Beam Dynamics with MAD - Part 4

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Dealing with Errors

1. The problem
2. A necessary tool: SELECT
3. Errors of alignment
4. Errors in the field
5. New components: monitors and kickers
6. Running with TWISS
7. CORRECT
8. loops

In the real world

There are errors in magnetic fields and in magnet positions. Accuracy of 0.1% in field, 0.1 mm in position are typical. (These are *very* rough numbers.)
So the *closed orbit* will not be the same as the *reference orbit* - what the designers intended.
Beam position monitors (BPMs) are used to measure the position of the orbit.
Adjustable magnets ('kickers') are used to correct this ('closed orbit correction')
MAD enables you to

- Add random errors to magnets
- See what happens to the closed orbit
- Measure that with BPMs
- Adjust kicker magnet fields to correct these values
- Do this many times to see what kicker fields will be needed / what kicker positions are best

The SELECT command

Used to select subset of components to which errors will be applied. Also to select variables for output etc. Note selection is cumulative.
Format `SELECT,FLAG=`*flag*`,`*selection specification*`;`
where *flag* can be one of:

- `ERRORS` - what we need here
- `MAKETHIN`, `SECTORMAP` or `SEQEDIT` - less useful
- The name of a table, such as `TWISS`
- `SAVE` - for use with the command `SAVE, FILE=mysave;`

and *selection* can be one or more of

- `RANGE=...` Usual *component* or *component1/component2* form
- `CLASS=...` Probably most useful as subclasses can be used
- `PATTERN=...` Filter components using regexp syntax - experts only
- `COLUMN=...` for table entries
- `FULL` or `CLEAR` . Use `SELECT, FLAG=`*flag*`,CLEAR;` when done

Warning! Selection spec. depends on flag

EALIGN - alignment errors

Use after `SELECT` to specify:

- Errors in position: `DX,DY,DS`
- Errors in orientation: `DPHI, DTHETA, DPSI`
- Errors in aperture `AREX,AREY` and in BPM readings `MREX,MREY,MSCALX,MSCALY` (less relevant)

```
TOL=0.001;
EALIGN,DX:=TOL*GAUSS(),DY:=TOL*GAUSS();
```

Also `RANF()` for uniform in [0,1] and `TGAUSS(cut)` which cuts at some number of sigma

Errors replace any existing errors, unless `EOPTION, ADD=TRUE;` has been used. `EOPTION` can also be used to set the random number seed.

`EPRINT` will print out what's imposed. Can be very useful.

EFIELD - field errors

Simplest:

```
EFCOMP, DKN:=0.001*GAUSS();
```

Apply 0.001 Gaussian absolute error to dipole(units curvature: m^{-1})

Bit more subtle

```
EFCOMP,
DKN:={0.01*GAUSS(),0.02*GAUSS()},DKS:={0,0.03*GAUSS()};
```

Apply errors to normal and skew dipole and quadrupole fields . Remember (or accept) the expansion $\vec{B} = \nabla\phi \qquad \phi = \sum_n r^n (a_n cos(n\theta) + b_n sin(n\theta))$

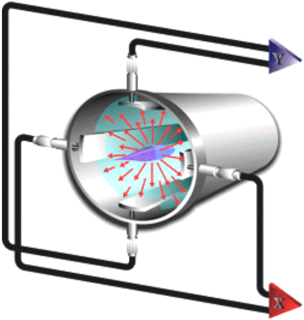
Complicated

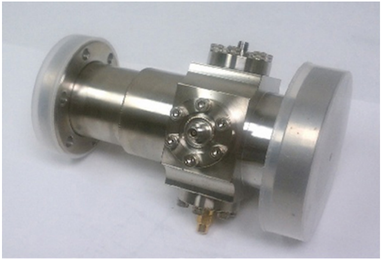
```
EFCOMP,ORDER=1,RADIUS=2,
DKNR:={0.01*GAUSS(),0.02*GAUSS()},DKSR:={0,0.03*GAUSS()};
```

Apply errors relative to dipole field (order 1) using $r_0 = 2$ m;

Even more complicated with hysteresis for AC magnets possible

BPMs - Beam Position Monitors





Measure mean transverse position of beam
Precision typically measured in microns
MAD component HMONITOR and VMONITOR
(also MONITOR but let's leave that alone)
Has position and a length (default L=0, probably OK)

Example of using stuff so far

Modifying the answer to problem 3 (without the RF stuff and the particle tracking)

```
  HBPM_NNN: HMONITOR,AT:=NNN*SLENGTH+.05;
  VBPM_NNN: VMONITOR,AT:=NNN*SLENGTH+.05;
  ...
USE SEQUENCE=MyMachine;
SELECT,FLAG=ERROR,CLASS=SBEND;
EALIGN,DX:=0.002*TGAUSS(3.0);
EFCOMP,DKN:=0.001*GAUSS();
EPRINT;
SELECT,FLAG=TWISS,COLUMN=NAME,S,X,Y,BETX,BETY;
TWISS,FILE=mytwiss.txt;
```

Gives the Twiss table written to mytwiss.txt

* NAME	S	X	Y	BETX	BETY
$ %s	%le	%le	%le	%le	%le
"MYMACHINE$START"	0	0.007064057553	0	4.467440616	369.1808182
"DRIFT_0"	0.05	0.006782588308	0	4.488108284	369.0008618
"HBPM_0"	0.05	0.006782588308	0	4.488108284	369.0008618
"VBPM_0"	0.05	0.006782588308	0	4.488108284	369.0008618
"DRIFT_1"	0.055	0.006754441384	0	4.49023909	368.9828694
"SB_0"	0.205	0.005940621252	0	4.482947476	368.9625154
"DRIFT_2"	0.95	0.002204255542	0	4.282868347	366.5735751
"SQ1_0"	1.05	0.00170262809	0	4.275357929	366.2903696
"DRIFT_0"	1.1	0.001451767618	0	4.273144346	366.1671418
"MID_0"	1.1	0.001451767618	0	4.273144346	366.1671418
"DRIFT_0"	1.15	0.001200907146	0	4.272101173	366.0439484
"SQ2_0"	1.25	0.0006992378853	0	4.273953293	365.7610779
"DRIFT_3"	2.05	-0.003313769618	0	4.460739899	363.2123328
"HBPM_1"	2.05	-0.003313769618	0	4.460739899	363.2123328

Next step: correct the closed orbit using Kicker magnets

Distinguish: 'Fast kicker' used in injection/extraction also known as 'kicker'. Response time nanoseconds.
These are DC kickers.
MAD component `HKICKER` and `VKICKER`
(also `KICKER` but let's leave that alone)
Has a position, length (default L=0, probably OK) and a KICK (in radians)
KICK defaults to 0. Usually leave it like that.

Correcting the orbit

Add some kickers to the lattice

```
HKICK1_NNN: HKICKER,AT:=NNN*SLENGTH+.05;
VKICK1_NNN: VKICKER,AT:=NNN*SLENGTH+.05;
```

and add the CORRECT command. Simple form (with output files)

```
TWISS,FILE=mytwiss1.txt;
CORRECT;
TWISS,FILE=mytwiss2.txt;
```

```
CORRECT,PLANE=X;
Want to correct orbit of a single ring
50 monitors and 50 correctors found in input
50 monitors and 50 correctors enabled
enter MICADO correction ...
Requested 0 correctors (???)  set to 50
start MICADO correction with 50 correctors
CORRECTION SUMMARY:
rms before correction:  3.201027 mm
rms after correction:  0.009371 mm
ptp before correction:  11.876860 mm
ptp after correction:  0.068557 mm

Max strength:  4.023777e-01 should be less than 1.000000e+00
```

Correcting the orbit (2)

`CORRECT` takes the `MONITOR` position values and maps how each kicker effects them all. Then chooses kicker value combination for smallest deviation. (Optimisation problem)
Other CORRECT options:

- `MLIST=`*filename*: generates before-and-after list of BPM values
- `CLIST=`*filename*: generates before-and-after list of corrector values
- `COND=1`: recommended to search out useful kickers to manipulate
- `MODE=`*method*: *method* can be SVD or LSQ. May give better results than default MICADO
- `PLANE=y`: Correct vertical orbit (default is x for horizontal orbit)

and other options - see documentation

High statistics studies

To repeat the errors/correction sequence many times use WHILE loop. E.g. by defining a macro

```
dostuff(NN): MACRO={
    EALIGN,DX:=0.0002*TGAUSS(3.0);
    TWISS,FILE=mytwiss_NN.txt;
    CORRECT,clist=myclist_NN.txt;
    };
```

and then using it

```
SELECT,FLAG=ERROR,CLASS=SBEND;
N=0;
while(N<50){
    N=N+1;
    exec,dostuff($N) ;
    }
```

Problem

Set up a 10 GeV proton storage ring with 12 bending magnets and a radius of 200-300 metres (to be assigned in class). Add quadrupoles to achieve a stable orbit.
Identify locations of high and low β.
Apply transverse Gaussian errors of 0.1mm in both directions to the dipole magnets and plot the closed orbit.
Add a suitable number of BPMs and at least 24 kickers (12 in both directions) to the ring, positioning them at high β locations. Correct the orbit. What is the maximum kicker strength required?
Now move the kickers to low β locations and repeat the exercise. Does the maximum kicker strength depend on the β value of the location chosen?
Validate your conclusion by a high statistics simulation.