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Partial return yoke for MICE – Engineering design

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DISCLAIMER

PARTIAL RETURN YOKE FOR MICE – ENGINEERING DESIGN*

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Abstract

MICE, which is an acronym for Muon Ionization Cooling Experiment, is a technology demonstration which is presently assembled at the Rutherford Appleton Laboratory in Didcot, UK. MICE aims to demonstrate ionization cooling experimentally, which is an essential technology for potential future accelerators such as a muon collider.

The MICE channel consists of up to 18 large bore superconducting solenoids, which produce a substantial stray field. This stray field can jeopardize the operation of electrical and electronic equipment in the MICE hall.

The concept of a partial flux return yoke has been developed, which reduces the stray field in the MICE hall to a safe level. This paper discusses the engineering design of the partial return yoke.

INTRODUCTION

MICE will be assembled in several steps [1]. At the time of writing it is aimed to finish construction of Step IV by summer/autumn 2014. MICE Step IV consists of 12 large bore superconducting solenoids (18 for Step VI). The MICE solenoids produce a substantial amount of stray field, which is a concern as some of the technical equipment in the MICE hall may not work.

This paper discusses the engineering aspects of a partial return yoke (PRY) for the MICE solenoids for Step IV; the partial enclosure is sufficient to reduce the stray fields to an acceptable level.

Details on the general design approach, the coil configuration of Step IV, expected shielding performance and effect on the performance of MICE are given in [3].

ENGINEERING CONCEPT

The evolution of the PRY geometries is shown in Fig. 1. It is important to note that in general all shown geometries have a similar shielding performance. The vertical extensions (middle plot) have been found to further reduce the stray field behind the PRY by preventing flux leakage from the unshielded part. The final geometry, shown on the right, was chosen because of engineering considerations.

The MICE PRY will consist of in total eight shielding plates, each of which is about 4 m long and 1.5 m wide. The thickness of each shielding plate is 10 cm or 12 cm depending on the desired shielding performance. The weight of a 10 cm thick shielding plate is about 4.8 tons, which is less than the limit of the lifting crane in the MICE hall.

To avoid field leakage (see section 'Vertical Gaps') two backing plates are installed on the inside and outside of the PRY covering the vertical joint. The thickness of each backing plate is half that of the PRY.

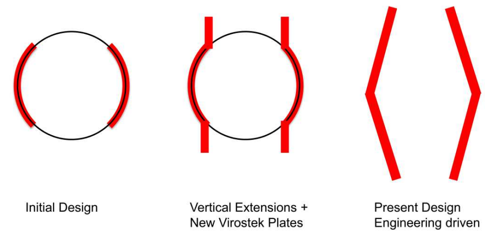

Figure 1: Evolution of the PRY geometry.

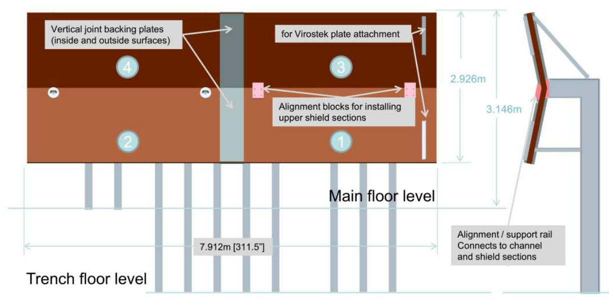

Figure 2: MICE Partial Return Yoke.

SUPPORT STRUCTURE

The support structure has been designed to cope with the dead weight of the PRY as well as magnetic forces. The magnetic forces on the structure were evaluated using the Maxwell stress tensor. The forces were evaluated for each of the shielding plates separately. The main force component is in horizontal direction, directed such that the shielding plates want to move towards the MICE experiment. The maximum force is equivalent to 34 tons for half of the PRY (four shielding plates) and occurs for the 240 MeV flip mode. There is no net longitudinal or vertical magnetic force on the PRY due to symmetry reasons.

The support structure, as shown in Fig. 2, consists of several S-beams which are anchored in the floor of the MICE hall. An ANSYS study was carried out to evaluate peak stresses and deflections. While the stresses are not a concern (123 MPa) a maximum deflection of 5 mm was ob-

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served at the top corner of the PRY. To avoid this eight horizontal support straps will be installed to transfer forces between the two PRY halfs. This reduces the deflection to 0.28 mm.

PENETRATIONS

Vertical Gaps

Vertical gaps in the PRY occur between two adjacent shielding panels. Initial investigations showed that vertical gaps in the PRY are detrimental for the shielding performance. Fig. 3 shows the position of a vertical gap in the PRY near the tracker region. The simulation result of the stray magnetic flux behind the PRY at a radius of 1.5 m and beam height is shown in Fig. 4. The figure shows that depending on the width of the gap the stray field behind the PRY increases substantially.

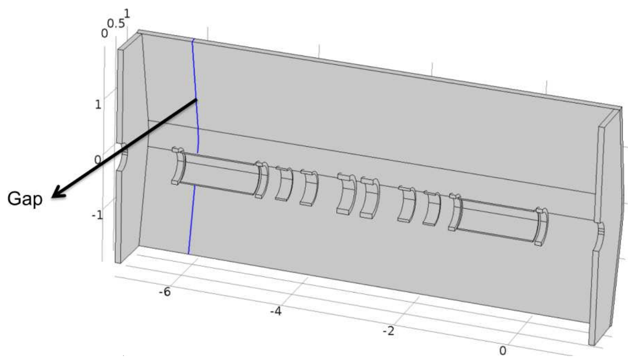

Figure 3: Geometry: Vertical gap in shield.

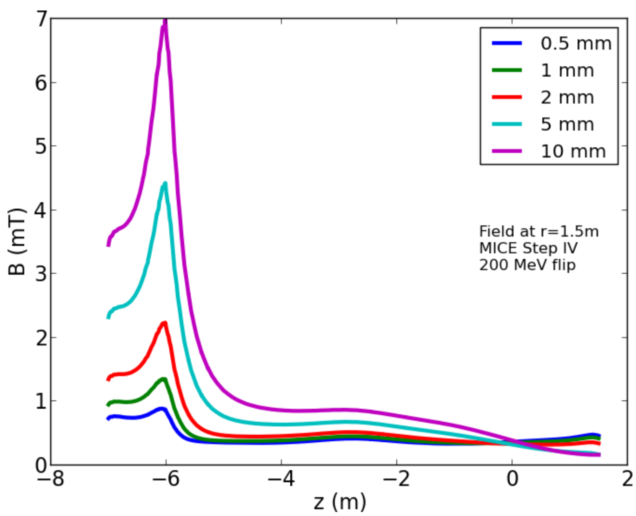

Figure 4: Modulus of the magnetic flux density at a radius of 1.5 m for 200 MeV flip mode assuming a vertical gap at $z = -6$ m.

To avoid performance impacts several potential solutions were studied. An adequate and easy to implement strategy is to double-up the PRY at the position of a vertical gap; Fig. 5 illustrates the concept. Each of the two backing plates is required to be half the thickness of the shield. The width of each backing plate is 0.4 m. The backing plates work by forming a low magnetic reluctance joint between neighbouring PRY sections; at the joint the magnetic flux is redirected into the backing plates, thus avoiding the vertical gap.

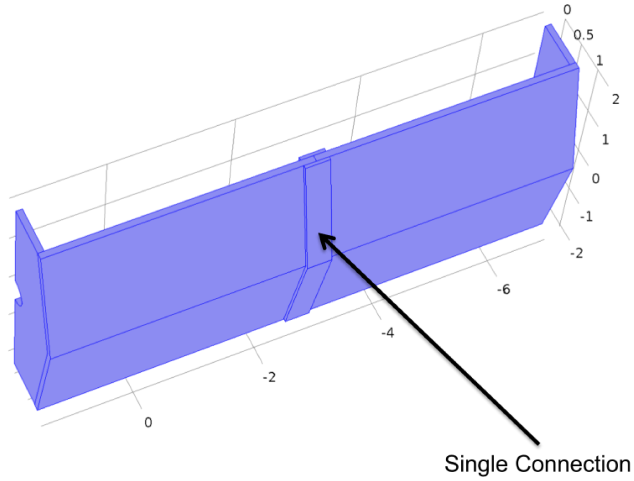

Figure 5: Concept of doubling up a vertical gap.

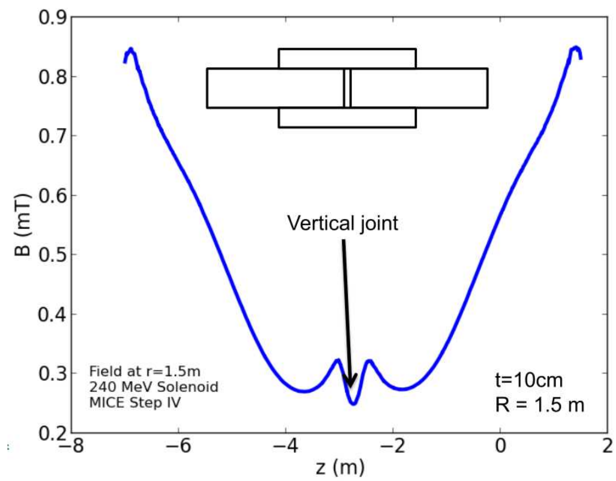

Figure 6: Modulus of the residual stray field at a radius of 1.5 m (beam height) for 200 MeV flip mode. The vertical gap is doubled up using to backing plates, each 40 cm long.

Horizontal Gaps

Horizontal gaps in the PRY were studied as well. Fig. 7 shows simulation results for the 200 MeV flip mode. The figure shows that the stray field behind the PRY by comparison is far less sensitive to horizontal gaps. Even gaps of 20 cm width produce only an increase in stray field of about 1 mT.

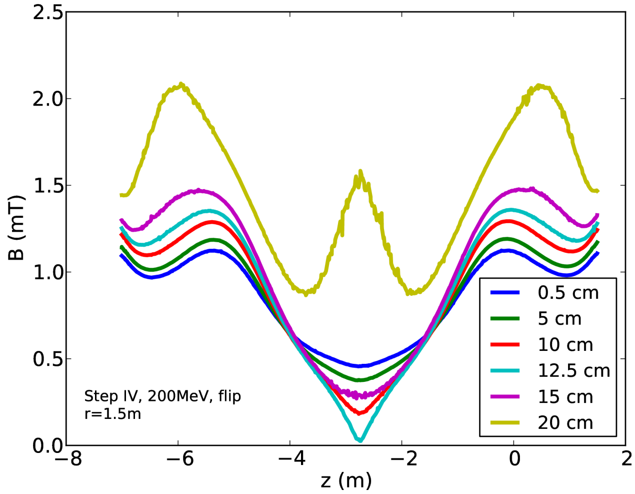

Figure 7: Modulus of the residual magnetic field at a radius of 1.5 m. The simulation assumes a horizontal gap in the PRY at beam height.

MATERIAL CONSIDERATIONS

The PRY is planned to be made out of AISI 1010 steel, which is a cost efficient material for magnetic shielding. One of the disadvantages of AISI 1010 steel is the variation of the magnetic properties depending on the exact composition. In general the higher the iron content the better the magnetic properties. In order to estimate the shielding performance we use measured magnetization curves of 1010 steels which have been used in various HEP experiments [2]. For comparison three magnetization curves are chosen: one representing very good magnetic properties (labeled 'ARMCO Atlas'), one with intermediate magnetic properties (labeled 'St1010 Germany') and one with poorer magnetic performance (labelled 'St1010 ATLAS').

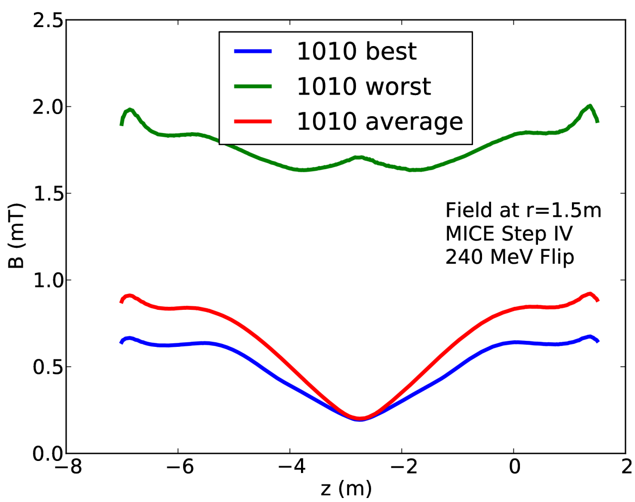

Figure 8: Stray magnetic field for different 1010 steels at a radius of 1.5 m (PRY finishes at a radius of about 1.35 m) and vertically at beam height.

The expected shielding performance can be seen in Fig. 8, which shows the residual stray magnetic field at a radius of 1.5 m or about 10 cm behind the PRY at beam height. The figure shows that the stray magnetic field (for 240 MeV flip configuration) varies between 0.6 and 2 mT. For average properties of 1010 steel a residual magnetic field of about 1 mT can be expected.

To limit the variability of the magnetic properties a better quality steel, for axample AISI 1008 or AISI 1006 can be chosen. In addition the PRY thickness can be increased which improves the shielding performance and hence the safety margin.

SCHEDULE

The PRY material procurement and fabrication is presently estimated to be completed in August 2014.

SUMMARY

This paper summarizes the engineering design of a partial return yoke for the Muon Ionization Cooling Experiment. A support structure was described which is capable of supporting the dead weight and magnetic forces on the PRY during operation. Both stresses and deflection are acceptable.

Penetrations of the PRY were studied and it was found that vertical gaps have a detrimental effect on the shielding performance. To avoid flux leakage vertical joints in the PRY are doubled up with two backing plates. Horizontal gaps are less critical and can be tolerated up to a width of several cm.

The designated material for the PRY is AISI 1010 steel. The magnetic properties of 1010 steel can vary significantly depending on the exact composition. Magnetization curves from literature of HEP physics experiments have been used to estimate the effect. It was found that the shielding performance for a 10 cm PRY varies from 0.6 mT up to 2 mT. To mitigate this a steel with a higher guaranteed Fe content can be chosen (for example AISI 1008 or 1006) and the PRY thickness can be increased to 12 cm.

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