Questions for the Optics Tutorial

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I.) Questions to relax … :

1.) Can you explain in your own words the meaning of …
phase advance
beam emittance
β-function
Both, the beta function and the beam emittance are defining "somehow" the beam dimension. Can you explain the difference ?
Do you have an idea how do to make beta smaller ?
… and - referring to protons - what would you do to achieve a smaller ε ?

2.) Explain the meaning of dispersion and chromaticity.
And now let's talk about the signs: A pure convention?
Why is the dispersion in a storage ring in general a positive number, what does that mean ? And can you imagine that there is a negative dispersion somewhere in a storage ring ?
And good heavens, why then is the sign of the uncorrected (so-called natural) chromaticity negative and can you explain what this tells us ?

3.) Consider a linear collider: The general structure of such a machine does not differ too much from the arc of a storage ring. Clearly – it is not a circular machine but anyway …
Does such a Linac have a chromaticity?
And if so how would you correct it ?

II.) Apertures and Beam Dimensions:

1.) The LHC magnet structure in the arcs consists of a symmetric FoDo with 90° phase advance per cell and an aperture radius of r_0 =17 mm.

a.) Given the value of β = 120m in a QF quadrupole lens, what beam emittance would just touch the vacuum chamber ?
b.) If the typical emittance of a stored beam at 450 GeV injection energy is $\varepsilon \approx 7.5*10^{-9}$ rad m, how many σ of beam envelope fit into the storage ring ?
c.) At injection and during the complete acceleration procedure the so-called injection optics is maintained in the machine ... why ?

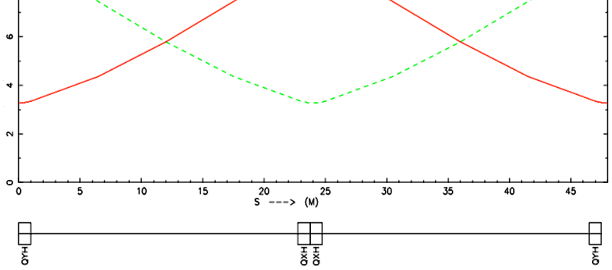
At high energy however finally the beta function at the mini beta scheme is applied to squeeze the β's at the interaction point to very small values. As we know, this leads unavoidably to very high beta values in the triplett magnets.
What is the beam emittance at the LHC luminosity energy E=7 TeV ?

If 21 σ aperture radius are recomended in the triplett magnets and the aperture radius there is 30 mm, what would be the maximum value of β that is acceptable in the ring ?
Why do we require more space in these triplett quadrupoles than in the arc ?

III.) FoDo Parameters

A storage ring is built out of 24 FoDo cells.
The length of each cell is L= 12m
The quadrupole lenses are symmetric, i.e. $k_{foc} = - k_{defoc}$=0.3659/m^2 and the length of the quadrupoles is l_q = 0.705m.
If the optics is treated in thin lens approximation:

1. *Is such a structure stable ?*
2. *Calculate the tune of this machine.*
3. *Calculate the value of the β-function in the foc. and defoc. quadrupole.*



IV.) If it were easy everybody could do it !!
Error in a quadrupole lens and the sensitivity of the beam

During the construction phase of a heavy ion storage ring one quadrupole magnet turned out to be too short by 1 mm: The one meter long yoke was stapled by steel plates, 1mm in thickness each, and one of them just was forgotten (this is no joke !).
Calculate the tune change in both planes if this error is not compensated and the beta functions at the location of the quadrupole are $\beta_x = 80\boldsymbol{m}$, $\beta_y = 20\boldsymbol{m}$ in the hor. and vert. plane respectively. The quadrupole strength is $\boldsymbol{k} = 2*10^{-2}\frac{1}{\boldsymbol{m}^2}$.

Lets assume that the beam will survive this error. (Clearly we corrected the error nevertheless).

Now lets have a look at a typical mini beta insertion:
Given the following parameters:

$$\boldsymbol{k} = 3.4*10^{-2}\frac{1}{\boldsymbol{m}^2}, \quad \boldsymbol{lq} = 1.9\,\boldsymbol{m}, \quad \beta = 1{,}6\,\boldsymbol{km}$$

Assume that the tune shift calculated above is a limit that can be tolerated for beam operation. What is the tolerance for the relative error of the magnet strength, (… or power supply stability, or magnet length …) at such a mini beta section ?

V.) Tuning Quadrupoles:

The main dipole and quadrupole magnets in a storage ring are often powered in series by one power supply. While such a set up facilitates the tracking of the main dipole and quadrupole magnets during acceleration it requires special "tuning" quadrupole circuits for tune adjustments. Assume your machine has one tuning quadrupole per plane, placed at a location where β_x = 180m, β_y =40m.
If the overall tune is Q=64.28, what is the maximum tuning range of this system if the maximum acceptable beta-beat in the machine due to the tuning is limited to10% ?
How can the system described above be improved, to obtain a larger tuning range with a beta-beat that is still smaller than 10% ?