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Kicker-magnet for the 5.0 MeV polarimeter at MESA

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The Mainz Energy recovering Superconducting Accelerator (MESA) is designed for high-precision measurements of parity violating observables which requires accurate knowledge of the spin polarization of the electron beam. A chain of polarimeters at different beam energies is planned, including a Mott polarimeter operating at 5.0 MeV. We present a preliminary design for an extraction beam line towards the Mott polarimeter. A special design of a kicker-magnet is introduced which offers advantages in comparison to conventional magnets.

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1. Introduction

1.1 Polarimeter chain at MESA

The MESA accelerator is being built at the Johannes Gutenberg-university in Mainz. It will produce a CW spin polarized electron beam with a polarization of ~ 85 %, a beam current of ~ 150 μA and a beam energy of ~ 155 MeV, for more details see [1, 2]. The accelerator may be equipped with a double-scattering Mott polarimeter [3] at 100 keV and will have a Mott polarimeter at 5.0 MeV. Both Mott polarimeters are based on the scattering of an electron beam off a gold target. In front of the experiment a Møller polarimeter will be employed[1]. Mott polarimeters destroy the electron beam and it is therefore not possible to operate the polarimeter and the experiment at the same time. In this paper we describe an arrangement which could allow minimizing the impact that this fact has on the execution of the experiments.

1.2 Purpose of a kicker-magnet

An dedicated beam line towards the polarimeter is planned, as can be seen in fig. 1. There are two possible advantages. First, a beam dump can be installed in a suitable distance behind the polarimeter, eliminating the risk of damaging sensitive equipment in the main beamline. Additionally more effective shielding of the radiation created in the beam dump becomes possible. Second, it opens the possibility for "quasi-online" operation, if a fast and reproducible extraction can be provided by a kicker magnet.

Using a dedicated beamline causes an interruption of the actual measurement process, in our case of the measurement of the parity violating observable at 155 MeV at the site of the P2-experiment [2]. A first challenge arises from the fact that the main beam parameters must be exactly restored to sent the beam back to the experiment after the polarisation has been measured. According to our experience with the 3.5 MeV polarimeter at MAMI [4] this is difficult if a conventional (iron-dominated) magnet is used because of its hysteresis. We will therefore use a magnet which is based on an air-coil where such effects could be minimal or even be absent. The relatively low beam energy of 5 MeV is helpful here.

Once this first goal is reached we hope to achieve further advantages which could alleviate problems that plague many of the polarimeters presently in use. They are related to intensity variations during the measurement process. These include possible drifts of beam polarisation and, in the case of the P2-experiment, problems associated with temperature transients of the liquid hydrogen target. In the case of our air coil arrangement we hope to extract a tiny fraction of the CW-pulse train of MESA continuously towards the polarimeter. A typical time structure would be to extract the beam for 10 Milliseconds with a rate of 1 Hertz. The electron beam would be switched off during the risetime of the kicker magnet which can be set to < 1 ms with moderate effort. The electron source, polarimeter and experiment would run under constant conditions with nearly 100, 1, and 99 % duty factor respectively. This will represent a quasi- online measurement of beam polarisation.

1.3 Geometry of kicker

The extraction will take place after the 5 MeV MESA-preaccelerator, the so-called MilliAMpere BOoster, or MAMBO for short [5]. Besides the polarization measurement, another task is to measure

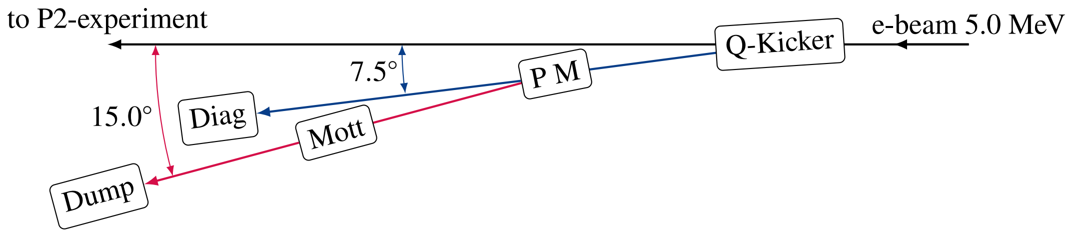

Figure 1: An another possible arrangement of 5.0 MeV beam distribution. The extraction from the main beam-line is provided by the kicker magnet. Q-Kicker: duty factor 0.01, rise time 0.1 ms. P M electro magnet: "on-state" Mott polarimeter, "off-state" beam diagnostic. Diag: beam diagnostic system (e.g. longitudinal phase space

Q-Kicker	Permanent Magnet	Beam accepted
OFF	ON	MESA-operation
ON	OFF	Beam diagnostics
ON	ON	Mott polarimeter

Table 1: Operational conditions of the fast kicker and conventional magnet

the longitudinal and transverse beam properties, see [6, 7] for details.

A bending angle of 15 ° in two stages is possible, e.g. a first stage of 7.5 ° with a kicker - see geometry in fig. 2 on the upper left panel - and a second stage of 7.5 ° with a conventional dipole magnet. The first magnet in the extraction line will allow fast extraction.

The second one could have an iron yoke to provide additional bending in a more compact set-up. Table 1 presents three operational modes of the kicker and the conventional magnet.

1.4 Electrostatic kicker

A length of 0.3 m is foreseen for the kicker and its aperture should me a minimum of 0.04 m. To achieve the desired bending, either magnetic or electric fields can be used. These can be related by the formula $E = \beta c B$, which results in this case in fields of 2.7 MV/m and 0.009 T respectively. The first estimation of a possible arrangement of the electrostatic kicker using a FEMM software leads to an extremely high voltage of $U_{plate} \sim \pm 54.0$ kV on the electrical plate. For this reason the electrostatic kicker is excluded.

1.5 Magnetic field kickers: BSC abd CCT

A classical solution is the bent saddle coil (BSC). For example steerers at MAMI are made according to such design. But this kind of kicker is difficult to produce and it is not easy to adjust the coil-windings in the right position. An additional problem is that it is difficult to achieve a short switch time because of the high inductance.

An interesting concept is called Canted Cosine Theta (CCT) coil, proposed in 1970 [8]. The CCT kicker consists of two coils, angled by e.g. 45 ° relatively to the z axis, see fig: 2 on the left. The turns of each coil are shown as red and blue spirals, with the corresponding magnetic fields being of the same color. The resulting magnetic field is marked with a black arrow. The direction of the incoming and outgoing electron is shown as dashed arrows.

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The second type see fig: 2 on the right consists of a number of long straight wires parallel to the z-axis of the kicker distributed according to the cosine law. Such systems are very common in superconducting applications and have been analyzed in detail in [9].

2. Numerical evaluation of kicker properties

2.1 Analytical calculation

Both kicker-types are iron free, so a simple method of calculation can be used. By parametric representation of each wire in each coil we can divide each coil into short segments. Each short segment is related to it's location in space and a current. Then the Biot-Savart law is applied to each of them. The code is written on Wolfram Mathematica [10]. The solution is very precise and proved on magic energies.

2.2 Good field regions

To estimate the homogeneity of the magnetic field inside the coil the field map is calculated along the z-axis of the coil, see fig. 2. The field map cross sections in the lower row show that the field variation is below 1‰. The position of those cross sections along the z-axis is marked with crosses in the picture above. This means we have a good chance to keep the emittance low after the kicker.

2.3 Transfer matrices

A transfer matrix describes the behaviour of the beam passing through the kicker. Transfer matrices for CCT and BSC kickers are presented in equations 1 in case of ideal entrance of the beam inside the kicker. The entry $\epsilon \leq 1.0 \times 10^{-6}$ points to an uncoupled motion of the electron in horizontal and vertical planes. Each bottom-left element of the sub matrix for the horizontal and vertical planes represents the focusing force for each plane , upper-right elements represent the optical length. The other elements are the angular and linear magnification. Importantly, the focusing force looks similar in both planes in the case of the CCT kicker and differs in the case of the BSC kicker. It it also to note that the optical length is similar in both vertical and horizontal planes for the CCT kicker and is different for the BSC kicker. The optical length could affect the time structure of the beam.
The spin direction changes to 7.594 ° while the electron rotates by 7.500 °. Since there is no electric field, the spin direction change corresponds to the theoretical value of $7.5\,°(a\gamma + 1) = 7.5938\,°$.

$$TM_{CCT} = \begin{pmatrix} +0.964 & 2.296 & \epsilon & \epsilon \\ -0.031 & 0.968 & \epsilon & \epsilon \\ \epsilon & \epsilon & +0.978 & 2.31 \\ \epsilon & \epsilon & -0.019 & 0.98 \end{pmatrix}, \; TM_{BSC} = \begin{pmatrix} 1.031 & 2.368 & \epsilon & \epsilon \\ +0.027 & 1.033 & \epsilon & \epsilon \\ \epsilon & \epsilon & 0.785 & 2.043 \\ \epsilon & \epsilon & -0.213 & 0.717 \end{pmatrix} \quad (1)$$

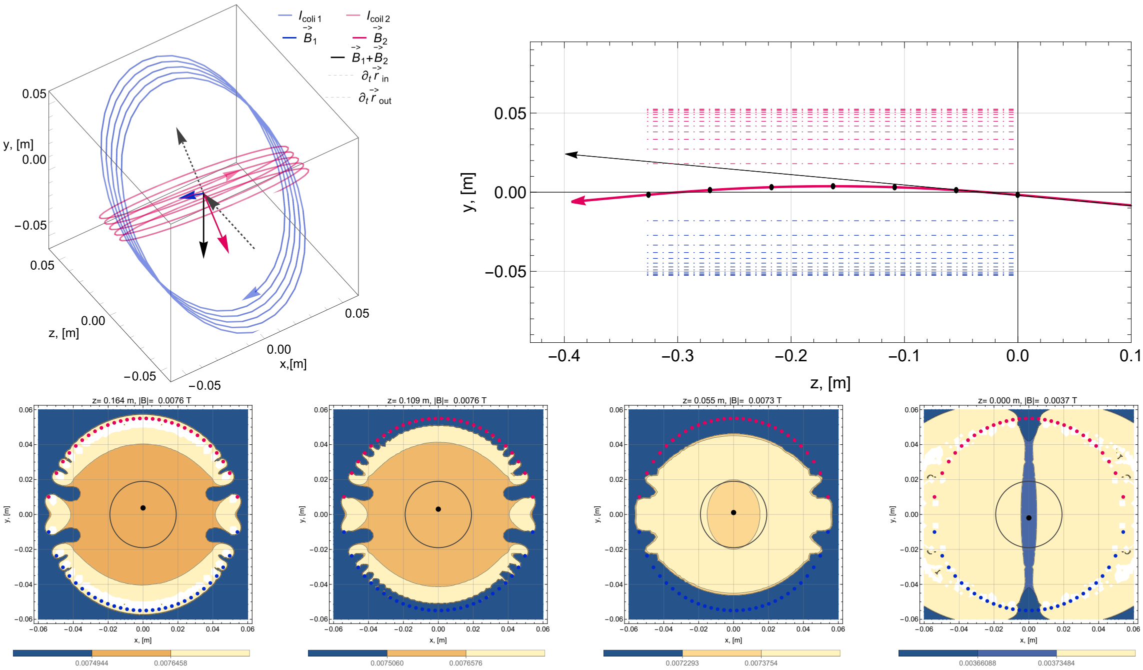

Figure 2: Top left: the main idea of CCT. Top rigth: view of the CCT kicker with an electron path with (red) and without (black) a magnetic field. Bottom row: magnetic field profile in xy directions along z-axis. Good field regions of $\pm 1\%$ are marked as points in the upper right picture. The black circle shows the vacuum tube.

2.4 Emittance growth with CST Software and MW

It is important to keep the emittance low in order to preserve the beam quality. The emittance growth for one CCT and five different BSC kickers in both horizontal and vertical planes is investigated. Using CST suite software [11] all five arrangements of BSC kicker lead to unacceptable emittance growth. It is shown that the emittance growth in the CCT kicker is low.

Emittance tracking Wolfram Mathematica Software [10] is investigated too. Tracking of typical electron beam on the path one meter up and downstream of kicker was simulated. A weakly focused beam has an initial diameter of about ~ 1.0 mm and a convergence of ~ 2.0 mrad. The start position is shifted by ~ 2.0 mm in x and y direction from it's ideal location, and still the growth of emittance stays below ~ 0.5 %.

3. Summary and outlook

The CCT kicker with straight wires is preferred and is under construction at the moment. Future investigations will also be directed towards the question which time structure of extraction is ideal for the P2-experiment, in particular with regard to the stability of the liquid hydrogen target.

Acknowledgments

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