Design of a quadrupole-free optics for the ballistic alignment in FLASH

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Abstract

Getting of coherent high intensity and high brightness synchrotron radiation on FLASH depends on a lot of factors. We need beam trajectory as straight as possible and very small beam sizes. Very small beam sizes are provided by strong quadrupoles. However, misalignment errors of quadrupoles bend beam trajectory. We have developed an optics which has turned off quadrupoles in order to apply the ballistic alignment technique. The beam follows a straight line and allows to find out misalignment errors of the beam transport line. The design of such optics for a line of FLASH is my task. Below it will be called "quadrupole-free optics".

Introduction

A free-electron laser, or FEL [1], is a laser that shares the same optical properties as conventional lasers such as emitting a beam consisting of coherent electromagnetic radiation which can reach high power, but which uses some very different operating principles to form the beam. FELs use a relativistic electron beam as the lasing medium which move freely through a magnetic structure, hence the term free electron.

FLASH ("F"reie-Elektronen-"LAS"er in "H"amburg) is a prototype of machine XFEL (X-ray Free Electron Laser). FLASH produces laser light of short wavelengths from the extreme ultraviolet down to soft X-rays. Principal parts of FLASH are RF gun, bunch compressor lines, accelerating structures, collimator, undulator and FEL Diagnostics (fig. 1).

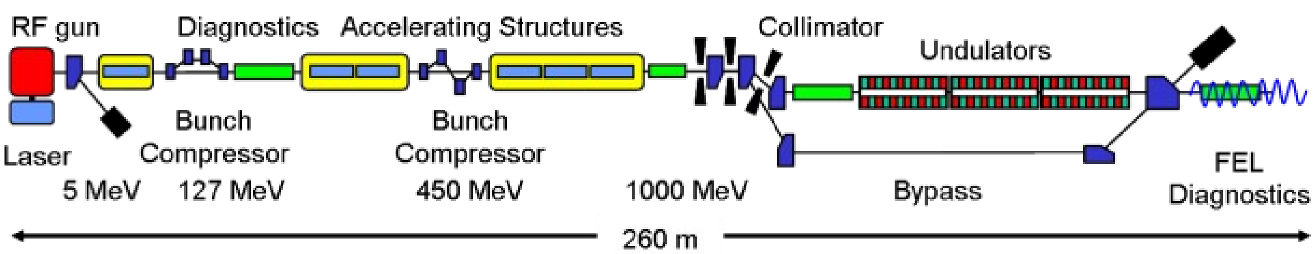

Figure 1. Structure of FLASH (not to scale) [2]

The last part of FLASH t (shown in fig. 2) was chosen as the quadrupole-free line. This line has undulators where beam trajectory should be straight in order to allow the FEL process. The chosen line has 31 quadrupoles.

[1] This work has been supervised by P. Castro, DESY, MPY

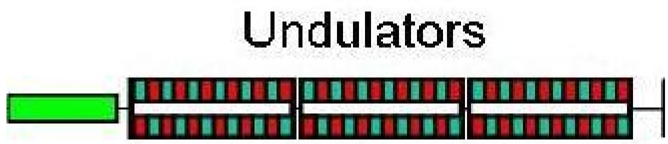

Figure 2. Quadrupole-free line (not to scale)

Method

The design optics has been calculated with MAD and it is shown on Figure 2. MAD was used to change design optics. MAD (Methodical Accelerator Design) Program is used for calculations, simulation and mathematical modeling of beam dynamics in accelerators [3].

Result of MAD calculations is an output file with beam evolution in the transport line. The resulting β-functions are shown in fig. 3 (the beam size is proportional to the square root of the β-function).

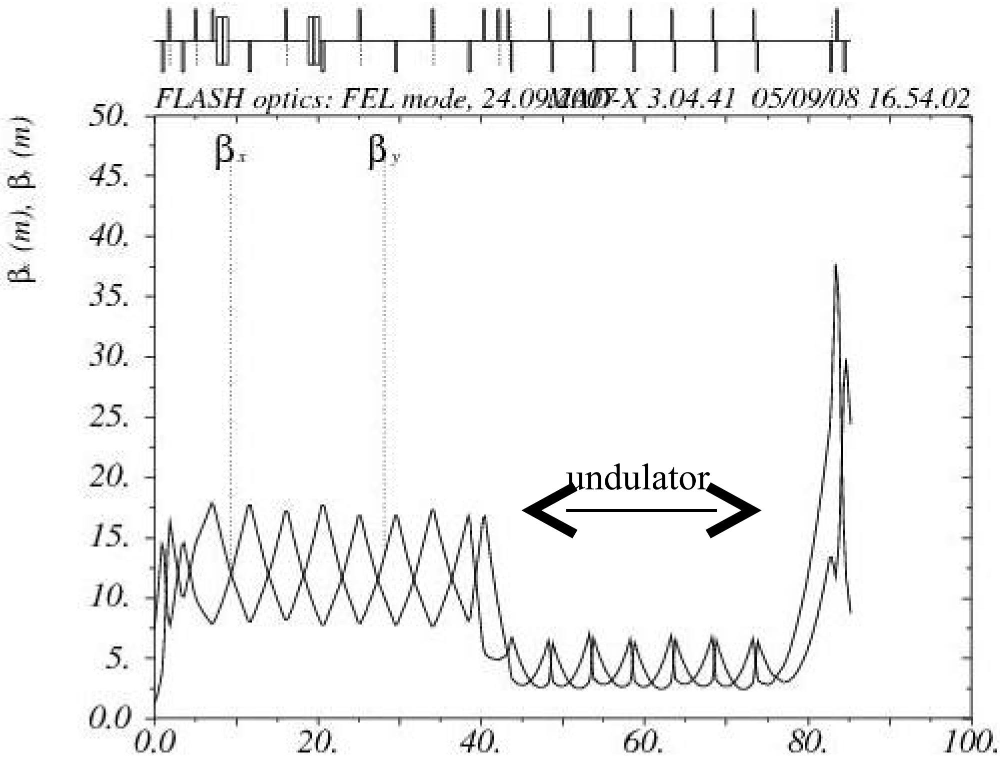

Figure 3. Design optics. Plot of β_x - and β_y -functions for the last of FLASH.

First, we have developed a quadrupole-free optics using the program MAD. In this optics 23 quadrupoles are turned off, which are over a distance of about 66 m. The maximum value of the β-functions are kept at around 100 m or below. The quadrupole-free optics is shown on fig. 4.

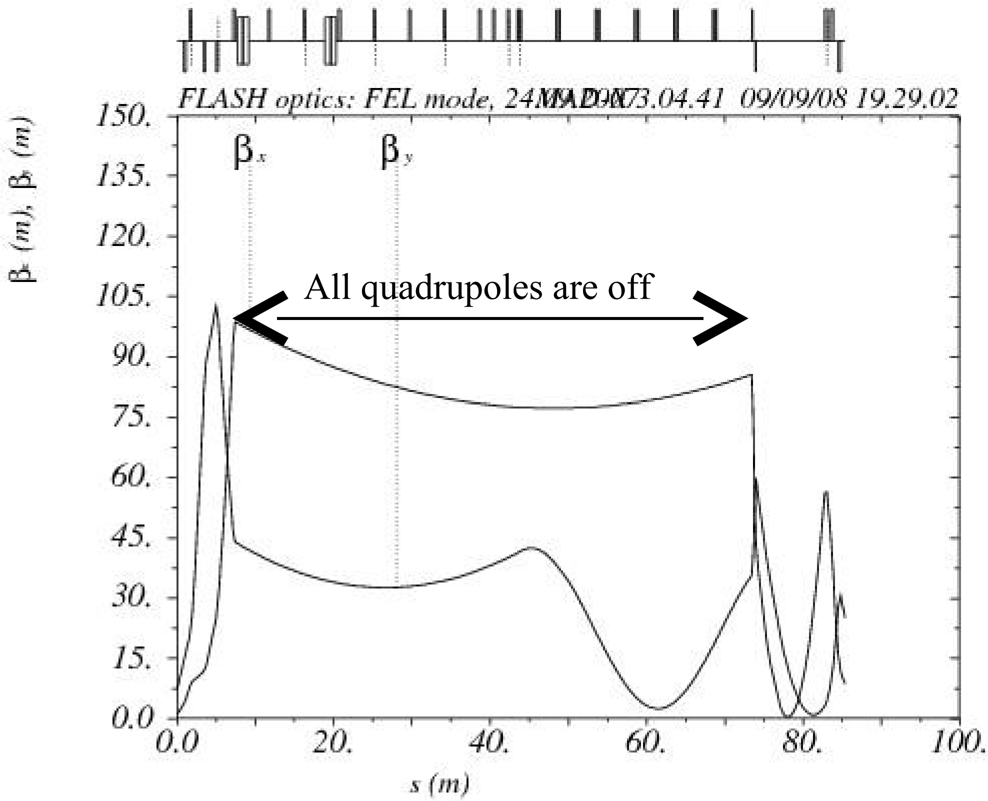

Figure 4. Result of design quadrupole-free optics. Plot of β_x - and β_y -functions

Additionally, we have developed a MAD input-file (a collection of commands for the program MAD) that allows the calculation of optics that makes possible a progressive (adiabatic) transition between the design optics and the quadrupole-free optics. Transition optics permits to find the solutions for step-by-step correction of the beam trajectory. Plot of β-functions of one solution for the transition optics is showed below (fig. 5).

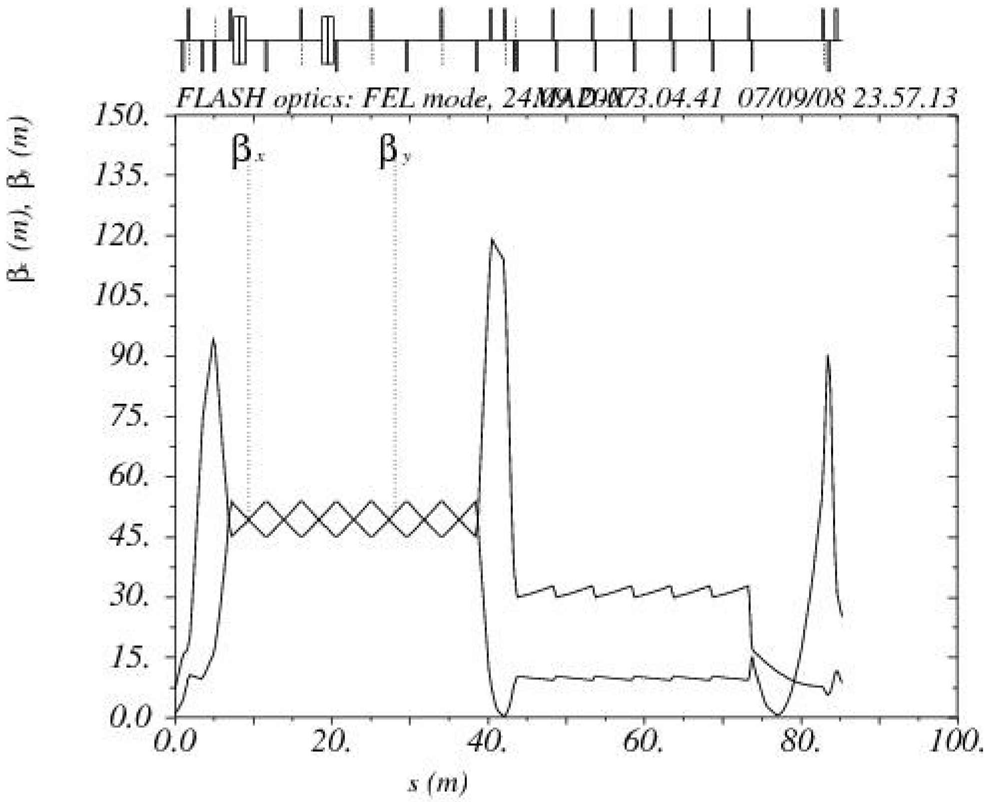

Figure 5. An example of a transition optics for a phase advance in FODO cell of 0.029, and a phase advance in undulator cell of 0.127

Program matches FODO cells as the first step for middle optics. It searches such values of normal quadrupole coefficient (K1) which are needed for matching twiss-parameters in the beginning and at the end of FODO cell. The same operation takes place for undulator cells. Then values of matched twiss-parameters are used as initial and final twiss-parameters for next matching. It is used special functions to match twiss-parameters of the upstream quadrupoles and FODO cells, FODO cells and undulator cells, undulator cells and the downstream quadrupoles.

Results

The quadrupole-free optics was developed with MAD. Turned off quadrupoles allow to reach the beam trajectory as straight as possible at the entrance of the undulator and measure the misalignment errors. In the same moment some turned on quadrupoles keep a small beam size and match the necessary initial and final values of the twiss-parameters.

There was an experiment (09.09.2008-10.09.2008) to try quadrupole-free optics. The result of the experiment is shown on fig. 6. Here we can see the beam size measure at several locations along the undulator of FLASH where quadrupoles are turned off. The top row is the horizontal beam size; the bottom row is the vertical beam size.

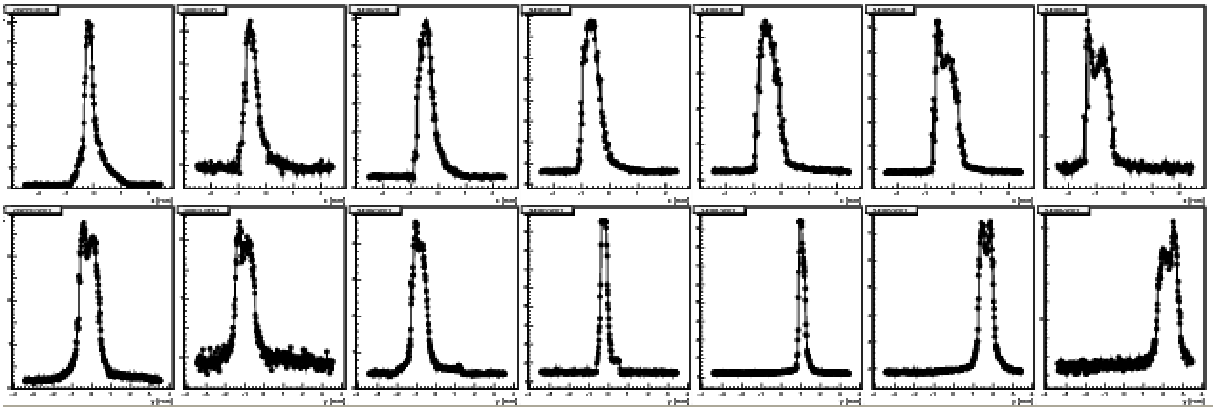

Fig. 6. Experimental data for quadrupole-free optics. The horizontal (top) and the vertical (bottom) beam sizes are measured with seven wirescanners (beam profile monitors) located along the undulator section.

We can see that the beam sizes are changing the same way like on fig. 4. So, the result of MAD calculation is in close agreement with experimental data. The transition optics was used for step-by-step correction of the beam trajectory.

Conclusions

The experiment showed that the quadrupole-free optics calculated with MAD can be used for reaching such beam parameters in the entrance of the undulator which we want. In that way we can use ballistic alignment along the undulator section for searching misalignment errors.

At the end of my work I would like to thank my supervisor Pedro Castro for the hard work, teaching and help in any problems. Thanks for the interesting and really useful tasks, for giving me very good experience and skills, for nice communication and for care during all DESY summer student program 2008. I also want to thank all MPY group. Only very nice people were around me all time. I really liked it! It gave me great pleasure to work here!

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References

[1] Wikipedia: http://en.wikipedia.org/wiki/Free_electron_laser

[2] http://vuv-fel.desy.de

[3] MAD User's guide, http://mad.web.cern.ch/mad/madx_manual.pdf