MAD-X

Bruce Yee Rendón
byee@post.j-parc.jp

Accelerator Division
Japan Proton Accelerator Research Complex (J-PARC)
High Energy Accelerator Research Organization (KEK)

Luis Eduardo Medina Medrano
lmedinam@cern.ch

Beam Department
European Organization for Nuclear Research (CERN)
Universidad de Guanajuato (UG)

Acknowledgement to Werner Herr, CAS

Some formalities

Course scheme:

1. Lectures (Friday 13 and Saturday 14). Introduction to concepts. Exercises.
2. Work in the Exercise in group (Tuesday 17). Assignation of an exercise to each group. Creation of a presentation with the solution.
3. Presentation in group (Thursday 19). Each group will have 10 minutes to expose and questions.

Instructors:

Bruce Yee Rendon

Luis Eduardo Medina Medrano

Disclaimer

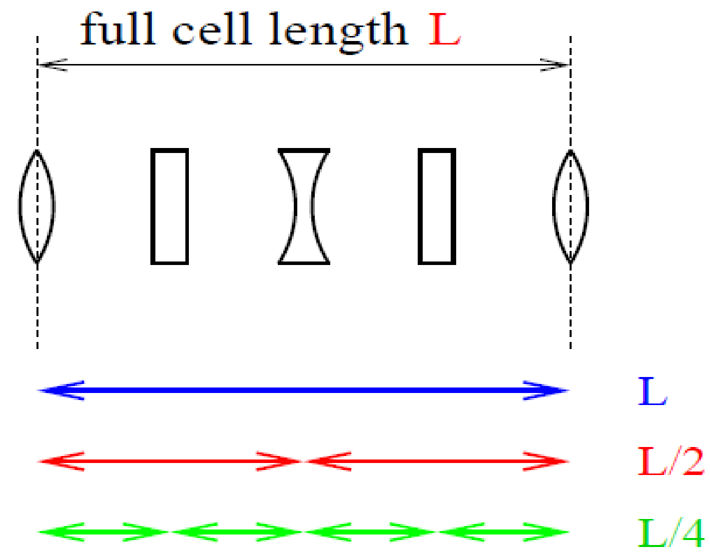
- This course is mostly based on **Werner Herr**’s CAS course.
- In some cases, Herr's slides may be used directly.
- This is an **introductory** course, thus, if you are interested in more information and details please go to the next link

http://zwe.web.cern.ch/zwe/

and/or contact him at werner.herr@cern.ch

Yesterday's problem

- The **FODO** cell is the basic structure.



Courtesy of W. Herr.

- The **length** of each FODO cell is

$$L_{FODO} = \frac{C}{n_{cell}} = \frac{1000}{8} = 125 \text{ m}$$

- The **bending angle** of each dipole is

$$\theta = \frac{2\pi}{2\times 8} = 0.3927 \text{ rad}$$

- This is enough to fully declare the dipoles, since we know their length and bending angle. Remember:

$$k_0 = \frac{1}{p/c} B_y = \frac{1}{\rho} = \frac{\theta}{l}$$

FODO cell

- To obtain the properties of the quadrupoles, remember that the phase advance, length and focal length, in a FODO cell are related:

$$\sin\phi = \pm\frac{L}{4f}$$

- Its maximum/minimum betas are given by

$$\beta^{\pm} = \frac{L}{\sin\phi}\left(1 \pm \sin\frac{\phi}{2}\right) = \frac{L\left(1 \pm \sin\frac{\phi}{2}\right)}{2\sin\frac{\phi}{2}\cos\frac{\phi}{2}}$$

- So, for a **maximum beta** β^{+} of 300 m, we have that

$$\frac{\beta^{+}}{L} = \frac{300}{125} = 2.4$$

Maximum beta I

- From the plot, we can choose a **phase advance** of $\phi \approx 32°$ or

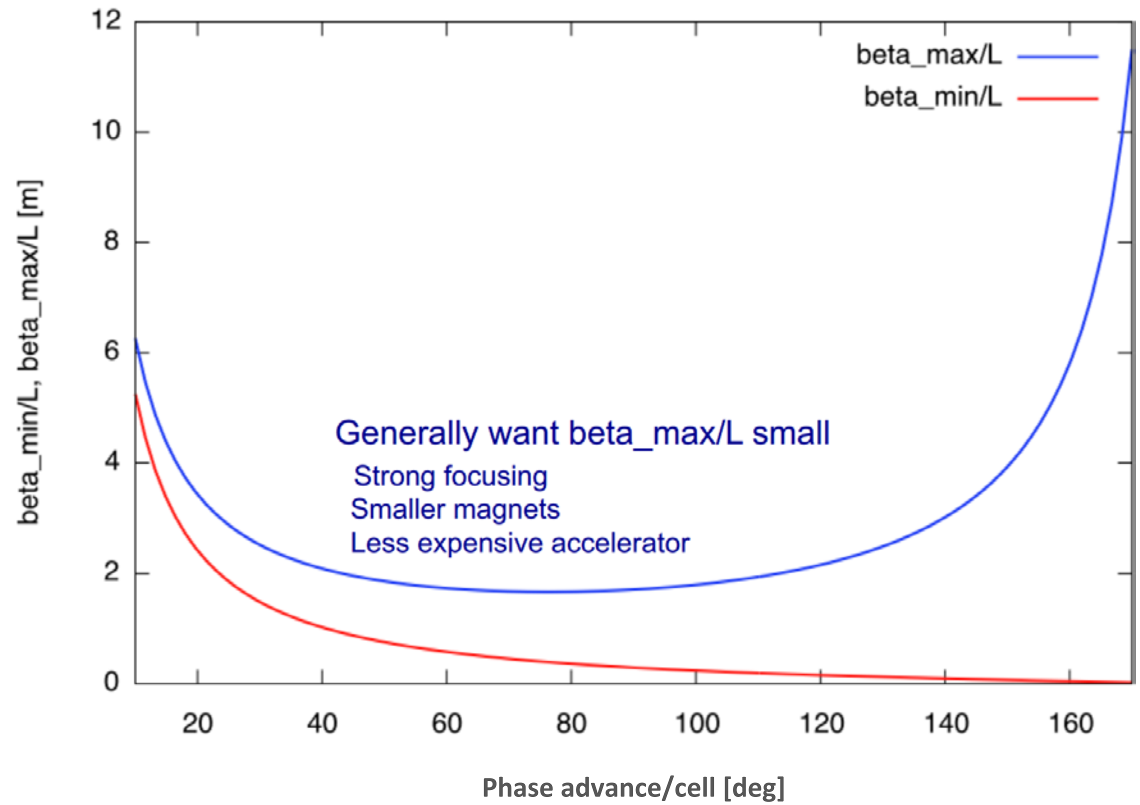
$$\phi \approx 0.56 \text{ rad}$$

- The **focal length** of the quadrupoles is then

$$f = \pm \frac{125}{4\sin(0.56/2)}$$

that is,

$$f = \pm 113.1 \text{ m}$$



Courtesy of T. Satogata

Maximum beta II

- The $\pm$ comes from the fact that both focusing/defocusing quadrupoles are considered to have the same magnitude, but opposite polarity.

- Then, the **quadrupole strengths** are

$$k_1 = \frac{1}{fL} = \pm 0.002947 \text{ m}^{-2}$$

- And we can declare the quadrupoles as follows:

```
qf:  multipole, knl = {0,  0.002947*lq};
qd: multipole, knl = {0, -0.002947*lq};
```

Exercise II

- *Start with the previous exercise and modify in such way that the maximum beta function is 100 m, but without changing the circumference.*

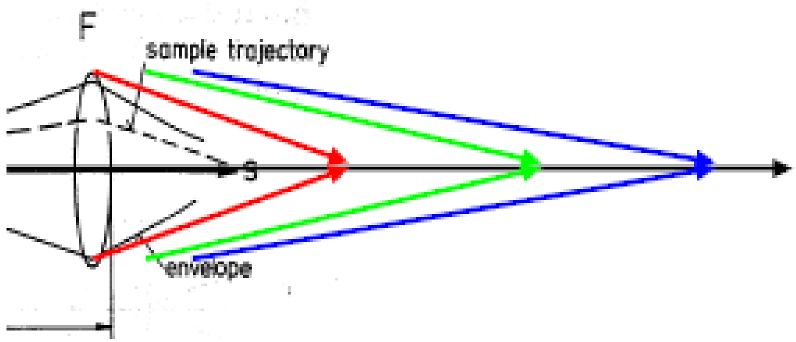
V. Advanced commands

- Chromaticity
- Q' correction
- Global matching

Chromaticity

- A **deviation** on **momentum changes** the **tune** of the machine:

$$\xi_{x,y} = Q'_{x,y} = \frac{dQ_{x,y}}{dp}$$



Particles with...
- higher energy
- the ideal energy
- lower energy

- This is know as **chromaticity**.

- The chromaticity is given by

$$\xi_{x,y} = -\frac{1}{4\pi}\oint k_{x,y}(s)\beta(s)\,ds$$

where $k_{x,y}(s)$ describes the quadrupole strengths along the ring.

Chromaticity: FODO

- In a ring made of n_{cell} identical FODO cells, the tune and chromaticity are given by

$$Q_x = n_{cell}\phi_x$$

and

$$Q'_x = -\frac{1}{\pi} n_{cell} \tan\frac{\phi_x}{2}$$

- In particular, for Exercise II,

$$Q_x = 2.4, \quad Q'_x = -2.5$$

Q' correction

- The way to correct the chromaticity (i.e, to make it equal to zero) is by introducing elements which depend on the momentum $\delta = \frac{\Delta p}{p}$.
- For **sextupole magnets**,

Quadrupole-like: kx

$$B_{sext} = \frac{B'}{2} x^2 \quad \rightarrow \quad B'_{sext} = B''x = B''D(s)\delta$$

- Thus, the change in the chromaticity is given by

$$Q'_x = (Q'_x)_{quad} + (Q'_x)_{sext}$$

$$(Q'_x)_{quad} = -\frac{1}{4\pi} \oint k_x(s)\beta_x(s)\, ds$$

$$(Q'_x)_{sext} \approx \frac{1}{4\pi} \sum_{SF} k_2^{SF} l_{sext} D^{SF} \beta_x^{SF} - \frac{1}{4\pi} \sum_{SD} k_2^{SD} l_{sext} D^{SD} \beta_x^{SD}$$

Q' correction: A hint

- To obtain the value k_2^{SF} use

$$Q'_x = -\frac{1}{4\pi} n_{cell} \left(k_2^{SF} l_{sext} D^{SF} \beta_x^{SF} - k_2^{SD} l_{sext} D^{SD} \beta_x^{SD} \right)$$

and

$$Q'_y = -\frac{1}{4\pi} n_{cell} \left(-k_2^{SF} l_{sext} D^{SF} \beta_y^{SF} + k_2^{SD} l_{sext} D^{SD} \beta_y^{SD} \right)$$

Global matching

- Some **global parameters** such as tune and chromaticity can be adjusted by **global matching**:

```
MATCH, SEQUENCE=CASSPS;
   VARY,NAME=KQF, STEP=0.00001;
   VARY,NAME=KQD, STEP=0.00001;
   GLOBAL,SEQUENCE=CASSPS,Q1=26.58;
   GLOBAL,SEQUENCE=CASSPS,Q2=26.62;
   LMDIF, CALLS=10, TOLERANCE=1.0E-21;
ENDMATCH;
```

Parameters to be varied: **quadrupoles** strengths

Desired **tune** values to be obtained

```
MATCH, SEQUENCE=CASSPS;
   VARY,NAME=KSF, STEP=0.00001;
   VARY,NAME=KSD, STEP=0.00001;
   GLOBAL,SEQUENCE=CASSPS,DQ1=0.0;
   GLOBAL,SEQUENCE=CASSPS,DQ2=0.0;
   LMDIF, CALLS=10, TOLERANCE=1.0E-21;
ENDMATCH;
```

Parameters to be varied: **sextupole** strengths

Desired **chromaticities** values to be obtained

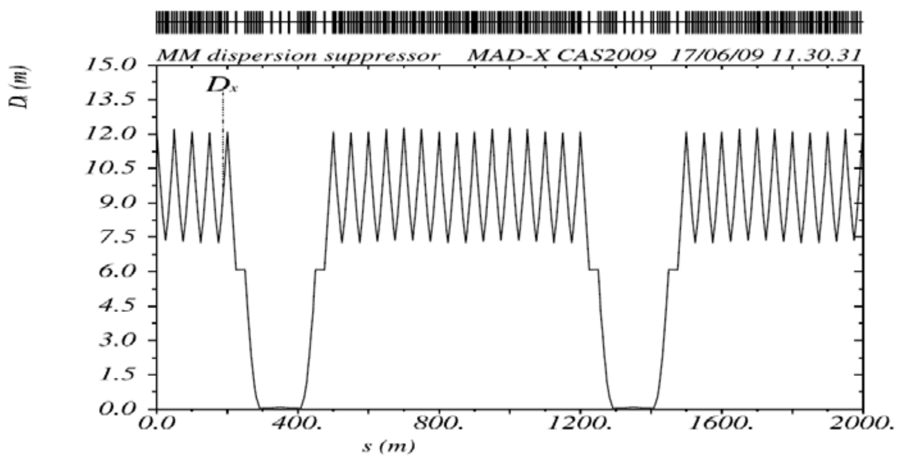
Courtesy of W. Herr.

Exercise III

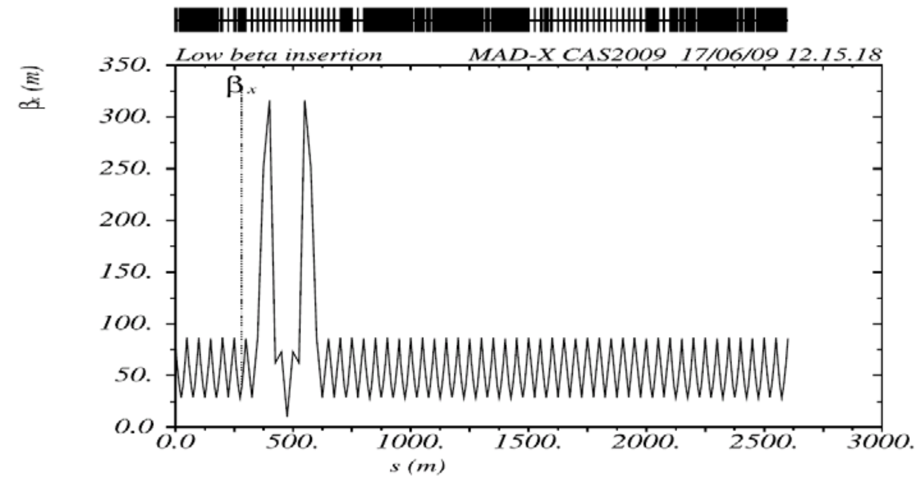
- *Start with the lattice from Exercise II and modify it to correct the chromaticity in both planes. Try first to calculate approximately the required strengths. Implements your correction scheme in MAD-X, and verify your calculation. Compute the precise strengths required by matching the global parameters Q_x' and Q_y' (in MAD-X names,* DQ1 *and* DQ2*, respectively). Compare the results with your calculations.*

IV. What we don’t have time for

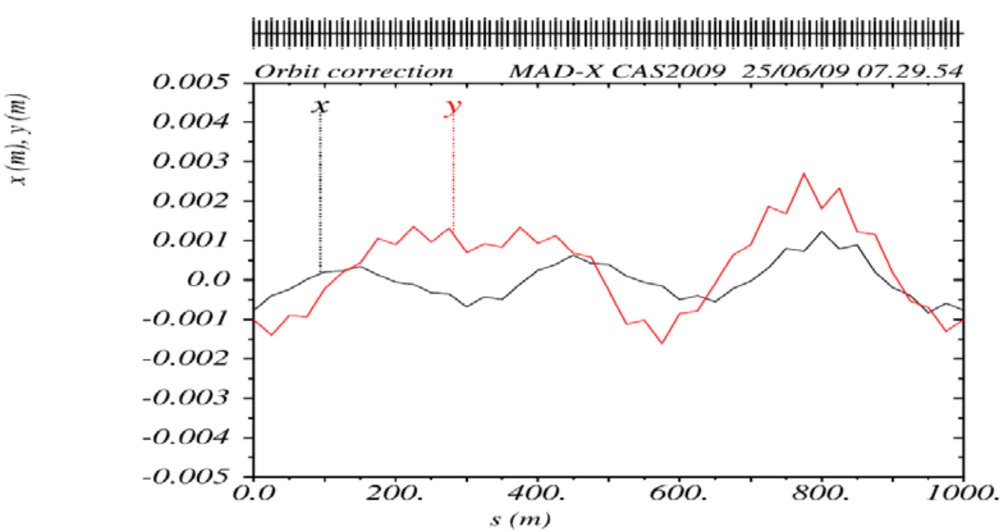
Local matching and orbit errors/correction



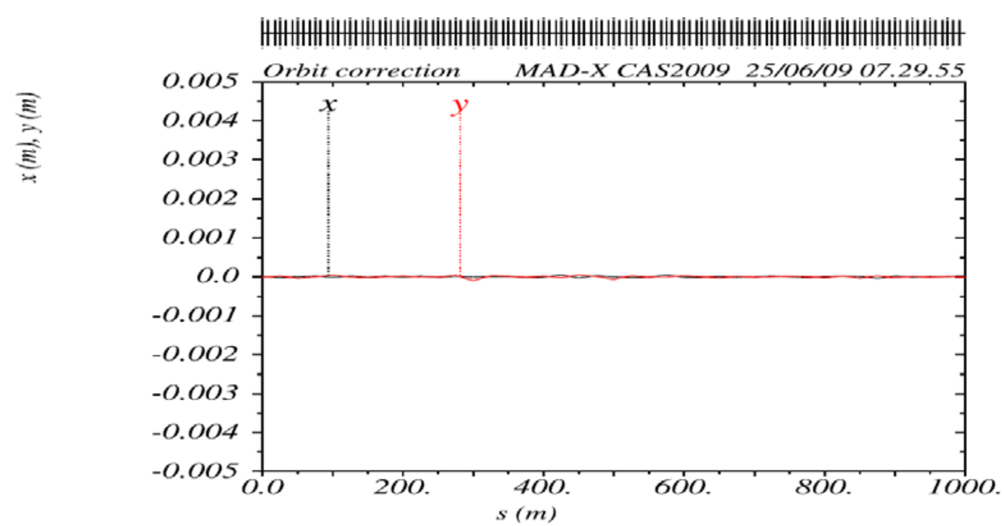
Dispersion suppressor



Low beta insertion



Orbit errors



Orbit correction

Particle tracking