DEVELOPMENT OF A PROTOTYPE BUMP MAGNET FOR CSNS\RCS INJECTION

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Abstract

China Spallation Neutron Source is a high intensity beam facility planed to build in future in China. It is composed of Linac, RCS and target station. Two sets of pulsed painting bump magnets, 4 magnets in each set , will be used in CSNS RCS to create a dynamic orbit bump for injection process. The design of these 8 bump magnets has been completed. One prototype bump magnet has been assembled and tested. In this paper, the magnetic field analysis, the eddy current and thermal considerations in the end plates of the prototype bump magnet are presented, and issues of the magnet development, construction and test are discussed.

INTRODUCTION

The CSNS accelerators consists of an 80 MeV H^- linac and a rapid cycling synchrotron(RCS) of 1.6GeV. It will be operated at a 25 Hz rate. The RCS accumulates protons via H^- stripping injection. The injection of the RCS takes place in a 9 meter long straight section, which contains four shift magnets (BC) to form a horizontal orbit bump, eight symmetrically placed dynamic bump magnets (BH&BV) for the phase space painting in both the horizontal and the vertical planes, two septum magnets and two strippers as shown in the Figure 1.

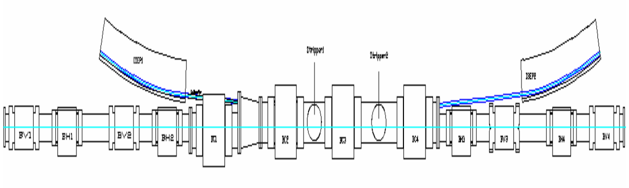

Figure 1: The components layout of the injection.

In order to create a dynamic orbit bump for injection process, the BH magnet should shift the circulating beam horizontally for painting the injection beam in the injection period. So the BH magnets form a magnetic field in 1 millisecond, keep the top of field 50 microseconds and drop the field between 500 microseconds and 700 microseconds. The 0.15 thickness silicon steel is laminated as the core to decrease the iron loss. In addition, the 25 Hz pulsed field induces eddy currents in the magnet components, especially in end plates, and heat generations are of great concerns. As shown in the Figure 1, the space for the BH magnets is limited, and the C-type [1] or asymmetric window-frame structure of the BH magnet core was considered. Because of the amplitude of pulsed exciting current is almost 18000A, the force on the coils is so large. In order to overcome these difficult problems, a prototype BH magnet has been designed and developed. The parameters of the prototype BH magnet are shown in the Table 1.

Table 1: The parameters of the prototype BH magnet.

Max. field(T)	0.2313
Structure	W-frame
Effective Length of Magnet(m)	0.3
Beam Aperture(mm)(H/V)	140/170
Peak Current(A)	18000
Peak Voltage(kV)	3
Turns per Coil	2
Rise Time of Field(ms)	1
Top Time of Field(us)	50
Drop Time of Field(us)	Prog. 500~700
Lamination thickness(mm)	0.15

THE DESIGN OF THE BH MAGNET

As the space between BH magnets and injection beam duct is limited, and to avoid interference, the initial structure design of the BH magnet was considered as C-type structure. But the problems such as the influence on the injecting beam by the BH stray magnetic field and the accuracy of BH magnet repetitious assembly are not solved easily, the final structure design of the BH magnet was selected an asymmetric W-frame. The schematic view of the three-dimensional model is shown in Figure 2.

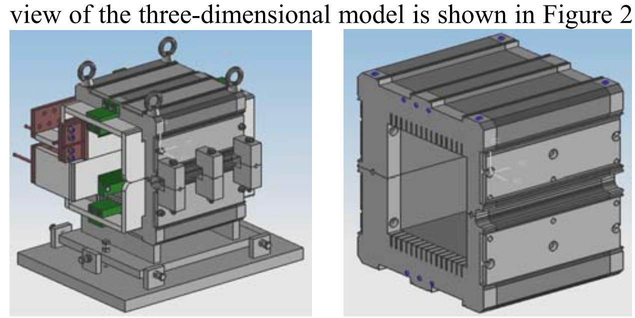

Figure 2: The 3D structure of the prototype BH magnet.

The core size of the horizontal paint bump magnet is 300 mm(H)*332 mm(V). The length of the core is 220 mm and the lamination sheet is 0.15 mm thickness. In order to install the coil, the core can be split into upper and lower halves. The maximum magnetic field is 0.2313 T with 1.8 kA exciting current. The two-turn coils are water-cooled, because the average heat power is so high. The ceramic vacuum chambers are used for the injection bump magnets to avoid shielding of a fast-changing magnetic field and to minimize eddy current heating.

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Magnetic Field Calculation

The BH magnet has been designed using a two-dimensional and three-dimensional electromagnetic analysis codes.

The results of OPERA-2D [2] analysis are shown in Figure 3. The magnetic flux density in the left yoke of the core is 4500 Gauss, while that in the right yoke is 6900 Gauss, so there is no field saturation in the core.

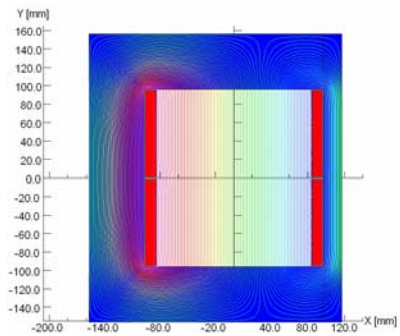

Figure 3: The results of OPERA-2D simulation.

The results of OPERA-3D [2] simulation are shown in Figure 4. The effective magnetic length is 318 mm while the core length is 220 mm.

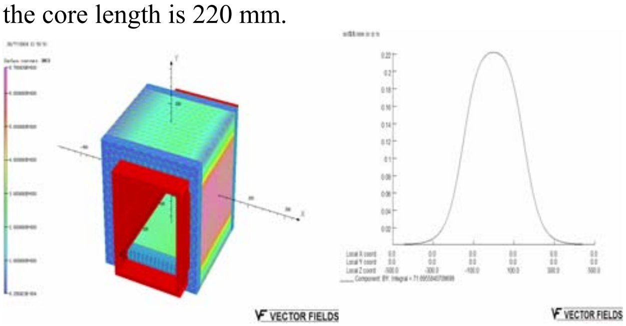

Figure 4: The OPERA-3D simulation.

The optimisation design of the core and the coils is performed using the OPERA-3D simulation. The calculated results of the integrated field distribution are shown in Figure 5. The field uniformity is less than ± 1.2% within the good field region of 130 mm in width and 140 mm in height.

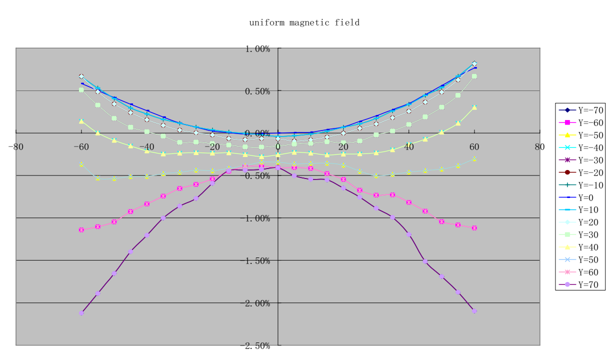

Figure 5: Integrated magnetic field distribution of the three-dimensional analysis.

Eddy Current Losses

The pulsed paint bump magnets are operated at a repetition rate of 25 Hz, and are excited with a trapezoid rectangle waveform current with about 1.6 milliseconds duration. The eddy current induced in the BH magnet is expected to be large. In order to decrease the eddy current losses, the BH magnetic core uses the laminated thin steel sheets with 0.15 mm thickness and the end plates are provided with the slit cut[3]. The distribution of eddy current in the end plates with and without slit cut is compared as shown in Figure 6. The eddy current losses of the end plates with slit cut have decreased obviously.

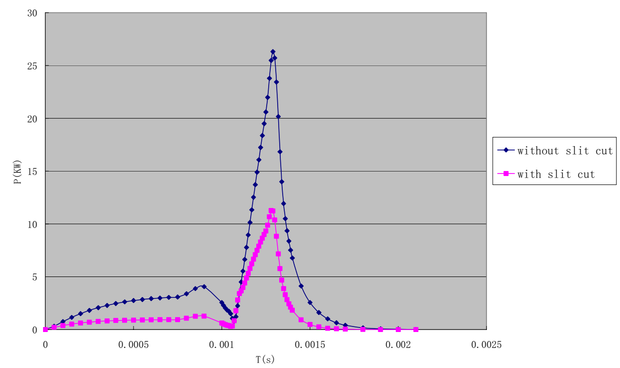

Figure 6: Calculated results of the eddy current losses.

Coil Cooling and Fixation

Because the average ohm heat power of the coil is high, the coil must be cooled with water. To avoid the influence of the cooling water pipe on the magnetic field distribution and the electric field, the coils are welded from many copper plates with cooling holes inside them. The insulation of the coil requires a high tension and a high radiation resistance, so the Kapton films are applied for the coil insulation from the core.

When the BH magnet is powered to full current, the large Lorentz force will cause the coil to have a vibration of 25 Hz. From the OPERA analysis, the magnitude of the harmonic force is about 52 kg in the middle part of the coil. So in order to reduce this vibration, the special fixing approach of the coils has been used[4]. Through the holes in the coils and the core, the long bolts pull the coils tightly on the core as shown in Figure 7.

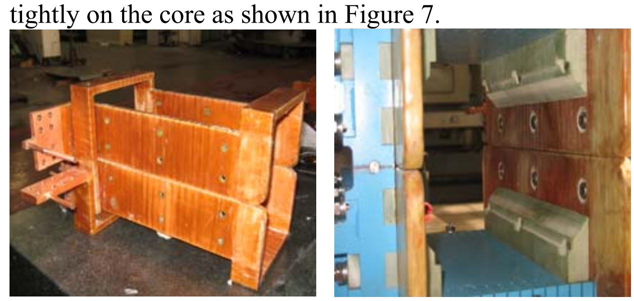

Fig. 7: The coil of the prototype BH magnet.

PROTOTYPE TESTS

After the assembly of the prototype BH magnet (Figure 8), the initial tests of coil performance have been done.

As shown in the Figure 9, the insulators, which insulate the power supply from cooling water pipe, are made of copper and ceramic tubes. Instead using the invar as transition connectors, the copper is directly used to weld with the ceramic successfully. The test of the insulators set the hydraulic pressure to 20 kg/cm^2 and kept for 15 minutes, and there is no water leakage.

Figure 8: The assembly of the prototype BH magnet.

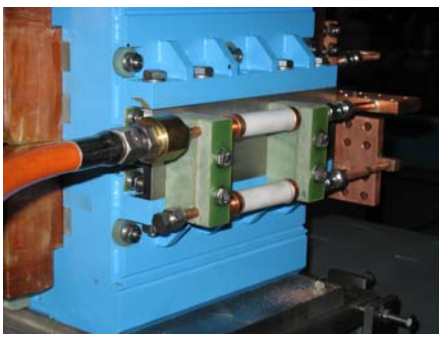

Figure 9: The insulator of the water pipe.

The other test of the coils is the withstanding electric voltage test. The setup of the test is shown in Figure 10. The maximum voltage set to 6.2 kV while the full operation voltage is only 3 kV, and there is no high leakage current.

Figure 10: The electric withstanding voltage test.

The measured inductance of the BH magnet is about 1.48 μH. And after assembling the magnet with the copper bus bars, the inductance increases to 2.24 μH.

The distribution of the integrated magnetic field will be measured recently and the results will be compared with that of the three-dimensional simulation. And the tests of the temperature rise of the end plates, the temperature rise of the coil and the vibration displacement of the coil will be measured accurately.

SUMMARY

The first prototype BH magnet for CSNS\RCS injection has been designed, developed and successfully assembled. In order to met the requirements, the core of the BH magnet firstly used the asymmetric window-frame structure, which has been simulation by the two-dimensional and three-dimensional electromagnetic analysis codes. Furthermore, to reduce the vibration of the coil, the special fixing approach of the coils has been adopted. The results of the coil withstanding electric voltage test show that the design of the coil fixation met the insulation requirement. The tests of the temperature rise, the magnetic field properties and the vibration displacement will be done in the coming month.

REFERENCES

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