DEVELOPMENT OF A PROTOTYPE KICKER MAGNET FOR CSNS\RCS EXTRACTION

W. Kang#, L. Wang, Y. D. Hao, J. X. Song, L. H. Huo, IHEP, Beijing, China

Abstract

China Spallation Neutron Source (CSNS) is a high intensity beam facility planed to build in future in China. It is composed of Linac, RCS and target station. The beam extraction from the RCS will be realized with ten vertical kicker magnets and one Lambertson magnet. One prototype kicker magnet has been successfully designed and developed in Institute of High Energy Physics. In this paper, the physical and structural designs of the prototype kicker magnet are presented, and issues of the magnet development, construction and test are discussed.

INTRODUCTION

The CSNS\RCS will be operated at a 25 Hz rate. The process includes injection, accumulation, acceleration and extraction. The extraction of the RCS takes place in one of the long straight sections as shown in the Fig. 1. When the beam is extracted, ten kicker magnets will deflect the beam vertically such an angle that the beam could leave the RCS centric orbit and enter the downstream extraction septum (Lambertson magnet). Then the septum will deflect the beam horizontally an angle of 15 degree and make the beam leave the RCS thoroughly.

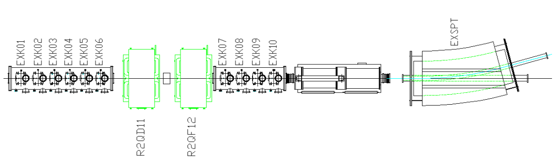

Figure 1: The components layout of the extraction.

In order to kick all of the particles of the beam, the kicker magnet should form a magnetic field in 250 ns, and keep the top of field more than 600ns. So the ferrite is used as the core material for its high frequency response and low loss. And the whole kicker magnet is installed inside the vacuum tank to avoid distortion of the field waveform. The inner surfaces of the ferrite will be coated with TiN to reduce secondary electron yield. In order to overcome these difficult problems, a prototype kicker magnet has been designed and developed. The specifications of the prototype kicker magnet are shown in the table 1.

THE DESIGN OF THE KICKER MAGNET

In the initial extraction scheme, five long twin C type kicker magnets [1] were used to kick the beam out of the RCS, each magnet was driven by two pulsed power supplies. But the problems such as current imbalance, time jitter difference and EMI between the two power supplies are not solved easily, so the final scheme was changed to use 10 short kicker magnets [2] with 10 power supplies.

Table 1: The required specifications of the kickers

Max. field	552G
Effective Length of Magnet	0.27m
Beam Aperture(H×V)	133mm×206mm
Peak Current	6000A
Peak Voltage	40kV
Turns per Coil	1
Rise Time of Field	250ns
Top Time of Field	>600ns

The fast kicker magnet is designed as a ferrite core rectangle frame magnet housed inside a vacuum tank with diameter of 600 mm. The cross section and 3D drawing of prototype kicker magnet are shown in Figure 2.

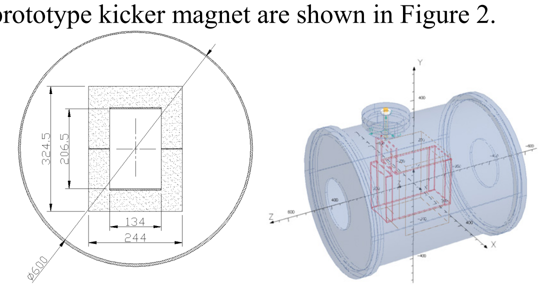

Figure 2: The structure of the prototype kicker magnet.

The window frame shape of the core is formed with two C-shaped Ni-Zn type ferrite blocks. The whole magnet core needs eight C-shaped blocks, which were developed in a Chinese ferrite company. The performances of this ferrite are very close to that of CMD5005 [3] from Ceramic Magnetics, Inc. The ferrite has the properties of high frequency response, low loss and low out gassing rate, which are important for fast pulsed magnet in high vacuum application. In order to install the coil, the core can be split into upper and lower halves. In the middle of the back legs, two copper strips are used to carry the beam induced image current and help to reduce the coupling between the beam and the ferrite. The coil is made of a single-turn copper conductor without water-cooling, because the average heat power is low enough while the pulsed power is high. High voltage current is fed from one end of the ferrite core. The inner surfaces will be coated with TiN films to reduce secondary electron yield.

The results of OPERA-2D [4] simulation are shown in Figure 3. Because of the copper strips in the middle of the back leg, which are used to reduce the beam impedance of the kicker magnet, the field decreases obviously near these areas. The lower is the beam impedance, the worse

#kangw@ihep.ac.cn

is the field uniformity. So the specifications of the field uniformity and the beam impedance must be balanced for the kicker magnet.

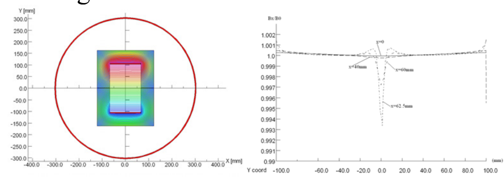

Figure 3: The results of OPERA-2D simulation.

The results of OPERA-3D [4] simulation are shown in Figure 4. Because the height of the gap can be comparable to the length of the core and the end field effect is obvious, the uniformity of integral field is worse than 4% within 90% aperture. The effective magnetic length is 299mm while the core length is 220mm. The inductance of the whole kicker magnet is 0.56 uH.

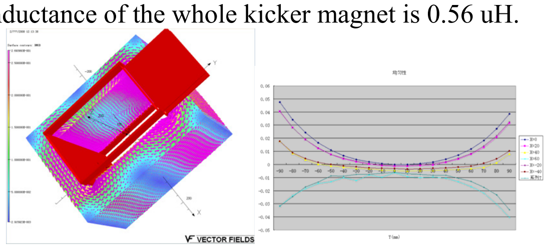

Figure 4: The OPERA-3D simulation.

The drawing of the prototype kicker magnet is shown in Figure 5. A sliding plate is used to fix and insert the kicker magnet into the vacuum tank. Before insertion, the magnet is aligned and fixed to its final position on the plate. Then the plate, with the magnet on it, is inserted into the tank. The magnet position in the tank will be adjusted by aligning the plate to the tank.

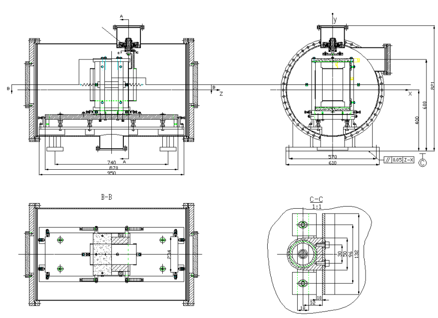

Figure 5: The drawing of the kicker magnet.

CONSTRUCTION OF THE PROTOTYPE KICKER MAGNET

The kicker magnet consists of vacuum tank, ferrite core, copper current bus, ceramic insulating supporter, sliding support plate and high voltage feedthrough. The vacuum tank is made of cylindrical stainless steel tubes of 600mm in diameter. It services not only to provide vacuum for the kicker magnet, but also to support the whole magnet. Since the aperture of the kicker magnet is so large, it need large C shaped ferrite blocks to form the window frame shaped core. However, to produce such large C-shaped ferrite blocks is not easy, before successfully developed, it went through many times of failure. The current bus is made from soldering several pieces of copper plates. It needs no water cooling because the average heat power on it is very low. To strengthen the insulation between the high voltage current bus and the ground, two large pieces of ceramic plates were produced and added on the top and bottom of the magnet. They were used not only to strengthen the insulation, but also to support and protect the ferrite core. The picture of prototype kicker magnet is shown in the Figure 6.

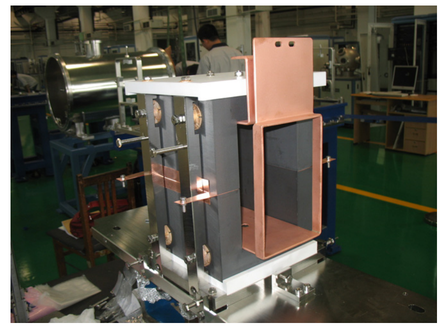

Figure 6: The picture of the magnet.

The kicker magnet is powered by a pulsed power supply. The 40 kV pulse from the power supply will be sent into the magnet in the vacuum tank by the coaxial HV feedthrough. The feedthrough has a tri-polar structure, which can isolate the ground of the pulsed power supply from the vacuum tank. It was difficult to solder the inner and outer metal conductors with the ceramic insulators. The developed HV feedthrough is shown in Figure 7.

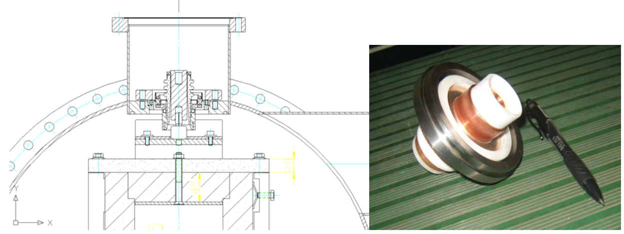

Figure 7: The high voltage feedthrough.

After all the components are finished, the much care need be taken on the assembly of the whole kicker magnet. The vacuum tank and flanges were made of 304L stainless steel. Before assembly, the vacuum tank was cleaned, the ferrite blocks and all machined parts were cleaned and baked to 200^{o}C. Firstly, the kicker magnet was assembled, aligned and fixed on the sliding plate. Secondly, the sliding plate carrying the magnet was sliding into the vacuum tank. By surveying the sliding plate in the vacuum tank, the magnet was moved to its final position, which was determined by beam dynamics. Thirdly, the tank was closed as shown in Figure 8.

PROTOTYPE TESTS

After assembly of the prototype kicker magnet, the vacuum test has firstly been done. The required vacuum quality for the kicker magnet is in the 2.0x10^{-8}Torr. Since large quantities of ferrite and ceramic are used in the system, to overcome the outgassing from porous ceramics, one 500L big ion pump was installed in the underside of the kicker assembly. The whole system was baked to 180^{o}C under vacuum and kept for 48 hours, after cool down, the vacuum pressure reached to 1.8x10^{-8}Torr, which meets the vacuum requirement.

Figure 8: The assembly of the prototype magnet.

The distributions of the integral magnetic field were measured with the long search coil. The picture of the setup for magnetic field measurement is shown in figure 9. The long bar in the center of the magnet gap area is the long search coil that is made of the epoxy resin. The coil loop line of the long search coil is wound with 0.18mm enamelled wire, and the loop size is 3mm in width and 1100mm in length by 1 turn.

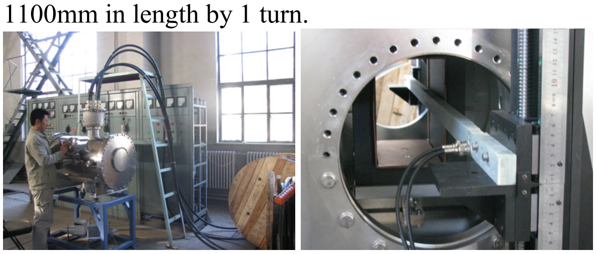

Figure 9: The test setup.

The magnetic field waveform (blue one) and the excited current waveform (pink one) are shown in figure 10. Two waveforms conform each other very well. In fact, the search coil could only get the differential signal of the magnetic flux. By using an integrator, the magnetic flux signal is calculated and then displayed on the oscillograph. So the figure 10 actually shows the magnetic flux waveform. The rise time of the waveform is about 250ns, the top time is about 600ns.

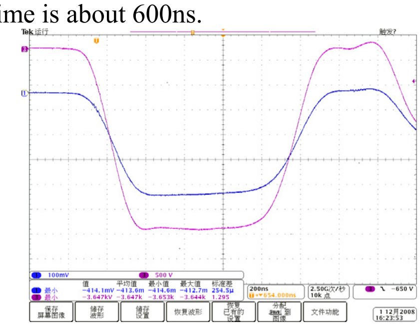

Figure10: The waveforms of the field and current.

The relationship between the integrated magnetic field and the excited current is shown in figure 11. The linear curve shows that the ferrite core of the magnet works in the linear region and does not appear saturation.

The distribution of the integrated magnetic field has been measured within the 90% of the magnet aperture. The uniformity of the field is about 4% as shown in Figure 12.

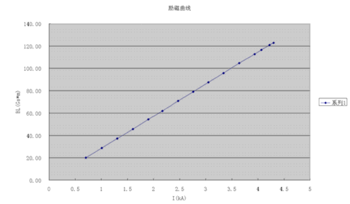

Figure 11: The relationship of the field and current.

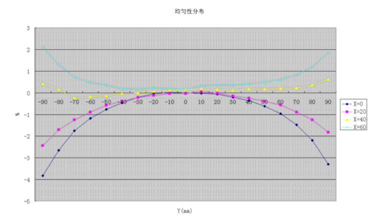

Figure12: The distribution of the integrated field.

CONCLUSION

A prototype kicker magnet for CSNS\RCS extraction has been designed and developed. Due to large gap of the magnet, the end effect causes the uniformity of integrated magnetic field worse than 4% within the 90% aperture. For the vacuum and fast pulse applications, the large C-shaped, good performance ferrite blocks have been developed. The prototype tests showed that the vacuum and magnetic specifications of the magnet met the requirements.

REFERENCES

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[2] C. Pai, et al, “Mechanical Design of Fast Extraction Kicker and PFN for SNS Accumulation Ring”, Proceedings of the 2003 Particle Accelerator Conference: 2147-2149 .

[3] www.cmi-ferrite.com.

[4] Vector Fields Inc.