

Documentation on Center-Beam.pl

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Goal: Center beam in position and angle of FRS target.

How to use:

- 1.) Read beam position on current grids
- 2.) Export magnet setting from ParamModi to directory ~/center-beam
- 3.) >center-beam.pl <x-CG01> <x-CG02> <y-CG01> <y-CG02>
- 4.) Import new steerer settings into ParamModi (file center-beam.txt) and [set]
- 5.) Check new beam position

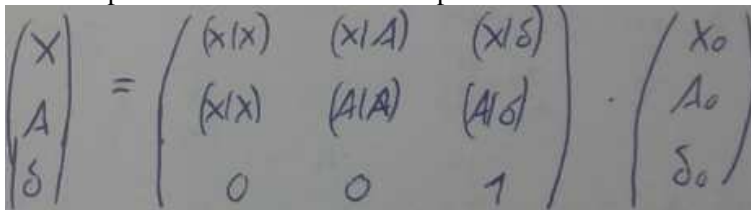
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[scheidenb@asl741 center-beam]$ ./center-beam.pl 1 2 0 0
x: cg01=1 mm cg02=2 mm, y: cg01=0 mm cg02=0 mm
on TA#2 in ion-optical coordinates:
dx=0.00206 m, dA=0.00089 rad, dY=0.00000 m, dB=0.00000 rad
file=/home/rifr/scheidenb/lnx/center-beam/test.txt
Input from parammodi:
Y steerers GTE1KY1, GTS1KY1 (VKICK): 0.0, 0.0 [rad]
X dipoles GTS1MU1, GTS1MU2 (HKICK): 0.0, 0.0 [rad]
Q doublet GTE1QD11, GTE1QD22, (K'L): 1.211089391E-01, 0.0
Q doublet GTS1QD11, GTS1QD12, (K'L): -5.294050903E-01, 5.776359350E-01

Output for parammodi:
X dipoles GTS1MU1, GTS1MU2 (HKICK): -0.1056, 0.7956 mrad
Y steerers GTE1KY1, GTS1KY1 (VKICK): 0.0000, 0.0000 mrad
done, created parammodi file center-beam.txt with dipoles/steerers.
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Method:

Calculate dispersion when tweaking only on dipole (or steerer) up to target. Then the relative change of a dipole causes a certain shift in position and angle at the target. Solve equations for required change on dipoles. Same method as used in grade_legen_2019_x+y.xlsx.

Each optical element is described by its 3x3 transfer matrix. Similar for Y direction.
X and Y-planes are assumed to be independent.


$$\begin{pmatrix} X \\ A \\ \delta \end{pmatrix} = \begin{pmatrix} (X|X) & (X|A) & (X|\delta) \\ (A|X) & (A|A) & (A|\delta) \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} X_0 \\ A_0 \\ \delta_0 \end{pmatrix}$$

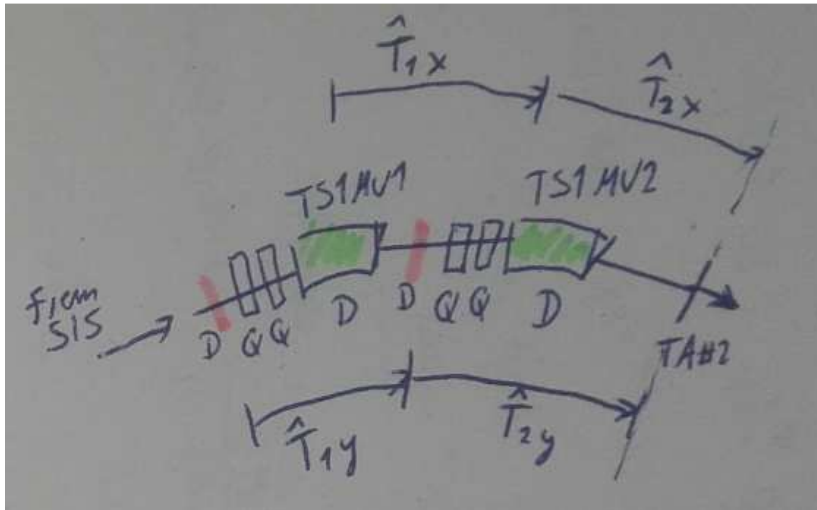
Five types of elements are used (exact equations from text book):

- Unit matrix for initialization (**U**)
- Drift of length L (**L**)
- Quadrupole with both solutions for focusing (sin) and defocusing (sinh), (**Q**)
- Sector dipole magnet (**D**)
- Dipole fringe field (**F**), hard edge fringe field depending on edge angle

Dipole magnets are fixed but $K'L = B'L/B\rho$ for quadrupoles is read from ParamModi export file.

The full system is divided into two halves:

- 1st: Entrance of first dipole up to entrance of second dipole -> transfer matrix (**T1x**)
- 2nd: Entrance of second dipole to target -> transfer matrix (**T2x**)



Magnets in front of the part which should be tuned must be ignored. The beamline geometry with distances, lengths, radii, dipole angles is hardcoded.

$$\mathbf{T1x} = L(0.3398\text{m}) * \mathbf{Q}_4 * L(0.232\text{m}) * \mathbf{Q}_3 * L(1.875\text{m}) * \mathbf{F}_1 * \mathbf{D}_1 * \mathbf{F}_1$$

$$\mathbf{T2x} = L(2.2886\text{m}) * \mathbf{F}_2 * \mathbf{D}_2 * \mathbf{F}_2$$

$$\mathbf{T1y} = L(0.926\text{m}) * \mathbf{F}_2 * \mathbf{D}_2 * \mathbf{F}_2 * L(0.4095\text{m}) * \mathbf{Q}_2 * L(0.984\text{m}) * \mathbf{Q}_1 * L(0.743\text{m}) * \mathbf{Dy}(L=0.2\text{m}, 1\text{mrad})$$

$$\mathbf{T2y} = L(2.2886\text{m}) * \mathbf{F}_2 * \mathbf{D}_2 * \mathbf{F}_2 * L(0.3398\text{m}) * \mathbf{Q}_4 * L(0.232\text{m}) * \mathbf{Q}_3 * L(0.749\text{m}) * \mathbf{Dy}(L=0.2\text{m}, 1\text{mrad})$$

Q_1 (TE1QD11) and Q_2 (TE1QD12) have an effective length of 0.666m, and Q_3 (TS1QD11) and Q_4 (TS1QD12) of 1.068m. Each Y-steerer is 0.2m long and the radius of TS1MU1 is $\rho=17.860$ m and for TS1MU2 $\rho= 11.650$ m. The sector angle on both is 7.5° .

Only the dispersion coefficients are really needed. For the 2nd dipole the $(x,\delta)_2$ and $(a,\delta)_2$ come directly from $\mathbf{T2x}$. For the first half the dispersion in $\mathbf{T1x}$ must be multiplied with the 2x2 matrix without dispersion of $\mathbf{T2x}$ of the second half.

$$(x,\delta)_{2e} = (x,\delta)_2 * (x,x)_1 + (a,\delta)_2 * (x,a)_1$$

$$(a,\delta)_{2e} = (a,\delta)_2 * (a,a)_1 + (a,d)_2 * (a,x)_1$$

These coefficients refer to beam at target position when changing the magnetic rigidity of the beam inside the dipole by δ .

Positions are measured on current grids CG01 (TS1DG5) and CG02 (TS2DG2). The orientation of the display in x-direction is opposite to ion-optical coordinates and the same in y-direction. With the known distances the positions on CGs are transformed to position and angle on target station #2.

Then the problem to solve is the matrix equation:

$$\begin{pmatrix} X \\ A \end{pmatrix} = \begin{pmatrix} (X/\delta)_{1e} & (X/\delta)_{2e} \\ (A/\delta)_{1e} & (A/\delta)_{2e} \end{pmatrix} \cdot \begin{pmatrix} \delta_1 \\ \delta_2 \end{pmatrix}$$

The solution is obtained by the inverse matrix:

$$\begin{pmatrix} \delta_1 \\ \delta_2 \end{pmatrix} = \begin{pmatrix} (A/\delta)_2 & -(X/\delta)_2 \\ -(A/\delta)_{1e} & (X/\delta)_{1e} \end{pmatrix} \frac{1}{N} \begin{pmatrix} X \\ A \end{pmatrix}$$

with $N = (x, \delta)_{1e} (a, \delta)_2 - (x, \delta)_2 (a, \delta)_{1e}$

For input to ParamModi as the relative change of the dipole value must be converted to an absolute kick angle in rad. Both dipoles have a sector angle of 7.5° . In addition the solution refers to a relative shift compared to the previous setting. This means the solution must be added to the old HKICK. In LSA (as in MAD or GICOSY) the definition of the deflection angle for a kick is opposite to a positive angle of a sector magnet. $HKICK > 0$ means kick to the left when looking with beam.

$$HKICK_1(TS1MU1) = \delta_1 * 7.5^\circ / 180^\circ * \pi + (1 - \delta_1) * HKICK_old1$$

$$HKICK_2(TS1MU2) = \delta_2 * 7.5^\circ / 180^\circ * \pi + (1 - \delta_2) * HKICK_old2$$

In Y direction the default deflection angle is zero. But by doing a calculation for 1 mrad deflection angle, the steerer can be treated like a sector magnet. In this case the relative change of $\Delta BL / BL$ is given in multiples of 0.001 rad. In Y direction a $VKICK > 0$ means a deflection upwards.

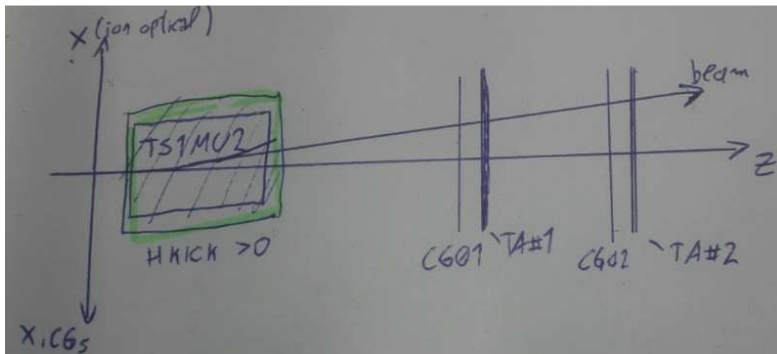
$$VKICK_1(TS1KY1) = -\delta_1 / 1000 + VKICK_old1$$

$$VKICK_2(TS1KY1) = -\delta_2 / 1000 + VKICK_old2$$

Tests:

As an easy example one can use a setting with only the last dipole tweaked. Making the dipole weaker causes a deflection by +1 mrad. This leads to a shift to positive X on target and both CGs. On the current grid it will be displayed as negative X. Because the beam diverges from the optical axis, the absolute deviation in X on CG02 is larger than on CG01. On target #2 it is again a bit larger than on CG02. It is a good test independent of quadrupole settings.

In numbers: $HKICK_1 = 0$ rad, $HKICK_2 = +0.001$ rad $\rightarrow x_CG01 = -1.854$ mm, $x_CG02 = -2.984$ mm.



In addition the program was tested versus a GICOSY calculation in forward direction. In this calculation an HKICK was added always in the middle of each dipole or steerer. The same method is used in GICOSYBACK. Without real beam the beamline was detuned in steerers, then the output as read by eye was taken from GICOSYBACK and used as input for center-beam.pl. After one or two steps the beam was centered. It also worked for different optics modes.