DESIGNING A BEAM TRANSPORT SYSTEM FOR RHIC'S ELECTRON LENS*

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Abstract

We designed two electron lenses to apply head-on beam-beam compensation for RHIC [1]; they will be installed near IP10. The electron-beam transport system is an important subsystem of the entire electron-lens system. Electrons are transported from the electron gun to the main solenoid and further to the collector. The system must allow for changes of the electron beam size inside the superconducting magnet, and for changes of the electron position by 5 mm in the horizontal- and vertical-planes.

DESIGN OF THE TRANSPORT SYSTEM

The most important issues in designing an electron lens beam-transport system [2] is to convey the electron beam from the gun's side to collector's side while controlling the electron beam's trajectory so that it follows the central line of the superconducting main magnet (SM).

Fig. 1 illustrates the layout of one electron lens, which has a gun side, an SM, and a collector side. Both sides have an almost identical solenoid design. Each side of one electron lens has three magnets; viz., GS1, GS2, and GSB on the left side, and CS1, CS2, and CSB on the right side.

GS1 is creates the electron gun field, GS2 is used for guiding electron beam, and GSB bends the electron beam towards SM.

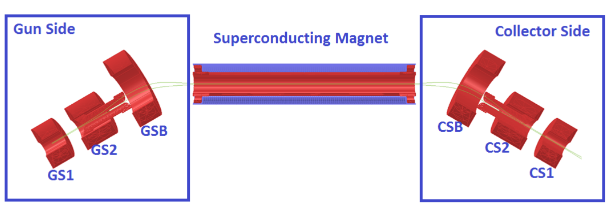

Figure 1: Layout of the electron lens.

With the electron lens operating in the default configuration, electron beam first emerges from the electron gun, and then travels through GS1, GS2, and GSB. Thereafter, it enters the SM solenoid, passing the SM along its central line. Then, it is transported via CSB, CS2, and CS1, and finally, dumped into a collector.

MAGNETIC FIELD AND SIZE OF ELECTRON BEAM

According to our design considerations, the size of the electron beam should match that of the proton beam inside the SM. Accordingly, this beam transport system also should be able to change the ratio of the magnetic field between the SM and GS1. The field of the GS1 can be changed from 0.2 to 0.8 T and the magnetic field of SM can be changed from 1 to 6 T (Fig. 2) this alteration will increase the beam's size by about 5 times from its minimum value $\sigma_{gun}\cdot\sqrt{\frac{1}{30}}$ to its maximum value $\sigma_{gun}\cdot\sqrt{\frac{4}{5}}$. However, because there are three magnets on each side, changing the electron beam size by modifying the GS1 field will not affect its trajectories.

This electron-transport system also should have magnetic fields that can suppress unwanted space charge effects, and the electron beam should be rigid enough so that is it not disturbed by other electromagnetic fields. Figure 3 plots the magnetic fields along the central line of GS1, GS2, and GSB The magnetic field along beam's trajectories is greater than 0.3 T.

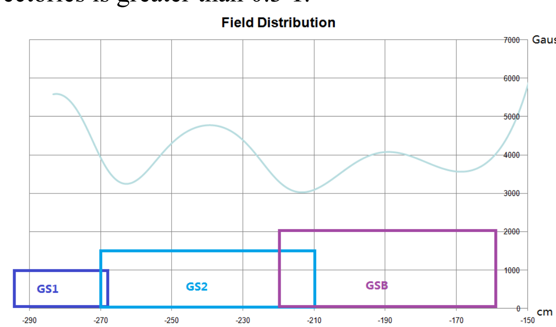

Figure 2: Magnetic-field distribution along the central trajectory line.

DESIGN OF THE STEERING DIPOLE MAGNETS

For head-on beam-beam compensation in an electron lens, it is very important to align the electron beam with the proton beam. To do so, it is easier and safer to control the electron beam rather than the proton beam. Because the two proton beams, separated by 10mm, share one beam pipe at IP 10, the electron beam should have the capability to shift 5 mm around the central line in the horizontal- and vertical- planes. To meet this requirement, we designed two dipole magnets (GSX and GSY) for each side of the two lenses, and placed them inside GS2 and CS2.

Fig. 2 displays the envelope of the beam trajectories after using the dipole magnet with the central beam's trajectory shifted up and down by 5mm. From the plot of the upper line of the electron beam's trajectories, we note that it emerges from upper side of cathode; the beam was shifted up by 5mm. The lower line represents the electron beam emerging from the lower side of cathode after a 5 mm downward shift.

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Table 1: Specifications of the Magnet Design

		GS1	GS2	GSB	GSX	GSY
Position and Angle						
Global Position	L_*_GCS (mm)	-1690	-1690	-1850	-1690	-1690
Local Position	L_*_LCS (mm)	1320	820	100	660	660
Angle	Theta (degree)	30	30	30	30	30
Parameters						
Conductor	h_cond (mm)	14	14	14	6.35	6.35
	ID_water(mm)	9	9	9	4.75	4.75
	b_insul (mm)	0.3	0.3	0.3	0.65	0.65
Solenoid Size	ID (mm)	173.5	234	480	194	210
	OD (mm)	553.1	526	859.6	208	224
	Length (mm)	262.8	379.6	262.8	500	500
	N_Layer	13	10	13	12	12
	N_pan	9	13	9		
	Resistance (ohm)	0.04	0.05	0.08	0.02	0.02
Optimization						
Power	Power (kW)	58.3	25.6	45	1.4	1.7
	Current (A)	1188	731	769	258	271
	Temp_Delta (K)	13.4	3.6	14.2	5.9	6.9
Water	Pressure_Drop (bar)	1.5	1.5	1.5	1.5	1.5
Field	(Gauss)	8000	4468	3202	190*	190*
Plus 40% Current						
Power	Power (kW)	114	50	88	2.9	3.4
	Current (A)	1663	1023	1077	361	383
	Temp_Delta (K)	26	7	8	12	14
Water	Pressure_Drop (bar)	1.5	1.5	1.5	1.5	1.5
Field	(Gauss)	11200	6256	4482	270 ^	270^

- * is the dipole magnetic field for 5 mm beam shift.
- ^ is the dipole magnetic field for 7 mm beam shift.

According to Fig. 2, we can optimize the drift tube's inner diameter so that the electron beam will not touch its inner side, following careful specifications.

Fig. 3 illustrates the geometry of one dipole X, and its maximum magnetic-field can be found in Table 1; both are the same for dipole Y.

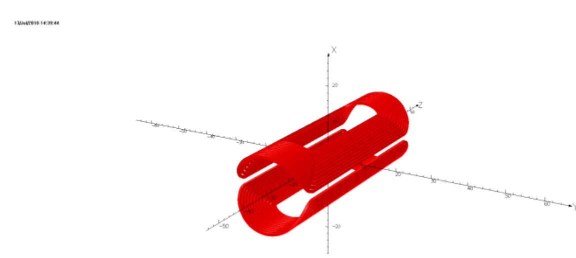

Figure 4: Dipole X magnet geometry

OPTIMIZING POWER CONSUMPTION

During the design of the electron lens, its running costs should be taken into consideration. Reducing power consumption in a transport system is an important issue. The power consumption for both electron lenses should be limited to 500 kW to avoid the need for upgrades of the electrical- and water cooling- systems in IR10.

We tried several approaches for optimizing power consumption. First, we can optimize the size of the conductor.

Table 2 lists some conductors, their power consumptions, currents, and space factors. The space factor is equal to the conductor's intersection area divided by the total intersection area [3]. All these conductors in the table are square outside with a round hole inside. H_Cond is the outer dimension and D_water is the inner diameter of the water cooling hole.

The second way to reduce the cost of power is to use a different operational configuration. For our default operating model, we tune the current of the GSB to control the beam trajectories. At that moment, the dipole magnets are turned off, After completing commissioning of the electron lens, if it is feasible to decrease the minimum magnetic field from 0.3 T to 0.15 T, for example, we can reduce the GSB's current while increasing the dipole magnet X's current that controls the beam's position.

Table 2: Conductor Parameters and Power Consumption Optimization

H_Cond	D_Water	P (kW)	Current (A)	Space Factor λ
9.7	7.9	77.88	418	0.43
11	8.8	77.58	557	0.45
6	4.5	72.94	175	0.46
6.35	4.75	73.6	198	0.47
10	7.5	71.58	480	0.50
7	5	68.27	240	0.51
8	5.5	64.35	311	0.54
13	9	65.78	837	0.57
9.52	6.35	59.26	418	0.58
14	9	54.5	846	0.62

Thirdly, we optimized some aspects of power consumption (layer and pancake number) for all three kinds of solenoids.

Finally, with 0.8 T in GS1, and 0.4 T in CS1, the total power consumption is about 430 kW for two electron lenses.

SPECIFICATIONS OF MAGNETS DESIGN

Table 1 gives the design specifications for our electron-lens beam-transport system, including the power-consumption calculations. The first part in this table includes the position and angle of GS1, GS2, and GSB. The second part of this table lists the conductor's parameters and the geometry of these magnets. The third part details power consumption of these solenoids, and the temperature increase and magnetic field that they cause in two different cases, viz., the nominal optimization case, and the nominal plus 40% current case. The origin of the coordinate system is the superconducting magnet centre, and the angle is defined as the angle between the GSB axis and superconducting magnet axis.

DISCUSSION

In designing an electron- beam transport system, we considered beam-position control, beam-size control, power consumption, cost, and ease of manufacturing.

With the help of GSB, GSX and GSY, we can control the position of the electron beam by 5 mm in the horizontal- and vertical-planes, which will allow to conveniently to align the proton and electron beams for head-on beam compensation.

The electron beam size also can be changed about a factor of 5 by changing the field ratio between electron gun and main superconducting magnet, which means this E-lens system can have the capability to be used for RHIC protons at lower energy and for gold. Power consumption is optimized by several methods and the nominal total power consumption is less than 500kW. This avoids upgrades the power and water cooling systems in IR10.

Beside these, there are some other factors that should be included for the entire electron system, such as a realistic solenoid, which could shift electron beam from the centre compared with the idealistic solenoid [4]; and the thickness of iron which surrounds the superconducting magnet, which should be compromised between the price of superconducting magnet and the effect of magnetic field shield. At last, to determine the distance between two electron lenses, the magnetic field interaction between them should be also taken in consideration.

REFERENCES

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