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Q-Kicker for the 5.0 MeV Mott polarimeter at MESA. Part II

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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 two Mott polarimeters and one Möller polarimeter at different beam energies is planned. Current design of the 5.0 MeV beam section containing a kicker design for a Mott polarimeter is presented.

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1. Introduction

The Mainz Energy-recovering Superconducting Accelerator (MESA), currently under construction at the Johannes Gutenberg University in Mainz, Germany, is designed to conduct high-precision parity-violating electron scattering experiments. A critical requirement for these experiments is the accurate measurement of the electron beam's spin polarization, which is achieved by using a chain of polarimeters, including a Mott polarimeter operating at 5.0 MeV. However, the destructive nature of Mott scattering necessitates a dedicated beamline equipped with a fast and reproducible kicker-magnet to extract a portion of the beam for polarization measurements without disrupting the main experiment.

Traditional iron-dominated kicker-magnets are limited by hysteresis effects, which complicate precise beam restoration and stability. To overcome these limitations, an air-coil-based kicker-magnet utilizing a Canted Cosine Theta (CCT) coil configuration [1] and referred to as the Q-kicker in the previous work [2] and this workshop paper, has been proposed. This innovative design minimizes hysteresis, allowing quasi-online polarization monitoring. Such capabilities are particularly crucial for experiments like P2 at MESA

This article presents the design, numerical evaluation of the measured magnetic field, and expected performance of the Q-kicker, demonstrating its potential to significantly enhance the experimental capabilities of MESA. By addressing the limitations of traditional kicker-magnets, the proposed Q-kicker supports the requirements for precision beam polarization measurements of next-generation parity-violation experiments.

2. Design and Features

The Canted Cosine Theta (CCT) kicker-magnet, referred to as the Q-kicker, is designed to achieve a bending angle of 7.5° for the 5.0 MeV electron beam at MESA. The magnet consists of two symmetrically oriented coils, each angled at 3.75° relative to the beam axis, with straight wires arranged in a cosine-theta configuration. This design generates a quasi uniform magnetic field perpendicular to the beam direction, ensuring precise and reproducible beam extraction.

The main features of the Q-kicker, along with its operational conditions, are summarized in Table 1. The design provides sufficient space for the electron beam while maintaining a compact form factor. The absence of iron yokes in the CCT design eliminates hysteresis effects, enabling precise control of the beam parameters and ensuring reliable operation over extended periods. This makes the Q-kicker a robust and efficient solution for beam extraction in high-precision experiments at MESA.

The major components of the Q-kicker were designed at our institute. The vacuum chamber is currently under production, and the parts for fixing the winding wires were also designed in-house and 3D-printed from Alumid. The choice of Alumid [3] is motivated by its insulating properties, which prevent short circuits in the winding, and its mechanical properties, which are similar to aluminum. Additionally, the use of 3D printing technology allows for easy modifications to the winding form if necessary.

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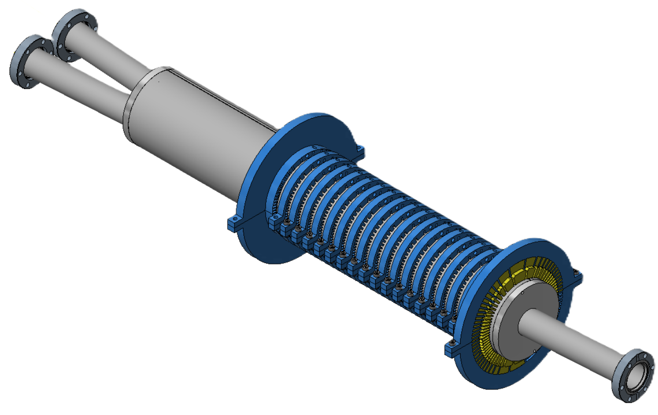

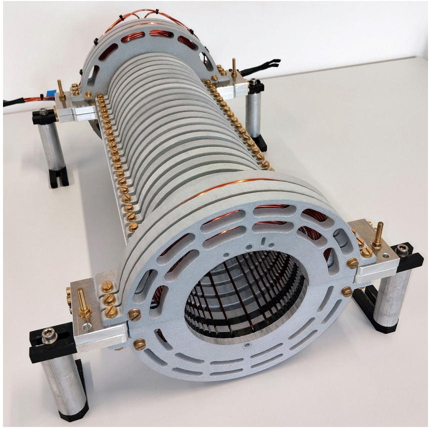

Figure 1: Left: Model of the vacuum chamber and coil of the Q-kicker. Right: The coil prepared for magnetic field measurements. The vacuum chamber and coil are shown as 3D models, with coil holders 3D-printed from Alumid.

Q-Kicker parameter	Values
Dimensions (LxBxH)	500 mm x 250 mmx 250 mm
Inner diameter	108 mm
Free diameter for beam	35 mm
Magnetic field in center	~0.0065 T
Working current	~22.5 A
Power consumption under CW	~120.0 W
Power consumption under pulse	~2.0 W
Electron beam energy	5.0 MeV
Beam bending angle	7.500°
Spin rotating angle	7.594°
Inductance	400 μH
Resistance	0.5 Ω
Material of coil holders	Alumide ®
Rise & fall times	1.0 ms
Hold times	10.0 ms
Repetition time	1.0 s

Table 1: Operational conditions and design parameters of the Q-kicker.

3. Magnetic Field Measurements

For the measurement of the magnetic fields inside the kicker gap, a three-axis matrix Hall probe was used [4]. The matrix consists of 16x16 modules, each comprising three sensors for 3D field measurements. All 16x16 sensors are spaced at 2.5 mm pitch steps. Movement in the Z-direction was 20 mm, with no steps in the X-direction and steps in the Y-direction of 2.5 mm. Four different field settings are possible, each with its own calibration file. With the 100 mT calibration, the total field error per sensor is around 40 µT.

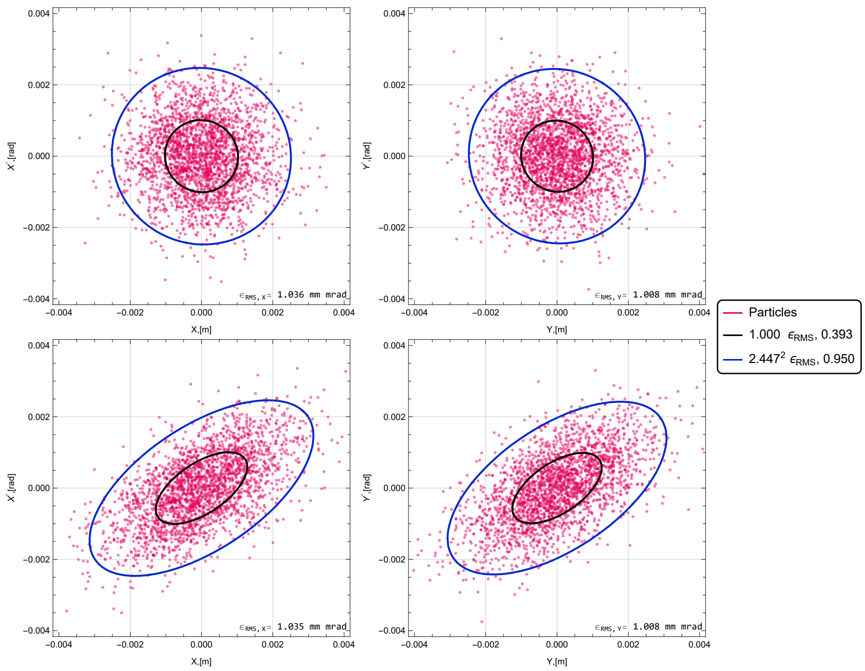

Figure 2: View of beam properties upstream and downstream of the Q-kicker. Top left and right: Beam entering the kicker. Bottom left and right: Beam downstream from the kicker. The modeled beam deflection at a distance of 0.4 m from the center of the kicker, simulated with 2500 electrons. Red points present positions and angle of electrons. Black ellipses overlap 39.3% of the electrons and blue ellipses overlap 95.0% of the electrons.

4. Beam Modeling and Simulations

Beam propagation simulations were performed using Wolfram Mathematica [5] to assess the impact of the Q-kicker on the electron beam. A virtual source with a Gaussian distribution in both vertical and horizontal postitions and angle was placed upstream at a distance of 400 mm from the center of the kicker. The observation point was chosen 400 mm downstream from the center of the kicker. The simulations tracked the trajectory of 2500 electrons with an energy of 5.0 MeV through the kicker, including the effects of the magnetic field on beam emittance and spin orientation. The results demonstrated that the Q-kicker introduces negligible emittance growth (see Fig. 2), with no observable increase in beam emittance in both the horizontal and vertical planes. Taking under consideration the four-dimensional covariance matrix, based on X, X', Y, Y' values, the lower left and upper right two-dimensional submatrices indicate only weak correlation between the vertical and horizontal planes. Additionally, the spin direction of the electrons was expected to rotate by 7.594° for a beam bending angle of 7.500°.

5. Discussion and Outlook

The Q-kicker is one of the major parts of the polarimeter chain at MESA. Its air-coil design, combined with the cosine-theta configuration, ensures minimal hysteresis, rapid switching, and excellent beam stability. The results of magnetic field measurements and beam simulations confirm that the Q-kicker achieves the required field homogeneity of ±1 %, introduces negligible emittance growth (below 0.5 %) and changes the spin orientation of all beam electrons uniformly. These features make the Q-kicker an ideal solution for quasi-online polarization monitoring, particularly for experiments like P2 that require precise control of beam parameters.

Looking ahead, future work will focus on optimizing the repetition- and hold times of the beam extraction. The successful implementation of the Q-kicker is expected to significantly enhance the capabilities of the MESA facility.

In summary, the Q-kicker provides fast, reproducible, and low-impact beam extraction which fulfills the requirements for a 5.0 MeV Mott Polarimeter, a critical component in the polarimeter chain of the MESA accelerator.

Acknowledgments

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