ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-MOPOTK060

AN INDUCTION-TYPE SEPTUM MAGNET FOR THE EIC COMPLEX*

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Abstract

The electron Ion Collider (EIC) project has been approved by the Department of Energy to be built at the site of Brookhaven National Laboratory (BNL). Part of the EIC accelerator complex and more specifically the Rapid Cycling Synchrotron (RCS) which accelerates the electron beam up to 18 GeV and the electron Storage Ring (ESR) which stores the electron beam bunces for collisions with the hadrons, will be built inside the same tunnel of the Relativistic Heavy Ion Collider (RHIC). This technical note provides information on the electromagnetic design of the induction-type septa magnets which will be employed to extract the beam from the RCS and inject into the ESR synchrotrons.

INTRODUCTION

The EIC accelerator complex [1] will collide various ions species at energies up to 270 GeV/amu with electrons at energies 5, 10, and 18 GeV. A schematic diagram of the EIC complex is shown in Fig. 1. The ions will be injected and accelerated to the final energy in the hadron acceleration complex with the final acceleration stage, the Hadron Storage Ring (HSR) [2], and the electrons will be accelerated in the electron acceleration complex which consists of a 400 MeV LINAC, the RCS ring which will accelerate the electrons up to 18 GeV and the ESR storage ring which will store the electron bunches for collisions with the hadrons. This paper discusses the electromagnetic design of the septa magnets for the RCS extraction and the ESR injection systems. A mechanical description of an induction type of magnet is given in [3]. The electromagnetic study was performed with the AC-module of the electromagnetic code OPERA [4]. Two AC-frequencies were used, 625 Hz and 835 Hz, to excite the magnet and compare some of the results in this paper.

THE SEPTA MAGNETS

Two similar induction septa magnets will be used in the electron accelerators of the EIC; one septum magnet in the beam extraction system of the RCS and the other in the beam injection system of the ESR [5]. The septum thickness will be 3 to 4 mm to minimize the strength of the kicker magnets. A detailed description of the extraction and injection systems is given in [5]. Fig. 2 shows the location of the RCS extraction septum in reference to the hadron beam lines which are located below the RCS ring.

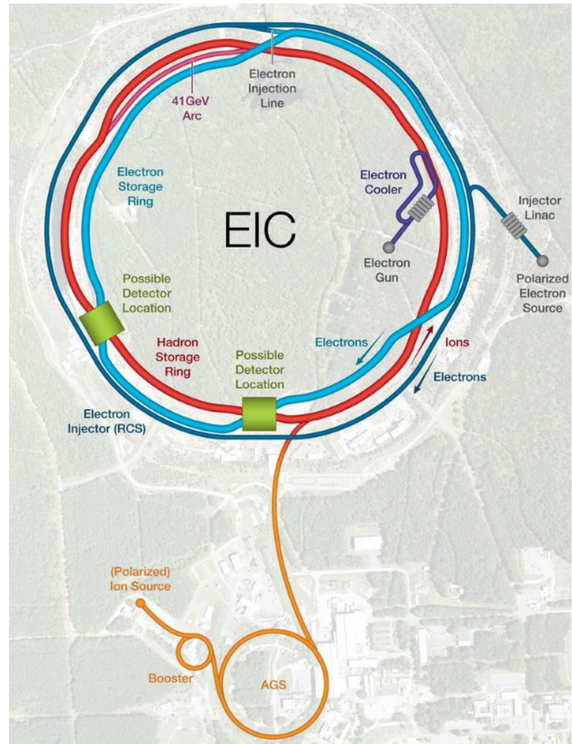

Figure 1: Schematic diagram of the EIC complex.

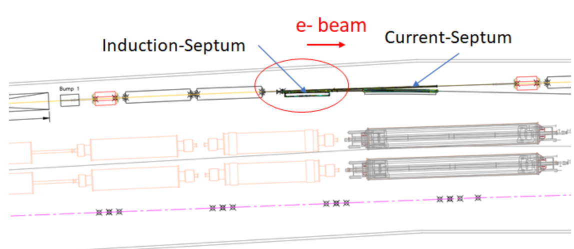

Figure 2: The location of the RCS Induction Septum.

MECHANICAL DESIGN OF THE MAGNET

Fig. 3 shows some views of the induction septum magnet. The coil of the magnet is wound around the back leg of the magnets, The magnetic iron core is made of laminations 0.35 mm thick to minimize the eddy currents. The septum plate shown in Fig. 3 is fused with the vacuum pipe of the circulating beam. The eddy currents generated in the plate and in the pipe create a uniform field in the injected beam region and also minimize the stray field in the circulating beam region.

* Work supported by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the US Department of Energy.
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ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-MOPOTK060

EM DESIGN OF SEPTUM MAGNET

The principle of operation of the induction septum is based on the eddy currents generated on the copper plate and circulating beam pipe, when the coil which is wound in the return yoke of the septum is excited with reasonably high frequency. The effect of the eddy-currents is twofold, first to minimize any B-field in the circulating beam region, and second to generate a uniform field in the injection beam region. In this design two excitation frequencies were used, 625 Hz and 835 Hz. Results from the electromagnetic study at f=625 Hz are shown in this paper and the eddy current losses in the various conductive parts of the magnet are presented for both frequencies. Fig. 4 shows the voltage and current vs. time of two consecutive pulses to excite the magnet for the injection of the two bunches every second. The rise time of the pulses in Fig. 4 is 0.4 msec. Although the electromagnetic calculations were done using the AC-module of the OPERA code for the two frequencies 625 Hz and 835 Hz at steady state, the actual operation of the magnet is shown in Fig. 4. Such transient study as shown in Fig. 4 is time consuming but it will be done soon.

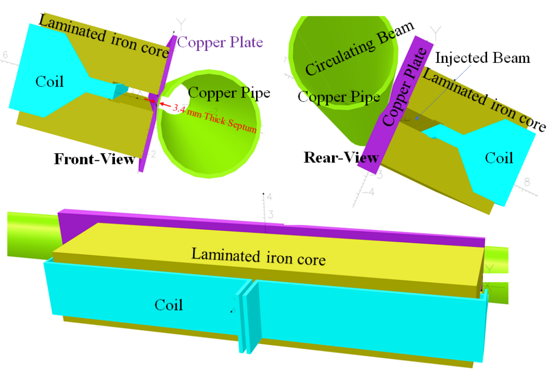

Figure 3: Three views of induction septum.

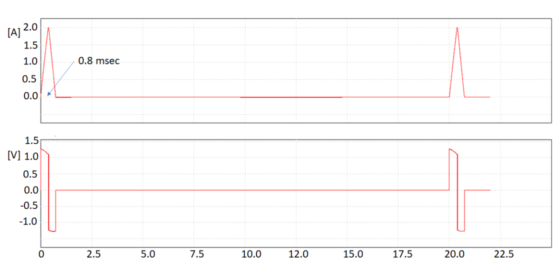

Figure 4: Consecutive pulses to excite the magnet at 1 Hz.

RESULTS FROM THE EM STUDY

The electromagnetic calculations were performed using the AC-module of the OPERA code. For comparison of the results two frequencies were used in the calculations; namely 625 Hz, and 825 Hz. These type of the AC calculations are rather conservative given that the magnet is excited with two pulses, each of 0.8 msec duration, every second as shown in Fig. 4. The magnetic field in the injection field region as a function of time for the frequency of 625 Hz is plotted in Fig. 5. The maximum field occurs at 0.75 msec with integrated field value of 0.572 [Tm] for a magnet 0.635 m long. The field uniformity in the region of the injected beam is very good. The field in the circulating field region close to the wall of the circulating beam pipe is plotted in Fig. 6 as a function of distance along the beam direction, and the maximum integrated field is 6.8x10^{-3} [Tm]. The circulating beam will experience a lesser field because it is farther away from the wall of the pipe. The peak value of the B-field plotted in Fig. 6 occurs at the entrance of the extraction septum and at the exit of the injection septum. A very important part of the calculations is to obtain good values on the power dissipation due to the eddy currents in the various conductive parts of the magnet, like the iron laminations, the coil conductors, and the vacuum pipes. Although the induction septum magnet is based on the use of the eddy currents, the drawback of the eddy currents is the Ohmic losses in the various conductive parts of the magnet. The section below discusses the ohmic losses.

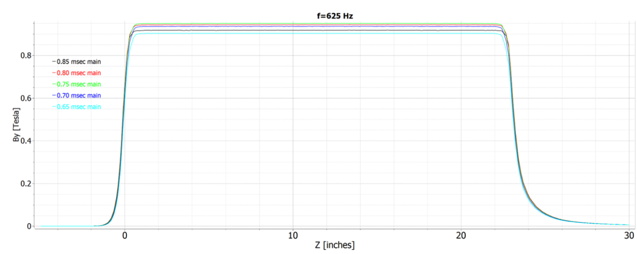

Figure 5: The B-field in the injected beam region.

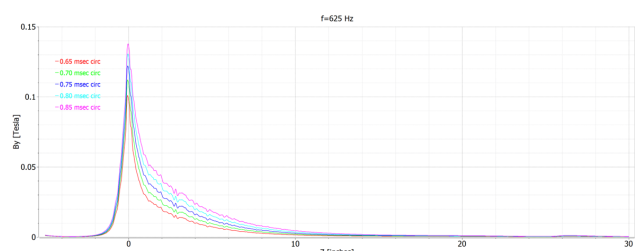

Figure 6: The B-field in the circulating beam region.

OHMIC LOSSES IN THE MAGNET

In the AC-OPERA calculations only 60 laminations were used in the core of the magnet, by placing 30 laminations at the entrance and 30 laminations at the exit of the magnet to reduce the calculation time to a couple of days. Fig. 7 show the 30 laminations placed at one end of the magnet. To increase the accuracy of the calculations of the eddy currents, each lamination in the OPERA model was split in two sections but both sections were electrically connected. This split is shown in the right figure of Fig. 8.

Fig. 9 shows the power dissipation in each of the 30 laminations when the magnet operates at 625 Hz steady state. The increase in the power dissipation of the lamination at

13th Int. Particle Acc. Conf. IPAC2022, Bangkok, Thailand JACoW Publishing
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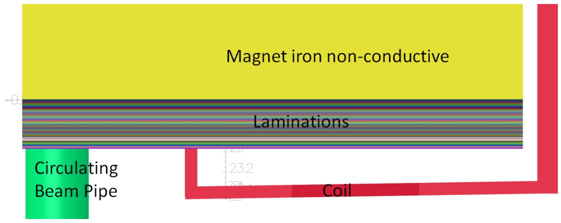

Figure 7: View of the 30 laminations, of 0.35 mm thick each.

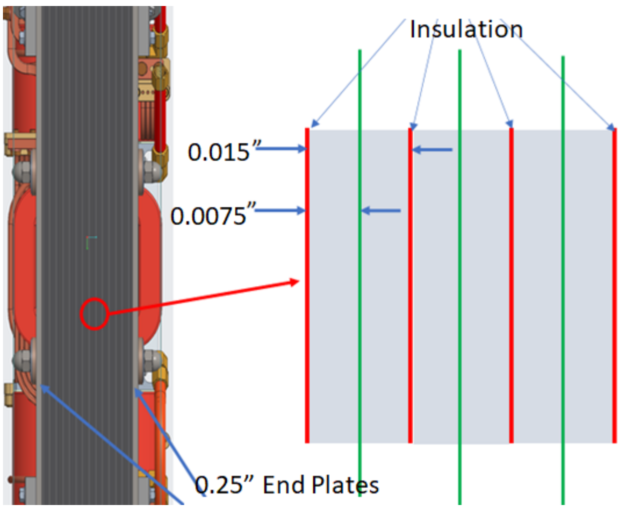

Figure 8: Zoom view of the Laminations on the right.

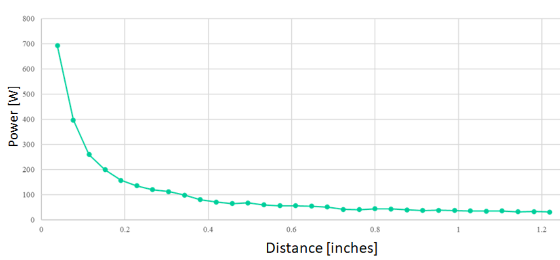

Figure 9: The power dissipation in each lamination.

the ends of the magnet shown in Fig. 9 is due to the normal component of the field on the lamination surface. This component generates eddy currents which circulate inside the laminations. Well inside the magnet this normal field component of the field is going to zero and the eddy currents tend to partially cancel each other.
Table 1 summarizes the Ohmic losses in the various conductive parts of the induction septum magnet for the two frquencies 625 Hz and 835 Hz. The Power is in kW. The power dissipation in the coil includes the power dissipated by the excitation current. The actual excitation of the magnet as a function of time is shown in Fig. 4 of two current pulses per second.

FIELD IN THE INJECTED BEAM PIPE

The field penetration in the injected beam pipe depends on the frequency of operation of the magnet the thickness and material of the vacuum pipe. The wall thickness of the vacuum pipe was chosen 0.35 mm. The eddy current density calculated on the pipe's wall is shown on Fig. 10.
Fig. 11 plots the B-field in the injected-field region for two type of pipe-material Inconel and stainless steel. Clearly this figure shows that Inconel is the best material to be used.

Table 1: Power Dissipation in the Conductive Parts of the Magnet. The units of the Power dissipation is in kW.

f [Hz]	Sep+Pipe	Coil	Injection Pipe	0.35 mm Iron Lamin.
625	18.9	59.0	0.25	1.3
835	21.1	56.6	0.18	2.6

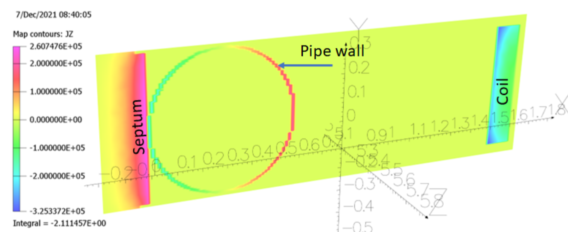

Figure 10: Eddy currents on the injection-beam-pipe.

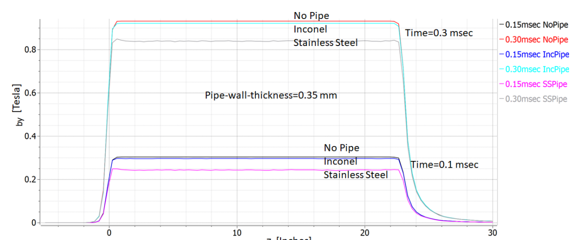

Figure 11: B-field of various material of the pipe at 625 Hz.

CONCLUSION

Electromagnetic calculations show that there is a good magnetic field uniformity in the beam injection region and a low fringe field in the circulating field region during the beam injection/extraction. The calculated power dissipation in the 0.35 mm thick laminations and other conductive parts of the magnet which is shown in Table 1 is rather low considering the small duration of 0.4 msec of the excitation of the magnet as shown in Fig. 4.

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