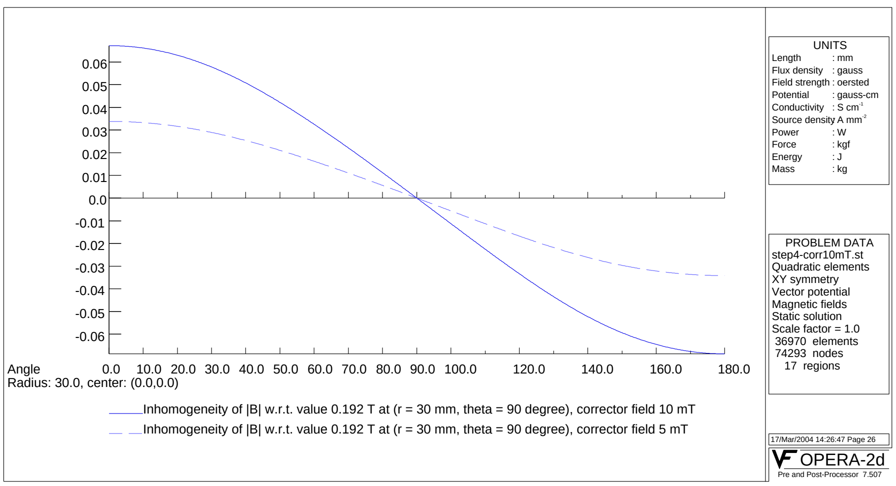

Figure 4: Inhomogeneity of |B| along radius 30 mm, $dB_y/dx = 6.4$ T/m

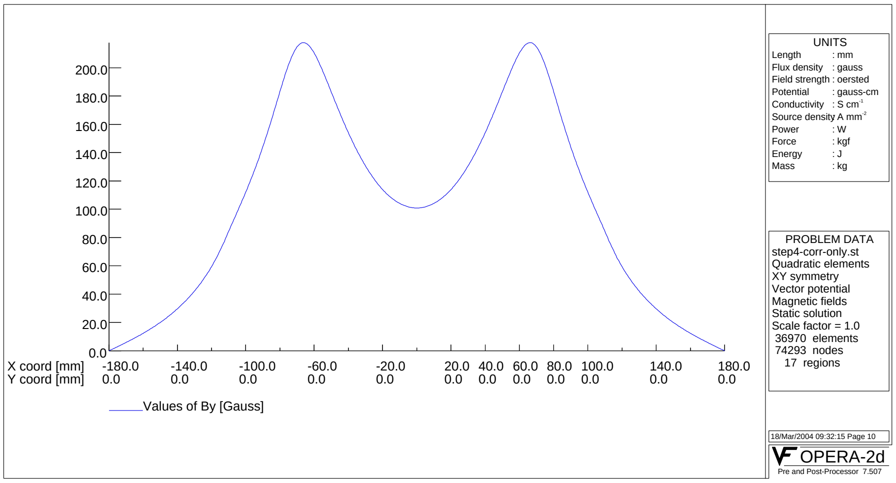

Figure 5: The pure corrector field along the x-axis

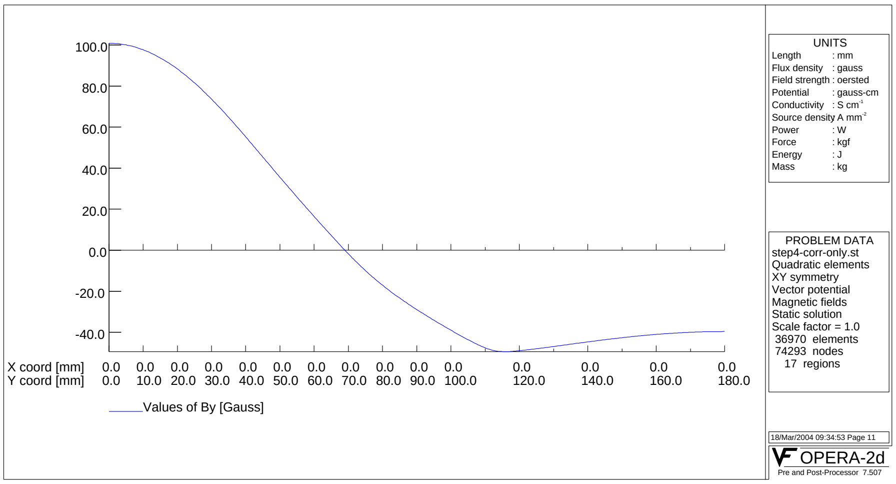

Figure 6: The pure corrector field along the y-axis

3 Input Data for OPERA-2d

After having read in the following command input file, you must clear the boundary conditions on all region faces inside the outer yoke periphery and the midplane. Use the pull-down windows:

Display / Nodes / Boundary Nodes / Return / Refresh, and
Model / Boundary cond. / Vect.Pot. / Clear,

and touch all concerned faces at both sides. Now you may call up the mesh generator.

```
set symm=xy soln=at elem=quad fiel=magn
unit leng=mm flux=gaus fiel=oers pote=gcm cond=scm dens=amm2,
powe=watt forc=kgf ener=joul mass=kg
bhda mate=4 type=isotropic
load file='EBG-M-940-50.bh'
$ do #i 1 29
r #i h+(b-h)*0.830 h -redr
$ end do
quit
reco -170 50 0 220
/ region 1 background
draw shap=back mate=0 n=0 symm=0 phas=0 sigm=0 perm=1 dens=0,
velo=0 mirr=no rot=1 dx=0 dy=0 nx=1 ny=1 tmir=0 trot=0
cart xp=0 yp=0
cart xp=70 curv=0 n=70 bias=0.5 f=dv v=0 dv=0
cart xp=112.5 n=48
cart xp=180 n=15
cart xp=215 n=5
cart yp=77.464 n=9 f=v
cart xp=146.232 yp=146.232 n=10
cart xp=77.464 yp=215 n=10
cart xp=0 n=9
cart xp=-77.464 n=9
cart xp=-146.232 yp=146.232 n=10
cart xp=-215 yp=77.464 n=10
cart yp=0 n=9
cart xp=-180 n=5 f=dv
cart xp=-112.5 n=15
cart xp=-70 n=48
fini n=70
quit
/ region 2 yoke and pole
```

```
draw shap=poly mate=4 perm=6000 mirr=no rot=1 tmir=0 trot=0
cart xp=35.355 yp=35.355
cart xp=37.5 yp=33.333 curv=0 n=2 f=no
cart xp=39.5 yp=31.646
cart xp=41.5 yp=30.120
cart xp=43.5 yp=28.736
cart xp=45.5 yp=27.473
cart xp=47.5 yp=26.316
cart xp=49.5 yp=25.253
cart xp=51.5 yp=24.272
cart xp=53.5 yp=23.364
cart xp=66.515 yp=17.680 n=18
cart xp=70.713 n=5
cart xp=83.75 yp=30.717 n=20
cart xp=148 yp=94.967 n=20
cart xp=180 yp=62.967 n=8
cart yp=0 n=14
cart xp=215 n=5 f=dv
cart yp=77.464 n=9 f=v
cart xp=146.232 yp=146.232 n=10
cart xp=57.5 yp=57.5 n=15
fini n=32
quit
copy reg1=2 2 thet=45 yes
copy reg1=3 3 thet=90 yes
copy reg1=4 4 thet=135 yes
/ region 6 coil: dens=-2.4570025 for 200 A, 40 turns
/ i.e. for field gradient 8 T/m
draw mate=1 perm=1 dens=-0.11 mirr=no tmir=0
cart xp=112.5 yp=3
cart xp=174.725 yp=65.225 n=19 f=no
cart xp=148.562 yp=91.388 n=8
cart xp=86.337 yp=29.163 n=19
fini n=38
quit
copy reg1=6 6 thet=45 yes
copy reg1=7 7 thet=90
copy reg1=8 8 thet=135
```

```
modi reg1=7 7 dens=+0.11 n=2
modi reg1=8 8 dens=-0.11 n=3
modi reg1=9 9 dens=+0.11 n=4
/ region 10
draw mate=0 dens=0 mirr=no tmir=0
cart xp=35.355 yp=35.355
cart xp=37.5 yp=33.333 curv=0 n=2 f=no
cart xp=39.5 yp=31.646
cart xp=41.5 yp=30.120
cart xp=43.5 yp=28.736
cart xp=45.5 yp=27.473
cart xp=47.5 yp=26.316
cart xp=49.5 yp=25.253
cart xp=51.5 yp=24.272
cart xp=53.5 yp=23.364
cart xp=66.515 yp=17.680 n=18
cart xp=70 yp=0
cart xp=0 n=70 f=dv
fini n=50 f=v
quit
copy reg1=10 10 thet=45 yes
copy reg1=11 11 thet=90 yes
copy reg1=12 12 thet=135 yes
/ region 14
draw
cart xp=66.515 yp=17.680
cart xp=70 yp=0 n=18 f=no
cart xp=112.5 n=48 f=dv
cart yp=3 n=2 f=no
cart xp=86.337 yp=29.163 n=38
cart xp=83.75 yp=30.717 n=2
cart xp=70.713 yp=17.68 n=20
fini n=5
quit
copy reg1=14 14 thet=45 yes
copy reg1=15 15 thet=90
copy reg1=16 16 thet=135
```