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MAGNET STUDIES FOR THE ACCELERATOR FLUTE AT KIT

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Abstract

At KIT (Karlsruhe Institute of Technology) we are currently constructing the compact linear accelerator FLUTE (Ferninfrarot Linac Und Test Experiment). This 41 MeV machine is aimed at accelerator physics and synchrotron radiation research, using ultra-short electron bunches. The electrons are generated at a photo-cathode using picosecond long UV laser pulses. A magnetic chicane is used to compress the bunches longitudinally to a few femtoseconds [1,2].

This contribution describes both the magnet design, in particular the optimization of the chicane dipoles based on finite element method (FEM) simulations, as well as the implementation of a magnet measurement system.

INTRODUCTION

Many important questions from solid state physics to biological applications demand an analysis within a wide spectral range from THz to IR. These wavelengths are difficult to cover with high intensity using ring-based light sources. However, if the bunch length is comparable to or smaller than the desired wavelength, the electrons start to emit coherently, yielding a significant increase in flux [3].

To study bunch compression down to the fs-range, to study the influence on the generation of CSR (coherent synchrotron radiation), and to further the development of related diagnostics, a linac-based test accelerator named FLUTE (Ferninfrarot Linac Und Test Experiment) is currently under construction at KIT. The planned top-level parameters are listed in Table 1. For more information about FLUTE and the planned experiments, please refer to [1, 2] and the references therein.

Table 1: FLUTE Design Parameters

Linac Energy	41 MeV
Repetition Rate	10 Hz
Bunch Charge	1 pC - 3 nC
Pulse length	1 fs - 300 fs

To achieve the desired flexibility for experiments and the strong compression, a D-type bunch compressor is foreseen, cf. Fig. 1. As a detailed analysis of the future experiments depends on a precise description of the magnetic lattice used, OPERA [4] finite element simulations have been carried out for the chicane dipoles [5]. Particular emphasis has been put on the comparison of the calculated fringe fields with the analytical treatment used in the ASTRA [6] tracking code; and the calculation of the expected multipole components. The results are presented in the following section.

To measure the real field distribution of said magnets a measurement system featuring both a 3D Hall-probe and a stretched-wire set-up has been installed [7]. It is described in detail in the subsequent section.

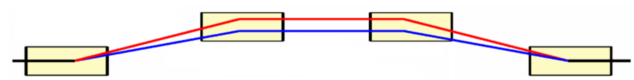

Figure 1: Schematic of a D-type bunch compressor. Particles with higher energy (blue) receive a smaller deflection in the dipole magnets (i.e. travel along a shorter path) than particles with a lower energy (red). For the correct initial energy distribution along the bunch, a bunch length compression can be achieved.

DIPOLE MAGNET DESIGN

Design Considerations

To allow maximal flexibility for future beam dynamics studies, the dipole magnets have to cover a large parameter range regarding beam energy and deflection angle, as listed in detail in Table 2. Two basic options are considered: a compact C-type and a wider, mechanically more stable H-type dipole magnet, cf. Fig. 2.

Table 2: Magnet Design Parameters

Electron beam energy	40 - 50 MeV
Deflection angle	0 - 15°
Magnetic field	0 - 120 mT
Magnet length	200 mm
Pole distance	45 mm
Transverse good field region C-type	76 mm
Transverse good field region H-type	240 mm

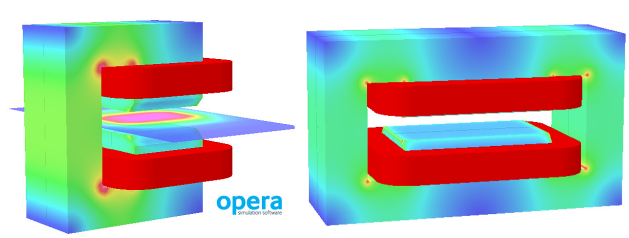

Figure 2: Possible C-type (left) and H-type (right) dipole magnet designs. The magnetic field strength within the magnet is indicated by colour map. For the C-type magnet, the magnetic field on axis is also illustrated

For the C-type magnets investigated, the transverse good field region (i.e. the area where the on-axis field does not

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change by more than a given fraction of the design field) is chosen as the sum of the calculated beam size plus the maximal beam deflection offset within the magnet (corresponding to 15° deflection angle). However, for operation at small deflection angles, this would make it necessary to make the two central C-type dipoles (and the beam pipe) of the D-chicane movable, cf. Fig. 1.

Stationary H-type dipoles with a transverse good field region wide enough to also cover the maximal displacement of the beam in the second and third dipole are currently under investigation (~160 mm beam displacement for 15° deflection angle and a distance of 500 mm between the outer and inner dipoles).

Comparison OPERA to ASTRA

The optimisation and error studies for the FLUTE bunch compressor chicane [8] are primarily based on the ASTRA tracking code [6]. In ASTRA, magnet fringe fields can be approximated using the analytic equation

$$B_y(d) = B_0 \left(1 + \exp\left(\frac{4d}{D_{\mathrm{gap}}}\right)\right)^{-1}, \qquad (1)$$

with d the normal distance from the magnet edge and D_{gap} the height of the magnetic gap.

However, for the relatively short and weak magnets foreseen for FLUTE, this approximation leads to a noticeable difference in the integrated field used by ASTRA and the one calculated by OPERA [4], as illustrated in Fig. 3. To achieve the same integrated dipole field (i.e. the same beam deflection angle), one can either adjust the length of the dipoles or the maximal field. For a more favourable ratio between constant field and fringe field, we have chosen the latter option. Tracking simulations in OPERA confirm that we now indeed attain the same beam deflection. The adjusted C-type dipole model has been used for all further investigations.

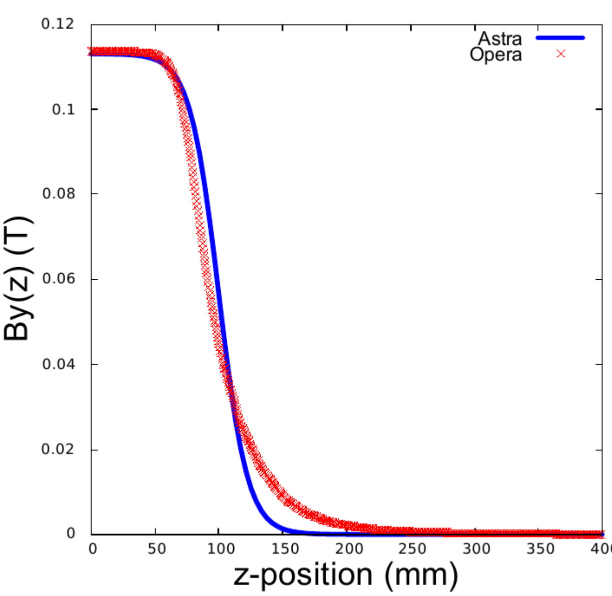

Figure 3: Comparison between the calculated fringe field in OPERA and the analytical approximation used by ASTRA, cf. Eq. 1. B_0=114 mT, physical magnet edge at z=100 mm. Similar results have been reported e.g. in [9].

Multipole Studies

The magnetic multipoles have been determined from the magnetic field components calculated on a circle of 6 mm around the (and orthogonal to) the reference trajectory (s) for an on-energy particle. As an example, the quadrupole strength along s is illustrated in Fig. 4.

The calculated multipole distributions have been integrated from $-\infty$ to 0 (the center of the magnet) and from 0 to $+\infty$. This allows to generate thin lenses for the beam tracking simulations, to be included right before and after the dipole.

The possibility to perform tracking simulations using the complete calculated field map in ASTRA or elegant [10] is currently under investigation.

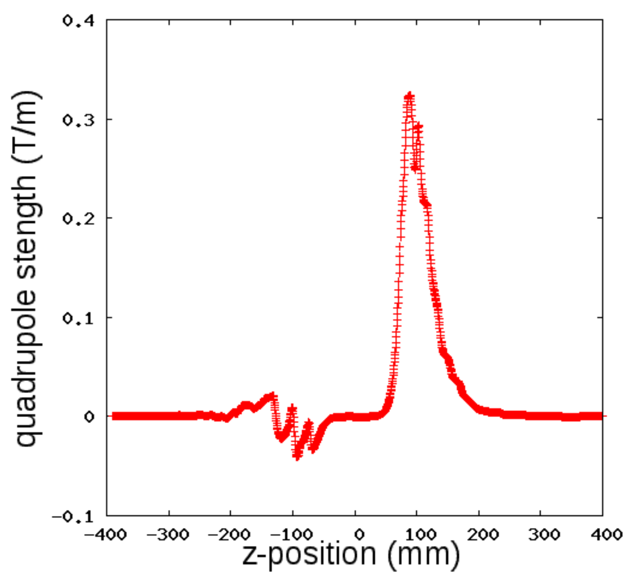

Figure 4: Quadrupole component of the dipole magnet, calculated along the reference trajectory for a beam energy of 41 MeV and a deflection angle of 9.4°. As the beam enters orthogonal to the magnets edge and exits under an angle, the difference in strength and the opposite signs can be understood (beam traveling towards larger s). Fluctuations are attributed to numeric noise.

MAGNET MEASUREMENT SYSTEM

Based on [11, 12], a magnetic measurement system has been installed recently [7]. It consists of 2 times 2 linear stages with 100 mm travel mounted in the xy-plane, and one linear stage with 500 mm travel mounted in z-direction. The system, assembled on a vibration damped, non-magnetic optical table can serve for both 3D Hall-probe and stretched-wire measurements. A detailed component list is given in Table 3.

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Table 3: Magnet Measurement System Main Components

100 mm stages	Newport M-ILS100CC
500 mm stage	Newport M-IMS500CCHA
Rotation stage	Newport UTR80A
Optical table	Newport M-RPR-N-46-8, Newport S-2000A-428
Nanovoltmeter	Keithley 2182A/E
Switch, Scanner Card	Keithley 7001, 7168
3D Hall-probe	Arepoc AXIS-3

Hall-Probe Measurements

The measurement system features a 3D Hall-probe, capable of measuring the magnetic field components in x, y and z direction simultaneously. As illustrated in Fig. 5, the probe itself is mounted in a carbon rod. A rotation stage allows the precise adjustment of the Hall-probes to the horizontal and vertical field components, respectively.

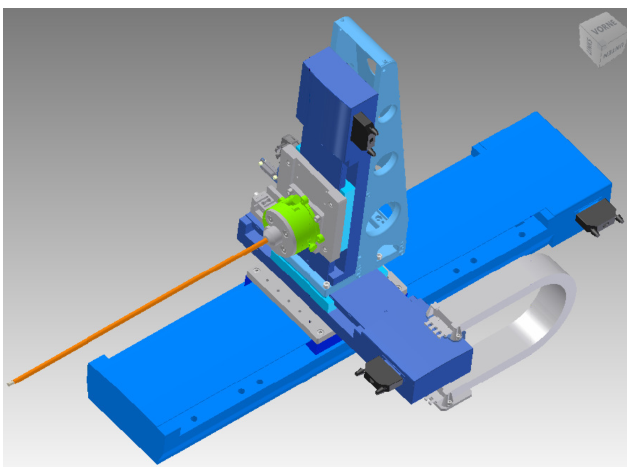

Figure 5: Hall-probe measurement system

First measurements have been carried out, characterizing the FLUTE electron gun solenoid. The results from the factory acceptance test have been reproduced.

Stretched-Wire Measurements

A stretched-wire system has been implemented, details of which are illustrated in Fig. 6. First measurements have been conducted successfully. The detailed analysis of the achievable resolution is still ongoing.

SUMMARY

At KIT, the test accelerator FLUTE is currently under construction. It will feature a D-type bunch compressor for a bunch compression down to femtoseconds. To allow a detailed analysis of future experiments, two dipole magnet scenarios have been derived and studied via FEM simulations.

A magnet measurement system featuring both the option for 3D Hall-probe and for stretched-wire measurements has been installed successfully.

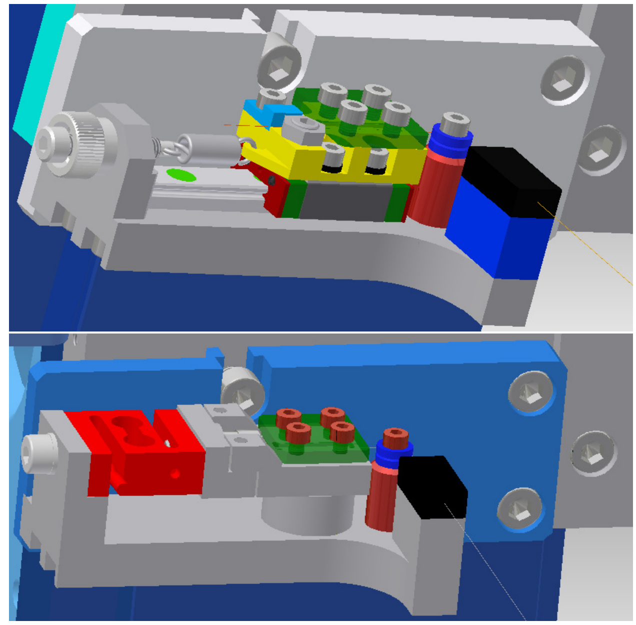

Figure 6: Mounting of the stretched wire. At one end, the wire is clamped to an electrically isolated sledge, fine adjustments to it tension can be made via a micrometer screw pulling on a spring (top drawing). At the other end, the tension is measured electrically (s-shaped sensor in the bottom drawing). Coarse adjustments can be made via movement of the z-stage. At both ends, the wire is guided through a Sorbothane ® block for vibration damping (black). The return wire (not shown) can be attached to the top part of the clamps.

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