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CHARACTERISTIC STUDY OF THE PULSE BUMP MAGNET IN HEPS*

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Abstract

In the extraction of booster to storage ring for High Energy Photon Source, four pulse bump magnets are applied to create a local bump to reduce upstream kicker strength and to ease extraction. In this paper, a lot of characteristics of the pulse bump magnet such as magnetic field, eddy current, induced voltage, vibration are introduced and thoroughly discussed. According to measurements, four pulse bump magnets are satisfied with the physical requirements of beams extraction in HEPS.

INTRODUCTION

High Energy Photon Source (HEPS) is a 6-GeV, the fourth-generation synchrotron radiation light source being built in China [1, 2]. The HEPS accelerators include a full energy injector and an ultralow emittance storage ring. The injector consists of a linac, a booster and three transport lines that connect the linac, booster and storage ring together [3, 4], as shown in Fig. 1. In the booster to the storage ring (BTS),

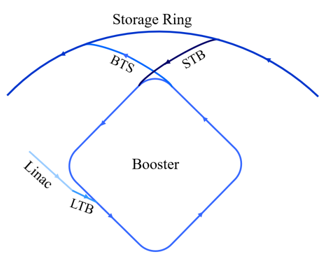

Figure 1: Layout of the HEPS.

an extraction system is proposed, in which electrons go into storage ring after accumulating in the booster. In this extraction system, one kicker provides vertical angles for the extraction beams and one Lambertson separates extraction beams. In order to reduce the kicker strength, a slow bump generated by four pulse bump magnets is needed. The four pulse bump magnets ramp with the main magnets in the booster cycles when beams extract from booster to storage ring [5, 6], as shown in Fig. 2.

For the discussion of pulse magnet performance, different sizes of magnets have different concerns, some focus eddy current, and some concern heat [7, 8]. In this paper, not only the issues of magnetic field and eddy current are discussed, but also the issues of vacuum chamber shape, induced voltage and vibration are all studied for the pulse bump magnet in HEPS, then the measurement results of the magnet are presented.

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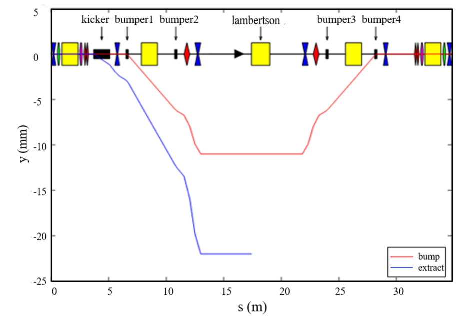

Figure 2: Schematic layout of extraction in BTS.

MAIN PARAMETERS OF MAGNET

The main specifications of four pulse bump magnets are the same and listed in Table 1.

Table 1: Specifications of the Pulse Bump Magnet

Parameter	Value	Unit
Quantity	4	-
Max. central magnetic field	0.2	T
Max. Deflection	2.0	mrad
Effective length	200	mm
Max. integral magnetic field	40	T·mm
Magnet gap	40	mm
Clearance (H×V)	30×30	mm
Good field range (H×V)	12×28	mm
Field uniformity	±0.5%	–
Bottom width of half sine current waveform	≤1	ms
Repetition rate	50	Hz

CHARACTERISTICS ANALYSIS OF THE PULSE BUMP MAGNET

Pulse current generates pulse magnetic field in the magnet. According to the Maxwell's Law [9], the changing magnetic field induces voltage and eddy current, so some issues such as magnetic field quality, eddy current effect, induced voltage, vibration should be carefully considered when the pulse bump magnet is designed. Firstly, eddy current causes phase shift and amplitude attenuation of the magnetic field waveform, spoils the uniformity of the magnetic field and heats the metal components of the magnet. Secondly, fast changing magnetic flux in the loop of the coils induces high voltage which causes great risk of magnet insulation failure. Lastly, fast changing magnetic forces lead to the vibration of the cores and coils, which sometimes makes large noise and destroys the integrity of the magnets.

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The core of the pulse bump magnet consists of laminated sheets and end metal plates. According to the specifications of the magnet, 0.15 mm thickness laminated sheet is considered. The magnet is composed of one H-type curved core and two racetrack coils, as shown in Fig. 3. The stainless-steel end plates and welded plates are used to fix laminated sheets. Then, the stainless-steel vacuum chamber is located in the aperture of pulse bump magnet.

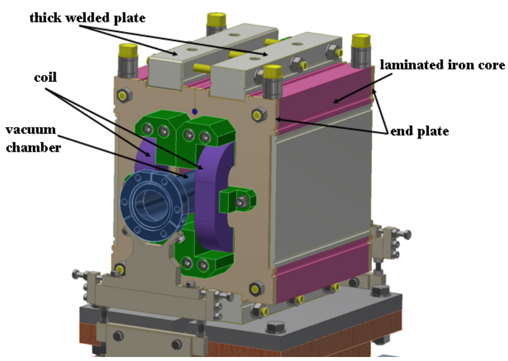


Figure 3: Structure of the pulse bump magnet.

Study of Eddy Current

Thanks to the OPERA Software [10], characteristic simulation of the pulse bump magnet has been done. Eddy current has a great effect on the magnetic field characteristic in laminated iron core, two end plates and four thick welded plates. Figure 4 shows distribution of eddy current density in two end plates and four thick welded plates at 0.1 ms. Eddy current density variation in all structure parts of the magnet is shown in Fig. 5, from which it can be seen that mean value of eddy current density in 2 ms is lower. It can be concluded that effects of eddy current are relatively smaller, and the heat effects can be ignored.

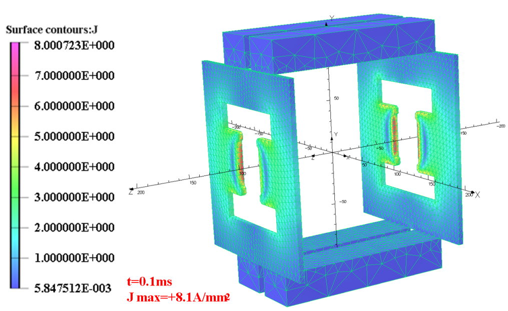


Figure 4: Eddy current calculation at 0.1 ms in end plates and thick welded plates.

Vacuum Chamber Shape

According to the size of the pulse bump magnet aperture four shapes of stainless steel vacuum chamber are introduced as shown in Fig. 6, whose wall thickness is 0.7 mm. It is requirement that eddy current in vacuum chamber is as possible as little. Phase lag and amplitude attenuation of magnetic field for four shapes of vacuum chamber are listed in Table 2. It can be seen that effects of eddy current in (b) is the least, and ones of (a) and (d) are similar. Considering

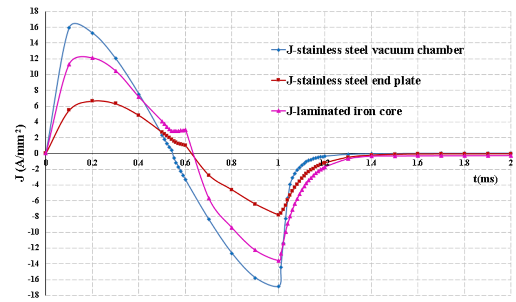
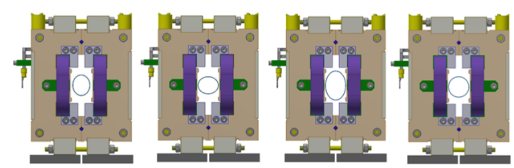


Figure 5: Eddy current calculation in magnet.

fabrication of vacuum chamber, the circle ø 36 mm is chosen at last.



(a) Ellipse 30 mm× 36 mm (b) Ellipse 36 mm× 30 mm (c) Ellipse 36 mm× 52 mm (d) Circle ø 36 mm

Figure 6: Four shapes of vacuum chamber.

Induced Voltage and Vibration

Through calculation, the maximum induced voltage reaches 225 V in 1 ms. The conventional method of coil epoxy casting was adopted, which can meet the withstanding high voltage intensity along the surface of the electric strength in 1 mm creepage distance.

The maximum force calculated on coils in y direction is only 16 N, which indicates that vibration has a little effect. In order to reduce the vibration, the coils are fixed tightly on the poles of the magnets by the fastening components, and all the bolts and washers used to fix the components of the magnets are chosen to prevent loosening in magnet structure design.

Magnetic Field Uniformity

At 0.55 ms, the integral magnetic field uniformity of the pulse bump magnet is better than ±0.33% in good field range ±14 mm, as shown in Fig. 7.

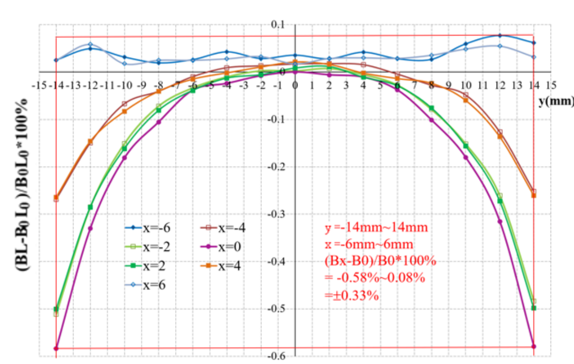


Figure 7: Integral magnetic field uniformity calculation in good field range.

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Table 2: Central Magnetic Field and Integral Magnetic Field of Four Shapes of Vacuum Chamber

Vacuum Chamber Shape	no	(a)	(b)	(c)	(d)
Phase lag of central magnetic field (ms)	0	0.04	0.04	0.05	0.04
Central magnetic field (T)	0.21234	0.21217	0.21231	0.21099	0.21214
Amplitude attenuation of central magnetic field (%)	0	-0.080	-0.014	-0.636	-0.094
Phase lag of integral magnetic field (ms)	0	0.05	0.04	0.06	0.05
Integral magnetic field (T·mm)	43.0876	43.0339	43.0713	42.9575	43.0412
Amplitude attenuation of integral magnetic field (%)	0	-0.123	-0.038	-0.302	-0.108

MANUFACTURE OF MAGNET

Manufacture of four pulse bump magnets were completed as shown in Fig. 8. After the magnet assembly, the performance of the coil has been tested. A DC voltage of 1 kV was applied between the coil and the laminated core, and there was no obvious appearance observed within 10 minutes such as leakage current, lighter and corona.

Figure 8: Pulse bump magnet.

MAGNETIC FIELD MEASUREMENT

The measurement of the central magnetic field and integral magnetic field were all done. Figure 9 indicates the exciting current waveform and magnetic field waveform measured for magnet without vacuum chamber. It is easy to read the amplitude of the magnetic field from the oscilloscope in the measurement, but difficult to measure the phase deviation because of the trigger time point is different with vacuum chamber or not.

The measurement results of the first one of four magnets are listed in Table 3, from which it can be seen the measurement results of the magnetic field meet the design specification. The measurement results of other three magnets are very similar to the first magnet.

TEMPERATURE MEASUREMENT

The temperature distribution of pulse bump magnet was measured with a Thermal Imager. After 8 hours' testing, the maximum temperature of the magnet was 26 ℃ and it was located in laminated iron core, and the maximum temperature in vacuum chamber was 56 ℃, when the ambient temperature was 21 ℃ in the measuring hall.

Figure 9: The exciting current waveform and magnetic field waveform.

Table 3: The Measuring Parameters Results of the Pulse Bump Magnet

Parameter	Value	Unit
Max. central magnetic field (no vacuum chamber)	0.217	T
Max. central magnetic field (with vacuum chamber)	0.212	T
Max. integral magnetic field (no vacuum chamber)	45.12	T·mm
Max. integral magnetic field (with vacuum chamber)	43.90	T·mm
Effective length	207.5	mm
Field uniformity	<±0.5%	–
Max. peak current	212.5	A

CONCLUSION

Four pulse bump magnets are carefully analysis and designed, including eddy currents, magnetic field, induced voltage, vibration and vacuum chamber shape before the magnets are manufactured. From the magnetic field measurement results, the performances of the pulse bump magnets have been proved to be excellent, and four pulse bump magnets are able to fulfill the physical requirements of extraction in HEPS.

At present, the four pulse bump magnets have been installed in booster of HEPS.

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