CORRECTION COIL SYSTEM FOR COMPACT HIGH INTENSITY CYCLOTRON *

Tianjue Zhang[1, †], Sumin Wei[1], Guofang Song[1], Jianjun Yang[1,2], Junqing Zhong[1], Chengjie Chu[1]
[1]China Institute of Atomic Energy, Beijing, 102413, P.R. China
[2]Tsinghua University, Beijing, 100084, P.R. China

Abstract

To limit the cost for the main magnet of a compact cyclotron CYCIAE-100, the cast steel is used for the top/bottom yoke and return yoke. The imperfection may not be ignored and the harmonic coils on the return yokes will make the fields reaching the requirements easier during the shimming. The centering coils will not only compensate the 1st harmonic fields at the center region, which is usually remain big, but also correct the off-center injection of the beam. The thermal deformation and the vacuum pressure may change the fields distribution during the machine operation and therefore It is necessary to use trim coils to adjust the fields. We arrange the trim coils inside the two opposite valleys of the main magnet. The second harmonics from the trim coils are not big eough to affect the beam dynamics significantly from the beam dynamics study. In this paper, the effects of correction coils of three types are presented. The detail configuration of the correction coils is introduced in the paper as well. One concern is the potential interference of some water cooled coils could have with vacuum. Some experience for the coils inside the high vacuum tank is tested and the results are given.

INTRODUCTION

Beijing Radioactive Ion-beam Facility (BRIF) is one of the most important projects in China Institute of Atomic Energy (CIAE) [1,2]. To be the driving accelerator, the compact high intensity cyclotron CYCIAE-100 is designed to provide 70MeV~100MeV, 200 μA proton beams, the H- beams are injected axially by two injection lines. It has 4 straight sectors and the small gap (6cm in the central region and 4.8cm in the extraction region).

After mapping and shimming, the isochronous fields and harmonic fields are expected to be much better than those in the separated sector cyclotron. And hopefully only few correction coils are needed for this compact machine. However, the top/bottom yoke and the return yoke of this machine are cast steel to limit the cost, the imperfection may not be ignored. The harmonic coils on the return yokes are used to make the fields reaching the requirements easier during the shimming (e.g. the 1st harmonic fields).

To compensate the 1st harmonic fields at the center region as well as correct the off-center injection of the beam, at least 2 sets of the centering coils are put on the pole face.

Normally, after the mapping and shimming the fields should be good enough for isochronism. But the thermal deformation and the vacuum pressure may change the field distribution. It is hard to organize the coils in the gap of the magnet, but we notice that the correction of the average field should not be too big, say less than 25Gauss. So 8 sets of trim coils are put into two opposite valleys (the RF cavity are put into the rest two valleys) to adjust the isochronous fields during the cyclotron operation.

The design of the centering coils on the pole face in the central region, the harmonic coils on the return yoke and the trim coils in the valleys are introduced in the following sectors in detail, including the configuration of the coils, the fields effect and the correlative design such as the mechanical design, the vacuum and so on.

CORRECTION COILS FOR HARMONIC FIELD

As introduced above, the cast steel is used for the top/bottom yoke and the return yoke of CYCIAE-100, the imperfection may not be ignored. And as we know, at the central region, the 1st harmonic field is big so need to be compensated. The H^- beam injected into the cyclotron axially, the off-center injection also need to be corrected. The centering coils on the pole face and the harmonic coils on the return yoke are designed to correct these harmonic fields.

Centering Coil

From the result of beam dynamics simulation, to correct 5mm off-center beam, 15Gauss 1st harmonic fields is needed in the central region and two sets of the centering coils are put on the pole face to produce it. First one is from 140mm to 300 mm in radial direction and the second is from 300mm to 500mm. The 1st harmonic fields motivated by centering coils are calculated numerically by building a 3D model in a FEM code.

Two different configurations of the coils were under consideration, as shown in Figure 1. There are two centering coils on each pole and also a pole trim coil for the isochronous fields at the radius 500mm to 720 mm. The right one in Figure 1 is selected in the final design to avoid the odd fields caused by the width of the conductor.

*support partly by NSFC(10125518, 10775185)
†tjzhang@ciae.ac.cn

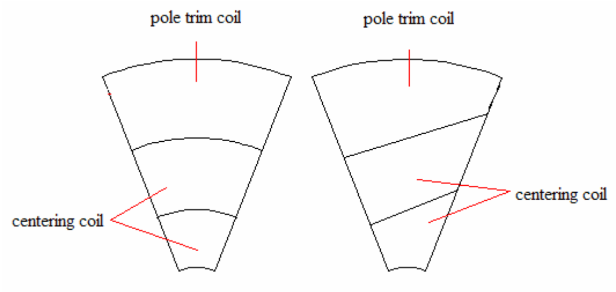

Figure 1: The configuration of the coils on the pole face.

After detailed calculation, it is verified the centering coils have the ability to produce the 1st harmonic fields for 0~15Gauss at any phase. Figure 2 shows the 1st harmonic fields produced by each set of the centering coil, the solid line is the first set and the broken line is the second set, in this case, the currents of two pairs of opposite coils is ±100A and the others is 0A. The 1st harmonic fields are about 17Gauss and 19Gauss.

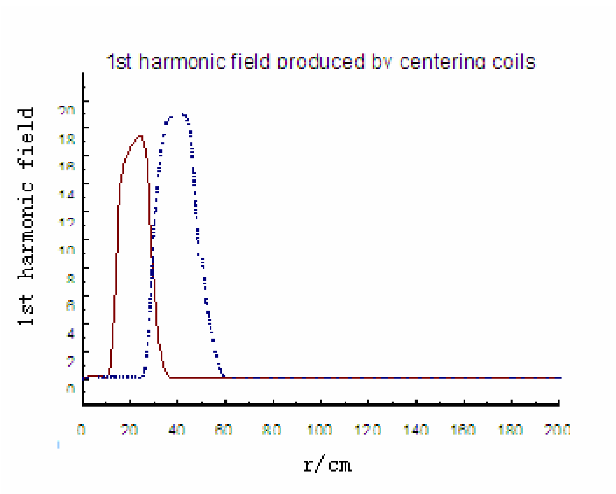

Figure 2: The 1st harmonic fields produced by each set of centering coil (±100A of opposite coil, rest are 0A)

Harmonic Coil

One set of harmonic coils on the return yokes are designed to correct the imperfect fields caused by the cast steel yoke, the artifactitious error et al. So the fields can reach the requirements easier during the shimming. The harmonic coils are designed to produce the 1st harmonic fields up to 50Gauss.

Figure 3 shows the configuration of the harmonic coils with the 360° model of the main magnet. they can produce the 1st harmonic fields on a large radius range. Table 1 shows the phase and amplitude of the 1st harmonic fields produced by these harmonic coils of different currents, at least, we can get 50Gauss 1st harmonic fields in arbitrary phase.

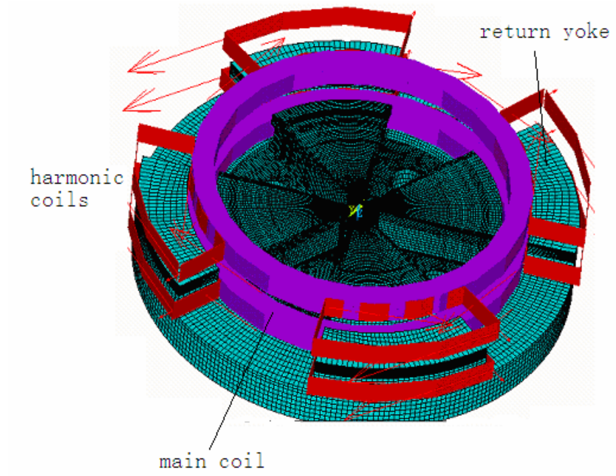

Figure 3: Harmonic coils on the return yoke.

Table 1: Phase and Amplitude of the 1st Harmonic Produced by Harmonic Coils of Different Current

Total current / A				Phase of 1st harmonic/deg.	Amp. of 1st harmonic/G
I1	I2	I3	I4		
-500	-500	500	500	90	52.2
-650	-350	650	350	73	54.5
-650	-160	650	160	59	49.5
-680	0	680	0	45	50.3

CORRECTION COILS FOR ISOCHRONOUS FIELD

As mentioned above, during the cyclotron operation, the thermal deformation of the magnet and the vacuum pressure may change the fields distribution, so we have to adjust the isochronous fields during it operation.

Different methods are considered to adjust the isochronous fields and the trim coil is selected, because trim coil is easy to control and does not damage the main magnet. It is hard to organize the coils in the gap between the poles because the gap is not big enough and the correction of the average fields we require is relatively small. It is calculated by a EFM code that when the temperature is changed by 25ºC the fields change caused by thermal deformation is less than 25 Gauss[3], We put 8 sets of trim coils in the two opposite valleys, (the rest two valleys are occupied by the RF cavities). They can motivate at least 25 Gauss fields in the radial range from 700mm to 2000mm.

In addition, the centering coils can also be used for adjusting the isochronous fields. We put one set of the pole trim coil on the pole face to adjust the isochronous fields too, shown in figure 1.

Figure 4 shows the configuration of the trim coils, and Figure 5 shows the changes of the average fields by each set of the trim coil at 1000AT.

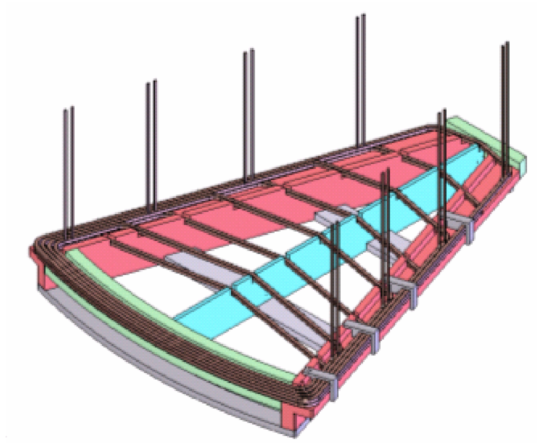

Figure 4: Configuration of the trim coils.

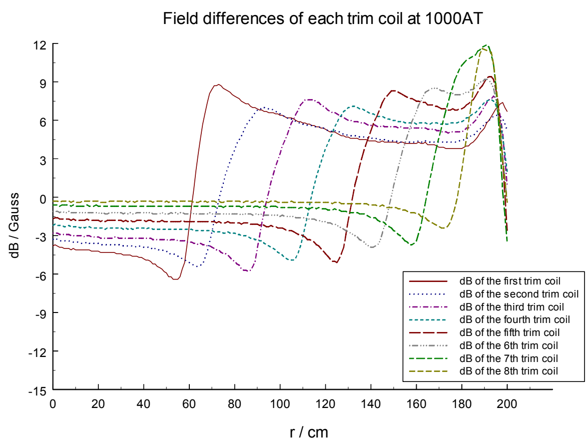

Figure 5: Filed effect of each trim coil at 1000AT.

A code that can adjust the isochronous fields on-line is developed in CIAE based on these results. By using this tool, we can calculate the current of these trim coils easily to compensate any given arbitrary error fields.

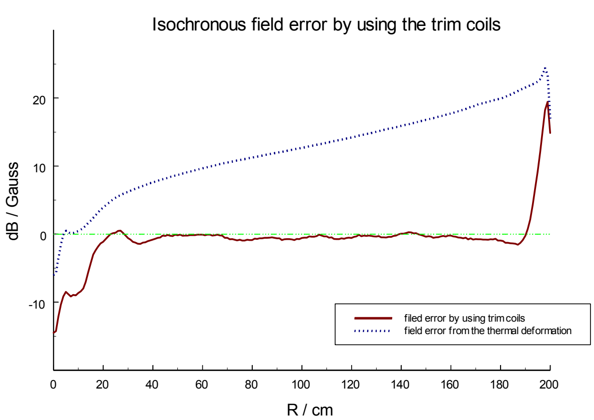

Figure 6: Filed adjust when the temperature changes by 25ºC.

One case is shown in figure 6, in which the doted line is the error of average fields caused by thermal deformation of 25ºC and the solid line is the fields error after corrected by the correction coils. The remnants fields error is less than 2Gauss in main acceleration region.

THE CORRELATIVE DESIGN

Since the trim coils and the centering coils work with high vacuum, the alumina is used for the isolation. Some experimentations for the alumina (made of different methods) inside the high vacuum tank are conducted and the result shows that spray method can satisfy the high vacuum requirement.

From the physics design of the correction coils, the current that the power supply need to provide is given. The highest current is 150A for the centering coils, 100A for the trim coils and 40A for the harmonic coils.

Since the highest current for the centering coils and the trim coils are 150A and 100A, the water cooled coils are used in the high vacuum, the feedthrough is selected to carry current and water, and isolate the high vacuum at the same time.

CONCLUSION

The correction coil system for compact cyclotron CYCIAE-100 is designed for adjusting the harmonic fields and the isochronous fields. Two sets of entering coils on the hills in the center region, eight sets of trim coils in the valleys and one set of harmonic coils on the return yokes are designed in details. The configuration of these coils, the isolation in high vacuum and so forth are designed. The machining will done based on this design lately.

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