

DEVELOPMENT OF A SEPTUM MAGNET WITH THIN SEPTUM WIDTH AND LARGE MAGNETIC FIELD

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Abstract

A pulse septum magnet with a thin septum and having strong magnetic field is designed and fabricated. The cross section of the septum coil is $2.3 \times 8.5 \text{ mm}^2$ and the applied magnetic field is 1.6 T. The current wave form is a single cycle sinusoidal wave and the peak current is 12 kA. The septum coil is attached by thin stainless steel bands to a copper plate, which is fixed to the yoke holder. The copper plate is cooled by water and the power loss in the septum coil is removed through a kapton tape which also works as an insulator. In the copper plate, eddy current is induced by the pulse flux. By this eddy current the leakage flux of the septum magnet is reduced by factor 6 compared with the calculated value and the field distribution is also improved. The magnetic field distribution is measured by a one-turn probe and found that the good field region in x direction is more than 10mm, where the homogeneity is less than 0.2%, and the good field region in z direction is over 7 mm. The fluctuation of the shot-to-shot peak current and magnetic field is less than 0.02% and is limited by the resolution of the ADC(12bits) used for the measurement.

1 Introduction

An electron synchrotron or a storage ring has a lot of advantages for the X-ray source and many compact circular accelerators have been designed and constructed. One of the important technical problems of these compact electron circular accelerators is its injection and extraction magnet system.

A septum magnet used as one of these magnets should meet many requirements. It is required to have a small bending radius (providing strong magnetic field) because there is only small room for its insertion, good field homogeneity in the large septum aperture, and minimum stray field at the circulating beam orbit. It should also have a thin septum coil especially when it is used as an injection magnet. Then the septum coil should be often operated with high current density under the poor cooling condition due to the structural limitation. Moreover, the magnet is sometimes required to be removable to align the center of the aperture to the extracting beam orbit or to compensate the closed orbit distortion(C.O.D.). Several kinds of septum magnet[1], passive septum magnet or Lambertson septum magnet for example, were designed and fabricated to avoid these difficulties in the septum coil.

In our laboratory a compact septum magnet of ordinary style is designed to have a small bending radius (about 1.9m) and strong magnetic field (1.6T) with small septum width(2.3mm) and to be removable for about 20mm and 10mm in x-and z-directions, respectively. The magnet is also equipped with the water cooling system to remove the power loss in the septum coil and to reduce the shot-

to-shot fluctuation of the magnetic field. The details of the magnet, pulse generator, the magnetic field distribution and other performances will be mentioned in the following sections.

2 Septum Magnet

A septum magnet is designed to extract an 1 GeV electron beam for 21.5 degree with bending radius of 1905mm.[2] The configuration of the magnet is shown in Fig.1. In Fig.1 x is transverse horizontal direction and z is vertical direction. The required magnetic field is 1.6T and the aperture of the septum magnet is $14.7 \times 8.5 \text{ mm}^2$. Both the septum coil and return coil are made from $2.3 \times 8.5 \text{ mm}^2$ and $20.0 \times 8.5 \text{ mm}^2$ OFHC block. The magnet laminations are punched from 0.2mm thick steel plate coated with electrical insulation.

The power loss in the septum coil is expected to be about 180 W/m and the Lorentz force is about 1840 ton. To remove the power loss and to hold the septum coil against the Lorentz force, the septum coil is attached to a water cooled copper plate by thin stainless steel bands of 0.1mm thickness. The bands are equipped in every 50mm along the septum coil. The width of the copper plate becomes wider from 1mm to 5 mm along the beam extraction orbit. A thin kapton tape of 50 micro-meter is used for the electrical insulation of the septum coil.

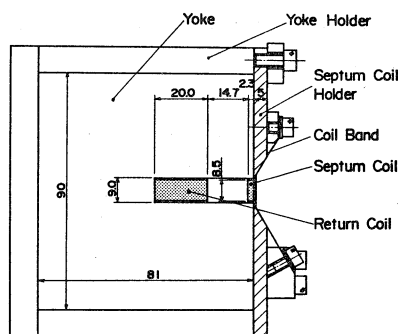


Fig.1. Schematic drawing of the septum magnet.

The magnet is designed to be removable in both x and z direction plane in the vacuum chamber and is mounted on an x-z stage driven by an induction motor installed outside of the chamber. The position is monitored by linear scales to the accuracy of 0.1mm. Two arch shaped thin copper spring plates of 1mm thickness are used as flexible connectors between the coils and the feedthrough fixed to the vacuum chamber.

In the magnet design process, two-dimensional magnetic field calculation are performed using the code TRIM to determine the core size, septum coil crossection and the operating peak current. Then the effects of the eddy current or hysteresis loss are not included.

3 Pulse Generator

The pulse current waveform is a single cycle sine wave of 2msec duration with a peak current value of 12 kA. This pulse duration can provide a flatness of less than 0.1% between 14 micro-seconds at the top of the waveform, which will be long enough for the beam extraction. The primary current pulse is provided by a capacitor(60 mF) discharging pulse generator when the charging voltage is about 100V. A thyristor(SCR) is used as switching device and a diod is also connected anti-parallel to the thyristor for return current from the septum magnet to flow into the capacitor after the turn-off of the SCR. With this diode the circuit can save the capacity of DC power supplier.

4 Stability of the current

The pulse current is monitored by a current transformer of Pearson Electronics, Inc., model 301X. To evaluate the stability of the generator, the peak current data are recorded by ADC of Nippon Atomic Industry Group Co.,Ltd. (E-551A) and multi-channel analyzer of Laboratory Equipment Corporation (MCA-48). The precision of the measurement depends on the number of the MCA channels(4096) and is about 0.025%. The current becomes stable after 15 minutes warming-up period. The dispersion of the pulse current of 3000 shots (1500 sec)is 0.015% and it might be limited by the bit error of an MCA.

A CRT of Tektronics 7104 OSCILLOSCOPE is also used to monitor the current waveform and to measure time jitter of the pulse generator. The result of the current jitter is less than 10nsec.

5 Magnetic Field Profiles

The magnetic field profiles are measured using a small one turn loop probe ($10 \times 1mm^2$), passive integrator and amplifire(Tektronics TM501 POWER MODULE). The probe is manually positioned with x- and z-stage. The probe position is determined by micro-meter to an accuracy of 0.01 mm. The accuracy of the measured field value was limited to 0.1% owing to the fluctuation of the amplifire. The field profiles under DC operation with lower cerrynt are also mesured using a hole probe of $2 mm^2$ detecting dimensions.

Fig.2 shows the measured and designed Bz-field distribution on $z=0mm$ plane. The small probe is placed about 20mm from the entrance of the septum magnet. In fig.3 X_{in} is the distance from the inner surface of the septum magnet. The solid and dotted lines mean the measured and calculated field from TRIM code, respectively. From this figure the measured and design field values are

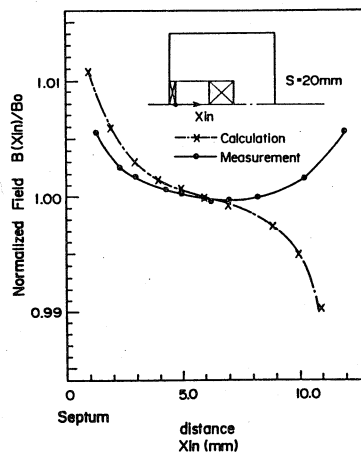


Fig.2. Magnetic field(B_z) distribution along x direction in the septum aperture under pulse operation. Measuring points are about 20mm from the septum entrance. The solid line is the measured value using a loop probe and the dotted one is the calculated value of TRIM code.

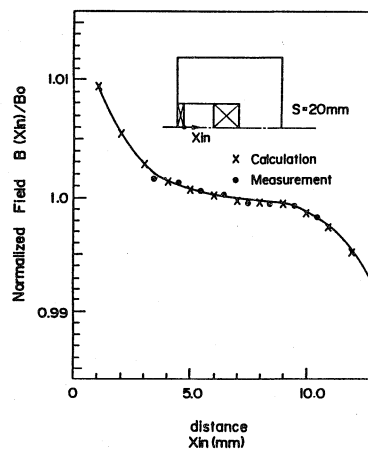


Fig.3 Magnetic field(B_z) distribution along x direction in the septum aperture under DC operation. Measuring points are about 200mm from the septum entrance. The solid line is the measured value using a hole probe and the dotted one is the calculated value of TRIM code.

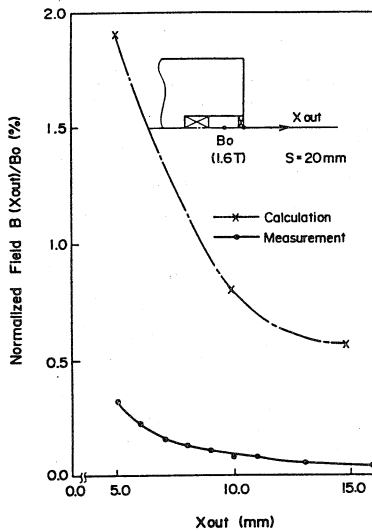


Fig.4. Distribution of the leakage field(B_z) out of the septum coil. The solid line is the measured value using loop probe and the dotted one is the calculated value TRIM code.

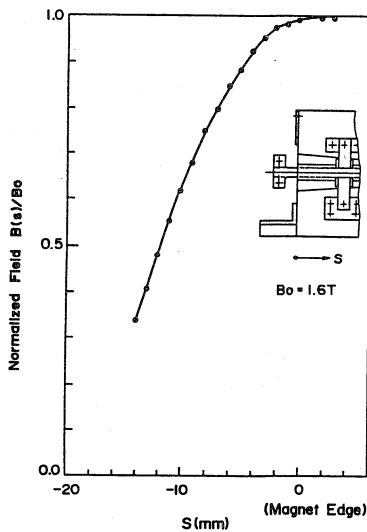


Fig.5. Fringe field(B_z) distribution along the beam orbit.

found to agree near the septum coil, however they differed around the return coil surface. The measured field profile of DC operation showed good agreement with calculated one.(Fig.3) Thus we concluded the mismatch between calculated profile and measured one under pulse operation depends on transient effects such as eddy current. The good field region inside the aperture, having the uniformity of less than 0.2%, is about 10mm. The field near the septum coil was actually 0.5

Fig.4. shows The distribution of the leakage field toward the circulating beam on the $z=0$ mm plane. The measurement is also performed by a small loop probe, placed 20mm from the entrance aperture. X_{out} is the distance from the outer surface of the septum coil. The meanings of solid and dotted lines in Fig.4 are same as those in Fig.2. The measured value is about one sixth of calculated value. The leakage field is weakened by the shielding effect of the copper plate on which septum coil is holded.

A plot of the fringing field at the magnet end along the center of the magnet aperture is shown in Fig.5.

6 Conclusion

By using the copper plate with cooling water pipe, a compact septum magnet is fabricated. The septum coil width is 2.3 mm. The magnetic field at the center of the septum is 1.5 T with the peak current of 12 kA. By measuring the field distribution, the good field region of about 10mm in the septum aperture is obtained. The leakage flux is about 0.1% of the central field and is one sixth of the calculated value by TRIM code. The shot-to-shot fluctuation of the peak current is about 0.02% during 3000 shots. The power loss in the septum magnet can be removed through the kapton tape to the copper plate

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