# DELTA Optics

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## Abstract

**DELTA** (**D**ortmund **EL**ectron **T**est **A**ccelerator) is a new 1.5 GeV electron storage ring now under construction at the University of Dortmund [1]. The facility consists of a 100 MeV LINAC, the ramped booster synchrotron **BODO** (**BO**oster **DO**rtmund) and the main storage ring DELTA (see Fig.1).

One of the most important goals for the DELTA lattice and the corresponding optical functions is the requirement of extremly low emittance, to enable DELTA to serve as a driver for different FEL experiments and to make a photon source of special beam characteristics available for single user SR experiments. Furthermore, the storage ring is optimized to provide highly flexible optics, suitable for various applications. Therefore, the lattice is based on a triplet focusing structure. The optical properties of such a triplet cell are investigated.

Founded upon this magnetic structure optional lattice configurations and corresponding versions of optics for alternative applications are available and presented in this paper.

The influence of inserted sextupoles, necessary for chromaticity correction, on nonlinear beam dynamics and energy dependence is also investigated in a rough manner.

## 1 The Triplet Cell

In general the 'basic cell structure' of accelerators determines the integral properties of the beam around the ring. In order to meet the requirements mentioned before, the lattice design based on a triplet focusing cell, consists of three quadrupoles located between two rectangular bending magnets. The layout of a basic triplet cell of the DELTA optics is shown in the insert of figure1.

In the bending magnets the beta functions and dispersion are quite small, yielding the required low emittance. Little additional focusing in the vertical plane is provided by the edge angles of the dipoles. The focusing quadrupole in the center of the triplet has twice the length of the defocusing one. The rectangular bendings, with 1.51 T field at maximum beam energy, have a magnetic

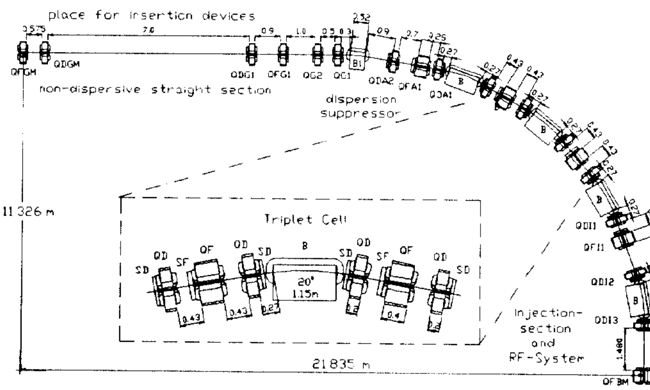


Figure 1: *One quarter of the basic magnetic lattice of DELTA and detailed view of the triplet cell structure*

length of 1.15 m providing a bending radius of 3.31 m , and a bending angle of 20° for each magnet. To obtain dispersion–free straight sections, two of these bendings are split into half magnets, located at the ends of each arc.

A criterion for the optical functions can be given, providing a minimum value of the emittance. In first order, assuming small bending angles and zero dispersion ($D_x = D'_x = 0$), the minimum emittance for an isomagnetic ring becomes [2]

$$\epsilon_{x_{min}}\,[rad\cdot m] \;\cong\; \frac{C_a}{4\sqrt{15}}\,E^2\,\Theta^3 \qquad (1)$$
$$\approx\; 9.475\cdot 10^{-8}\,E^2\,[GeV^2]\,\Theta^3\,[rad^3]$$

With Θ=0.349 rad and E=1.5 GeV the corresponding emittance of DELTA becomes $\epsilon_{x_{min}}$=$9.06\cdot 10^{-9}$ rad m. In order to reach the required emittance of $\epsilon_{x_0} \approx 1\cdot 10^{-8}\, rad\cdot m$ ,the number of dipoles $N_D$ is given by

$$N_D = \sqrt[3]{\frac{C_a\,E^2\,(2\pi)^3}{1\cdot 10^{-8}\,4\sqrt{15}}} \cong 17.41 \qquad (2)$$

with $\Theta = \frac{2\pi}{N_D}$. For DELTA a number of 18 bending magnets is chosen. With $\Theta = L/\rho$ we get the characteristic dimensions of the DELTA dipoles. Without approximations and considering the dispersion function, the optimum emittance for the rectangular DELTA dipole is minimized

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to be [3]

$$\epsilon_{x_{opt.}} = 2.95 \cdot 10^{-9} \; [rad \cdot m] \qquad \text{at E=1.5 GeV.} \qquad (3)$$

This calculated optimum value for the dipole represents a theoretical threshold. The actual design values of the lattice function differ from the optimum solutions, leading to a beam emittance which is larger by a factor of three to four than obtained theoretically. The reasons are higher-order chromatic and geometric aberrations, which can be very large for the ideal solution and would limit the dynamic aperture severely. To get more detailed information about

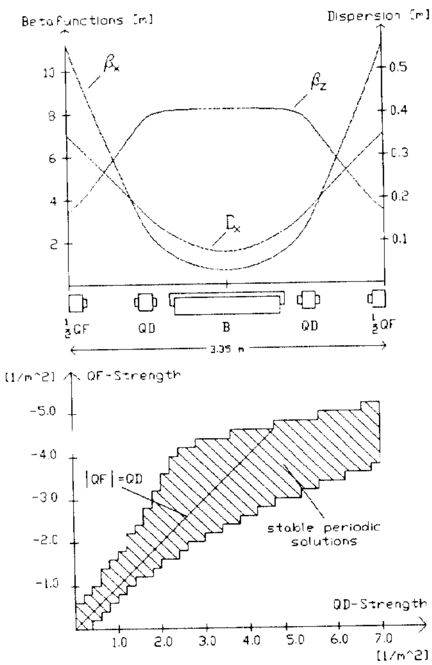


Figure 2: *Optical functions and range of stable solutions in dependence on the quadrupole strength of one triplet cell*

this particular optics, the exact triplet structure is calculated with the 'thick-lens matrix technique' using a computer code. The program calculates the periodic solution, determines the eigenvalues of the triplet transfer matrix $\tilde{M}_{Trip}$ and solves the main sychrotron-radiation integrals. Fig.2(bottom) depicts the range of periodic solutions of a triplet cell in dependence on the quadrupole strength (necktie stability diagram). The trace of the transfer matrix is $\tilde{M}_{Trip} \leq 2$, corresponding to stable solutions only in the framed area. The diagrams in fig.3 reveal the most important graphs and represent equivalent calculations for emittance, chromaticity and phase advance.

Based on the triplet structure, several lattice configuations and optics have been calculated. The lattice in fig.1 represents the basic version with three quads in the center of the straight sections. This magnetical configuration allows to adjust the emittance over a wide range from $5.0 \cdot 10^{-8}$ to $5.0 \cdot 10^{-9}$ rad m at 1 GeV. Because DELTA is a test storage ring, the philosophy is to adapt the straight sections to the requirements of the particular experiment

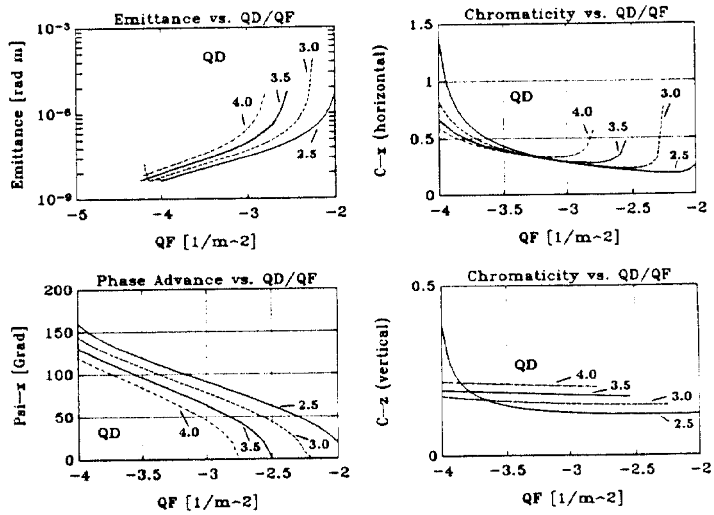


Figure 3: *Chromaticity, phase advance and emittance as dependent on the strength of QF and QD*

keeping the arcs unchanged. Therefore, the two 20 m long straights of the racetrack-shaped storage ring are available for insertion devices.

# 2 FELICITA II

FELICITA II will be the second FEL experiment at DELTA, operating in the wave length regime from 100 to 20 nm.

Because of the quads in the straights necessary for optical matching the available space for long undulators is limited to about 14 m.

The most important parameters of FELICITA II, which determine the influence on the optical functions are:

- undulator length $L = 13.97m$
- period length $\lambda_u = 3.4cm$
- number of periods $N_p = 411$
- peak field $B_0 = 1.07T$
- electron energy $E = 0.5 - 1.0GeV$

Picture 4 shows the focusing properties of the FEL undulator on the electron beam. In horizontal direction the undulator provides no focussing and acts just like a drift space, whereas, in vertical direction, there is a kind of quadrupole focussing, leading to two betatron oscillations over the whole undulator length. Thus, the undulator produces a tune shift of 1 for the storage ring optics. Accordingly only a little change of the optics without insertion is necessary. This is provided by the quads in the straights. Similar results have been obtained from a 3-dimensional numerical FEL simulation code [5].

# 3 Superconducting Wiggler

The demand for synchrotron radiation in the soft x-ray regime is increasing continuously. Unfortunately, the radi-

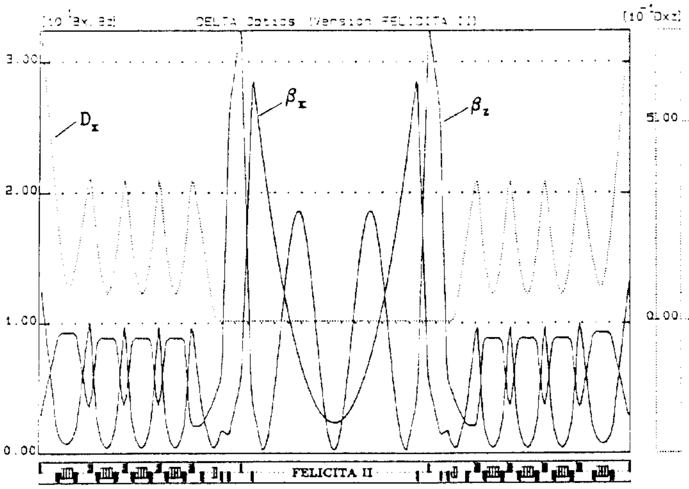


Figure 4: *Optics for FELICITA II calculated with an undulator of 411 periods*

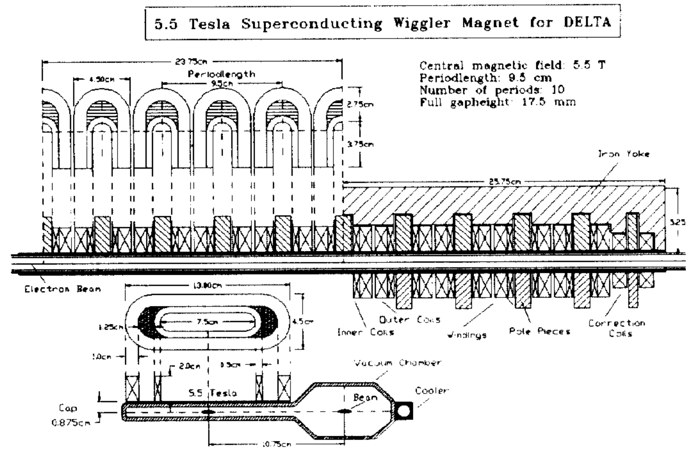


Figure 5: *Schematic view of the proposed 5.5T Wiggler*

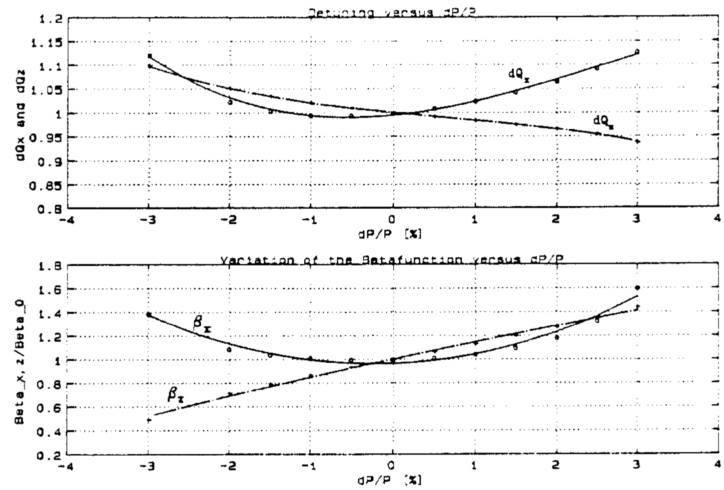


Figure 6: *Tracking results plotted as a function of the energy dependence*

ation from the DELTA bending magnets of 1.5T strength has a characteristic wave length of only 5.47 Å. To enlarge the range of wave length of the machine for short–wave–length users, the installation of a superconducting wiggler is foreseen. The wiggler will be inserted in the straight section of the fourth quadrant, for which the effects on beam optics due to edge focussing are compensated by additional quads. The design parameters of the magnet are mainly defined by the SR properties determined by the experiments of the user. Some users are interested in photons with a critical wave length of 1 Å and a photon flux of about $10^{15}$ [photons/mA/0.1%BW] in a horizontal radiation fan of 10 mrad. As a consequence, the design must be optimized to provide extremly short period length and a small gap heigth, requiring superconducters with high critical currents. Fig. 5 shows a preliminary design for such a wiggler with 20 poles. The design field at the orbit is about 5.5 T, based on Nb–Ti superconducters with a critical current of $10^3 A/mm^2$ at $8T$ and $4.2°K$. Further studies on a detailed magnet design is under work.

# 4 Tracking Studies

An effective compensation of the chromaticity for low–emittance optics has been evaluated by testing various arrangements of sextupole families. Satisfactory results have been obtained with a correction scheme of four sextupole families regularly distributed over both arcs at positions with nonvanishing dispersion.

The sextupolar strengths are optimized to minimize the non linear effects, in accordance with energy dependence and dynamical aperture.

Some results of these investigations are given in fig.6 As can be seen, the relative variation of the tunes and the optical functions in the center of the arcs is sufficiently small the range of 3%. Also, the tunes do not approach any resonance of third, half or integer order.

# References


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