

# A PULSE SEPTUM MAGNET WITH LOW OUTGASSING RATE

Yuan Ji Pei, W.M.Li, D.M.Jiang, X.Q.Wang

National Synchrotron Radiation Laboratory  
University of Science and Technology of China  
Hefei, Anhui 230029, P.R.China

## Abstract

A novel pulse septum magnet for the injection system of NSRL storage ring which is a dedicated synchrotron radiation facility was described in this paper. The main parameters and measured results of the septum including its magnetic field distribution and its vacuum characteristic were given also. After making a shim the stray field near current strip to gap magnetic field was reduced to 0.1%, and the pressure of the vacuum chamber, in which the septum magnet was installed, is less than  $5 \times 10^{-10}$  mbar after baking. Now the septum magnet is playing an important part in getting a high injection efficiency and high accumulating current in the NSRL storage ring during the machine running.

## I. INTRODUCTION

HLS (Hefei synchrotron radiation Light Source) is a major equipment of NSRL (National Synchrotron Radiation Laboratory), which consists of an electron LINAC of 200MeV and a storage ring of 800 MeV. The LINAC was built in a tunnel and the storage ring was built above ground. The difference in vertical direction between the position of the LINAC and the storage ring is 3.2m. The electrons from the LINAC pass through the transport line of 88 m and then is injected into the storage ring by mean of the injection system which is composed of three kickers and two septum magnets. The two septum magnets were designed to carry out deflection in vertical direction and horizontal injecting into the storage ring<sup>[1]</sup>. It is very important to develop a novel pulse septum magnet with a good magnetic performance and low outgassing rate so that it can be installed into the ultra-high vacuum chamber directly to raise the injection efficiency and increase the transverse admittance near the injection point of the storage ring. There were some way to solve these problems mentioned above in existing machine<sup>[1,2,3,4,5,6,7]</sup>. One of these is to separate the vacuum chamber of the storage ring from the transport line vacuum chamber using a metal foil, such as Beryllium foil of 0.05 ~ 0.1mm or a koplion foil of 0.02 ~ 0.05mm thick. Another way is to increase the gap size of the septum magnet so that the vacuum chamber can be mounted in the gap directly or reduce the conductance of gases from the vacuum chamber of the septum to the vacuum chamber near the injection point of the storage ring and using a SIP with higher pumping speed to exhaust them and so on. In order to keep a higher injection efficiency, adopting thin koplion foil to separate the two vacuum chamber is a better way. But when the electron beam of 200 MeV passes through the koplion foil of 50  $\mu\text{m}$ , the divergent angle of the beam will be increased up to 1.24 mrad which is larger than the allowed acceptance of the storage ring of NSRL at the injection point<sup>[8,9]</sup> so the thin foil cannot be adopted in our

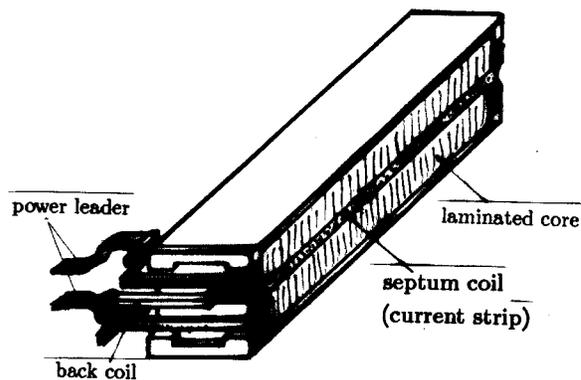


Figure 1. Schematic drawing of pulse septum magnet

case. On the other hand it is impossible to obtain the required pressure of  $10^{-9}$  mrad, if the pulse magnet is directly mounted in the chamber of the storage ring. Because the pulse magnet was made of steel sheet (0.6mm thickness), its total surface area is about  $10^5 \text{ cm}^2$  and the outgassing rate of the commercial steel sheet with isolating coating is about  $10^{-10} \text{ mbar} \cdot \text{l} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$  at least. So the total outgassing quality of the septum magnet will be reach  $10^{-5} \text{ mbar} \cdot \text{l} \cdot \text{s}^{-1}$ . Obviously it is difficult to reach a pressure of  $10^{-9}$  mbar or less. Finally a new magnetic material which is a low carbon steel sheet of 0.6mm thickness with  $\text{Al}_2\text{O}_3$  powder coating has been searched after testing repeatedly. The test results show that its outgassing rate is negative after baking for 24 hours at  $200^\circ\text{C}$ . The whole septum magnet was mounted in the storage ring chamber, its pressure was less than less  $5 \times 10^{-10} \text{ mbar}$  after bakeout and pumping of 48 hours<sup>[10]</sup>. This is an exciting result. Now the septum magnet is playing an important part in getting a high injection efficiency and high accumulating current in the NSRL storage ring.

## II. MAGNETIC PERFORMANCE OF THE SEPTUM MAGNET

The septum magnet is laminated by steel sheet of 0.6mm thickness with ceramic powder coating (coating thickness about 50  $\mu\text{m}$ ). Its exciting coil is a single turn coil with  $\text{Al}_2\text{O}_3$  powder coating also. The schematic drawing in Fig.1 shows the basic components of the septum. The cross section of the septum magnet is shown in Fig. 2. The main parameters is summarized in Table 1.

Integrated magnetic field along the electron beam direction was measured by means of a set of long coil. Its distribution vs transverse direction is shown in Fig.3. The magnetic field near the end of the septum measured along beam moving direction by point coil is shown in Fig.4.

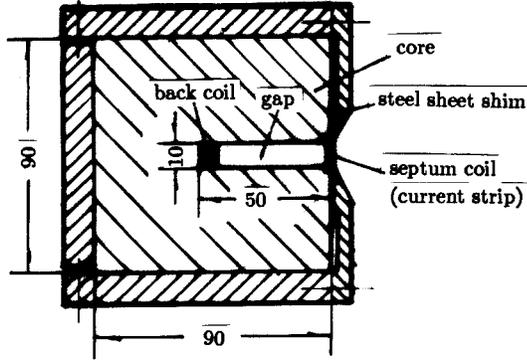


Figure 2. Cross section of the septum magnet

Table I  
Main parameters of the septum magnet

Max. pulse magnetic field	5.6 kGauss
Radius of curvature	4.77 m
Deflection angle	104.7 mrad
Effective length	499.5 mm
Magnetic field waveform	half sine
gap highness	10 mm
Thickness of current strip	2 mm
Max. exciting current	4500 A
Max. current density	214.3 A/mm <sup>2</sup>

The curve 3 in Fig.3 shows that the stray field near the current strip vs the magnetic field in the gap is about 0.1% after a suitable shim. With our testing data we calculated the injection efficiency to be about 100%. This indicated that the magnetic performance is good enough for our machine.

### III. VACUUM CHARACTERISTIC

According to calculation of the lifetime of 8 hours in the storage ring, the pressure in the storage ring chamber with stored beam of 300mA must be less than  $3 \times 10^{-9}$  mbar. In order for the pulse septum magnet to be mounted in the ultra-high vacuum chamber directly, and not influence the vacuum condition, it is necessary to search and develop a new magnetic material which outgassing rate must be lower than  $10^{-12}$  mbar · l · s<sup>-1</sup> · cm<sup>-2</sup>. Unfortunately, the outgassing rate of the commercial steel sheet with isolating coating is about  $10^{-10}$  mbar · l · s<sup>-1</sup> · cm<sup>-2</sup> at least. After testing repeatedly, we have found that outgassing rate of the low carbon steel sheet of 0.6mm thickness with ceramic powder  $Al_2O_3$  coating is negative after bakeout for 24 hours at 200° C. Fig.5 shows the outgassing rate curve tested in different case. According to curve 1 and 2 in fig.5, the outgassing rate is about  $4.2 \times 10^{-13}$  mbar · l · s<sup>-1</sup> · cm<sup>-2</sup>. Obviously, the steel sheet with  $Al_2O_3$  powder coating have some absorption capacity after baking<sup>[10]</sup>.

In order to understand the phenomenon we put the steel sheet of 706 cm<sup>2</sup> area into a testing vacuum chamber, and got a raising pressure curve in different condition after pumping. Fig.6 shows the test results. After one week being without pumping, the chamber remained a good vacuum condition of  $10^{-9}$  mbar

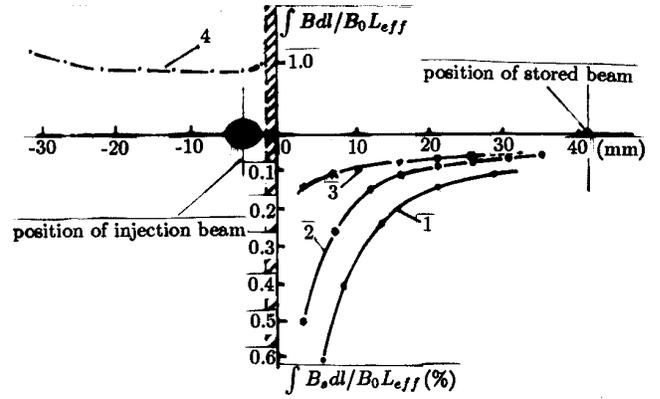


Figure 3.  $\int B dl$  vs transverse distance from the face of current strip

- 1 – without shim
- 2 – reducing the length of current strip without shim
- 3 – reducing the length of current strip with shi
- 4 – field distribution in the gap

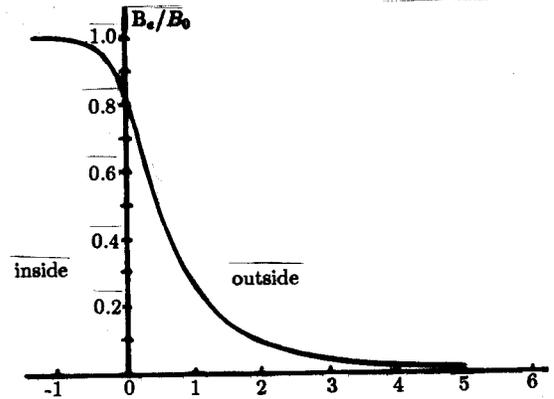


Figure 4. Magnetic field distribution near the end of the septum along beam direction

also.

Finally we manufactured the pulse septum magnet from such a material(steel sheet and copper strip) with  $Al_2O_3$  coating. So far the septum magnet was mounted in the ultra-high vacuum chamber of storage ring, and is running well. The pressure near the septum magnet is about  $8 \times 10^{-10}$  mbar without beam and  $2 \times 10^{-9}$  mbar with stored beam of 150mA.

### IV. CONCLUSION

After mounting the pulse septum magnet which was made of steel sheet and copper current strip with  $Al_2O_3$  powder coating, into the ultra-high vacuum chamber of NSRL storage ring, the machine has successfully run for 5 years. All of these show that the septum magnet is of high quality with respect to both magnetic performance and vacuum characteristic. Especially, the septum magnet is of benefit to increase injection efficiency for a low energy electron storage ring.

As for the absorbing function and the mechanism of  $Al_2O_3$  powder coating have yet to be investigated further.

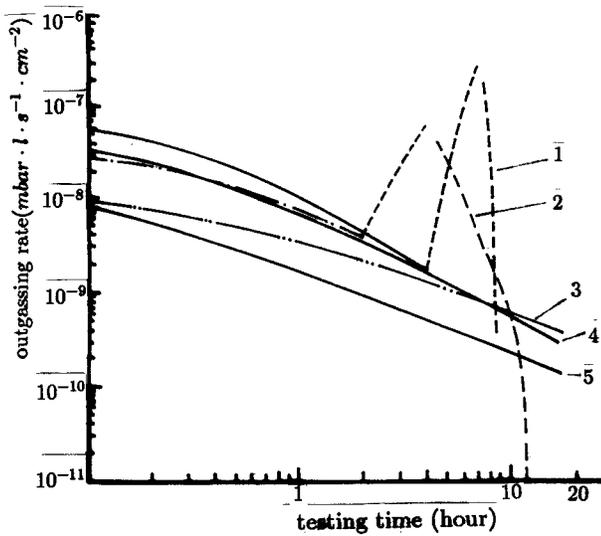


Figure 5. Outgassing rate curve of different material

- 1 – copper plate with  $Al_2O_3$  coating after baking
- 2 – steel sheet with  $Al_2O_3$  coating after baking
- 3 – steel sheet with  $Al_2O_3$  coating at room temperature
- 4 – copper plate with  $Al_2O_3$  coating at room temperature
- 5 – steel sheet with inorganic isolating coating at room temperature

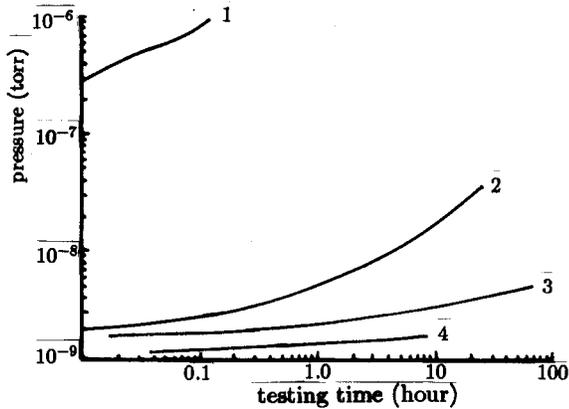


Figure 6. Raising pressure curve in different case

- 1 – steel sheet with  $Al_2O_3$  coating at room temperature
- 2 – background (without sample)
- 3 – steel sheet with  $Al_2O_3$  coating after baking
- 4 – steel sheet with  $Al_2O_3$  coating after re-baking

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