FIELD MEASUREMENT OF A PULSED SEPTUM MAGNET AS AN R&D FOR SPRING-8

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Abstract

A pulsed septum magnet whose external fields are shielded by eddy currents in the copper septum (wall) was measured. And the shield mechanism was analyzed from measured and calculated data. The stray field was reduced to be small enough for the tolerances by placing a thin silicon steel plate outside the copper septum unless the silicon steel plate become saturated magnetically. We also found a required thickness of copper and steel plate confront to the strength of a gap field and we could find a design plan for the actual magnet.

Introduction

The injection system of the storage ring of SPring-8 is planned to consist of four septum magnets and four bump magnets[1]. The last septum magnet located most downstream from the injection line to the storage ring is the passive type shielding magnet excited with a pulsed current. The external magnetic fields on reference orbit and bump orbit of the storage ring (It is called 'stray fields') is shielded by eddy currents in the septum (wall)[2]. In this type of a septum magnet, the structure of septum (wall) can be simple and its thickness can be small. Actually, the thickness of the septum wall at the exit from injection section is required to be about 1.5 mm to acquire high injection efficiency. In the respect of beam dynamics, the strength of stray fields should be smaller than 30 gauss on the bump orbit, while smaller than 1 gauss on the reference orbit of storage ring is required along the last septum magnet of 700-mm length.

We have made experiments using a existing septum magnet which is similar to the last septum magnet. The aim of our experiment was to estimate the following parameters:
(1) Strength of the stray field against the magnet gap field on the injection orbit (It is called 'the source field'),
(2) Pulse width of an exciting current,
(3) Thickness and structure of septum (wall),
(4) Highest possible strength of the peak gap field.

We measured the strength, time dependence and distributions of magnetic stray fields for various thicknesses, materials of the septum (wall), and pulse widths of the exciting current. Further, we tried to analyze the mechanism of magnetic stray fields induced by eddy currents in the septum (wall).

Apparatus

Septum Magnet

A cross sectional view of the septum magnet is shown in Fig.1. The gap distance is 5 mm, the magnet length is 1 m and the inductance is 6.5 μH. The magnet core is laminated from 0.35mm thick silicon steel plates coated with electrical insulator, and glued with epoxy. And the core is surrounded with copper plates. Three copper plates with thicknesses of 0.8 mm, 1.0 mm, 2.0 mm and a few silicon steel plates (the thicknesses are 0.15mm and 0.10mm) were prepared as the septa(wall).

The bump orbit is located in the distance of 4 mm from the magnet core (x=4 mm) and the reference orbit in 20 mm (x=20 mm) as shown in Fig.1.

Power Supply

The septum magnet is operated with a half-sine pulse of 40-μsec or 100-μsec width produced by discharge of capacitors. The block diagram of the power supply is shown in Fig.2. The maximum peak current are 1100 A for a pulse of 40-μsec width, 2700 A for 100μsec.

Measuring Devices

Magnetic fields were measured by a cylindrical search coil. The coil was wound 35 turns with 0.1-mm diameter copper wire, having the dimensions of 2.66-mm diameter and 2.4-mm height. An induced voltage on the coil by change of magnetic field was measured by a digitizing oscilloscope and was integrated by a personal computer. An exciting current supplied to the magnet was measured by a current transformer and from which the strength of the source field is derived.

Results and Discussions

Time Dependence of Stray Field

A typical time dependence of the source field and the magnetic stray field is shown in Fig.3. When the septum magnet is excited with a pulsed current of 100-μsec width, the gap field (source field) corresponds to exciting current, while the strength of the stray field has a maximum just after an exciting current finish. Fig.4 is the conceptual figure of appearance of stray field. The stray field is given by the subtraction of the field induced by eddy currents on the septum (wall) from the source field.

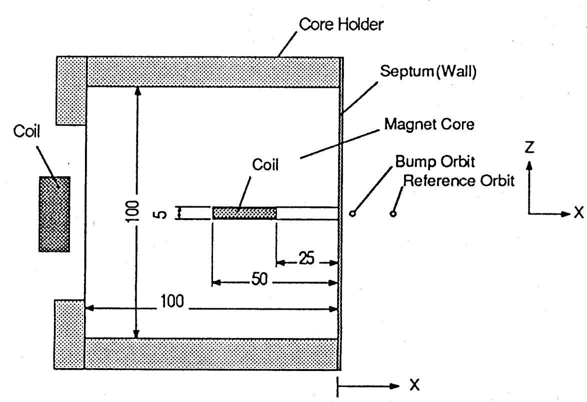

Fig.1 Cross sectional view of the septum magnet.

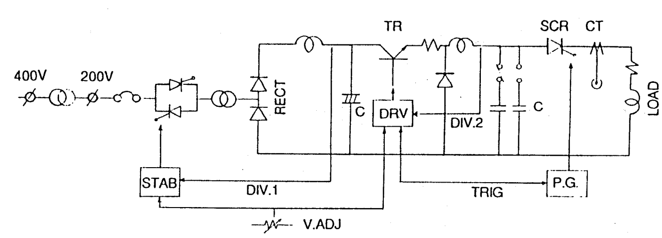

Fig.2 Block diagram of the power supply.

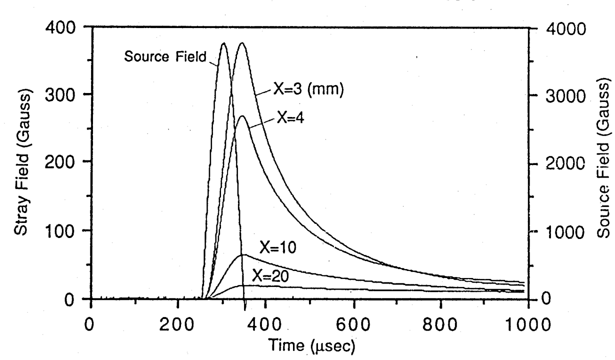

Fig.3 Time dependence of the magnetic stray fields on condition that the septum (wall) is a copper plate of 0.8-mm thickness and the exciting current is a pulse of 100-μsec width.

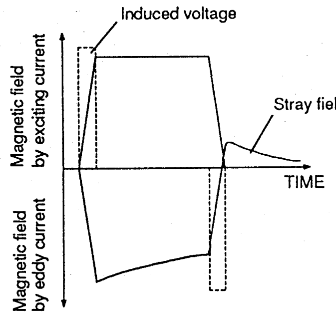

Fig.4
Conception of appearance of stray fields.

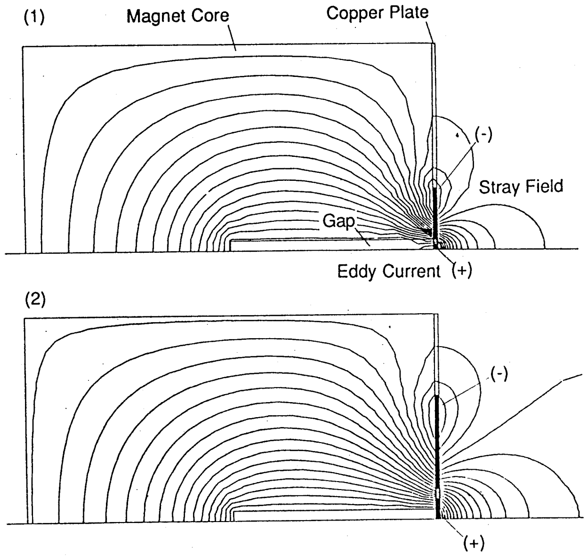

Fig.7 Calculated field lines. The eddy currents diffuse with time from (1) to (2), and the distribution of stray fields changes.

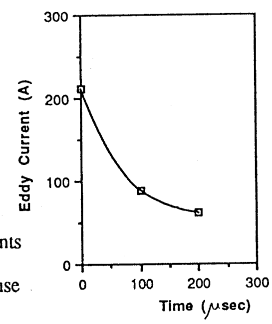

Fig.8
Calculated time variation of eddy currents on the same condition as Fig.6. The decreasing time constant changes because a current circuit diffuse with time.

Variation of the Distribution of Stray Field

Figure 5 shows the change of distribution of the stray fields at the different times. At the beginning [Fig.5(a)], the distribution of stray field is concentrated around a median plane and it is flattened as the time going [Fig.5(b)].

Time variations of distribution of stray fields on the median plane are shown in Fig.6 which was obtained on condition that the septum(wall) is a copper plate of 0.8-mm thickness and the exciting current is a pulse of 100-μsec width. The numerical calculations of stray fields were carried out with two-dimensional program TRIM assuming that the eddy current distributions were illustrated as Fig.7. The line (a) and the line (c) correspond to Fig.7-(1) and Fig.7-(2), respectively. Each amount of an eddy current was determined so that the calculated field strength was equal to the measured one at x=3mm. Good agreement of the experiment and the calculation curves in Fig.6 indicates that the eddy currents diffuse from the position close to the magnet gap toward upper and lower end of the septum(wall).

The calculated time variation of eddy currents is shown in Fig.8. The decreasing time constant changes with time are in the same order of magnitude of the value calculated by resistance and inductance of the equivalent circuit modeled as shown in Fig.7-(1),(2).

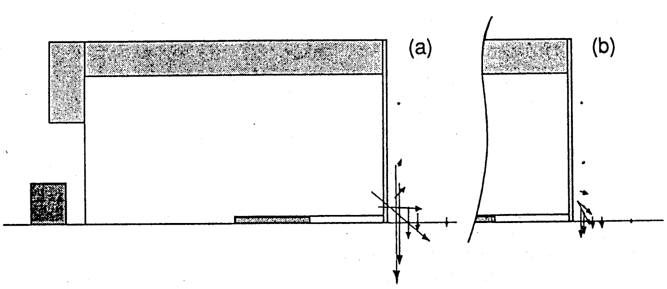

Fig.5 Change of distribution of the stray fields. The exciting current is a pulse of 40-μsec width. (a) is the distribution just after an exciting current finish. (b) is the distribution 180 μsec after.

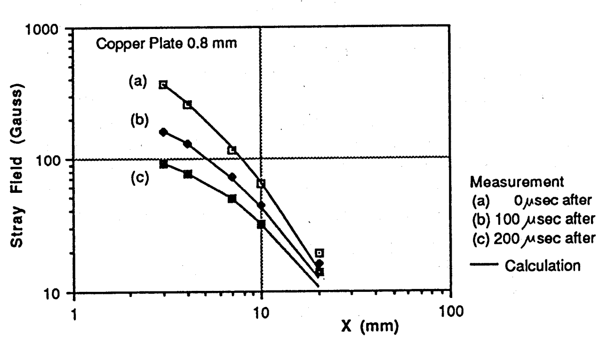

Fig.6 Time variations of distribution of the stray fields on the median plane. Peak strength of source field is 3770 Gauss. Pulse width is 100 μsec. Septum is a copper plate of 0.8-mm thickness. They are measured at several times after an exciting current finish.

Field Shielding with a Silicon Steel Plate outside of the Septum

In order to reduce stray fields, we tried to use a silicon steel plate outside the septum of copper plate.

Time dependence of the stray fields are shown in Fig.9 in case the septum(wall) is the copper plate of 0.8-mm thickness combined with a no-oriented silicon steel plate of 0.15-mm thickness and a exciting current is the pulse of 100-μsec width. Fig.9-(1) shows the strength of the stray fields at the current strength that the silicon steel plate is just saturated magnetically. Fig.9-(2) is under condition that the silicon steel plate is saturated enough. Fig.10 shows the calculated field distributions of the septum magnet with a silicon steel plate outside the copper plate under the same conditions of calculation shown in Fig.7.

If the distribution of eddy currents is assumed as Fig.10-(1), the magnetic field strength in the silicon steel plate is estimated to be about 1.7 tesla in a state of Fig.9-(1). On this condition the silicon steel plate is considered to be saturated.

As shown in Fig.9-(2), the stray field appeared abruptly when the silicon steel was saturated during the rising process of the fields induced by the eddy currents. But on the process of its descent, the stray field continued to exist even after the eddy current became smaller. This is because the distribution of eddy current changes gradually from Fig.10-(1) to Fig.10-(2) and the magnetic fluxes which pass through the silicon steel plate at the side of the median plane increase with time, and the silicon steel plate keeps saturating.

Fig.11 shows measured and calculated time variations of distribution on the median plane in case the septum(wall) consist of a copper and a silicon steel plate. The line (a) and the line (c) correspond to Fig.10-(1) and Fig.10-(2), respectively. The amount of an eddy current in the calculations is the same as used in Fig.6. The calculated distributions approximately agree with the measured ones. If the strength of eddy current is assumed as

Fig.6(c) and their distribution as Fig.7-(1), the calculated value distributes like Fig.11(d). This results does not reproduce the experimental data because the silicon steel plate is not saturated on this condition. Therefore it is considered that the time variation of eddy current distribution in Fig.10 is similar to the actual one.

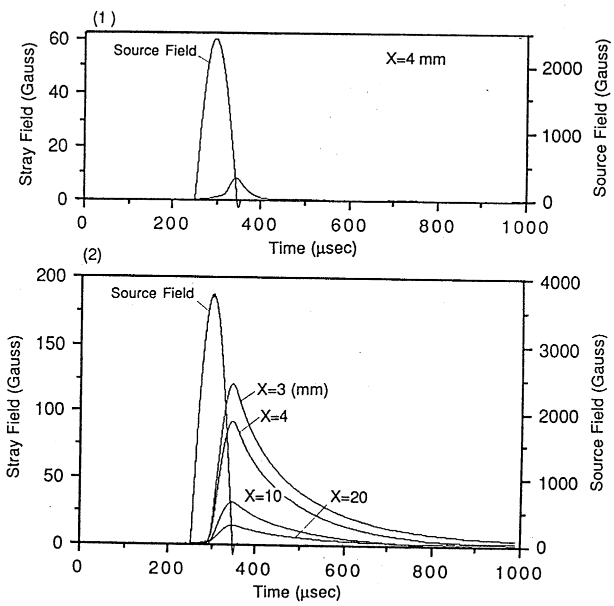

Fig.9 Time dependence of the stray fields on condition that the septum (wall) is the copper plate of 0.8-mm thickness combined with a no-oriented silicon steel plate of 0.15-mm thickness, and the exciting current is a pulse of 100-μsec width. (1) At the current strength the silicon steel plate is just saturated. (2) The silicon steel plate is saturated enough.

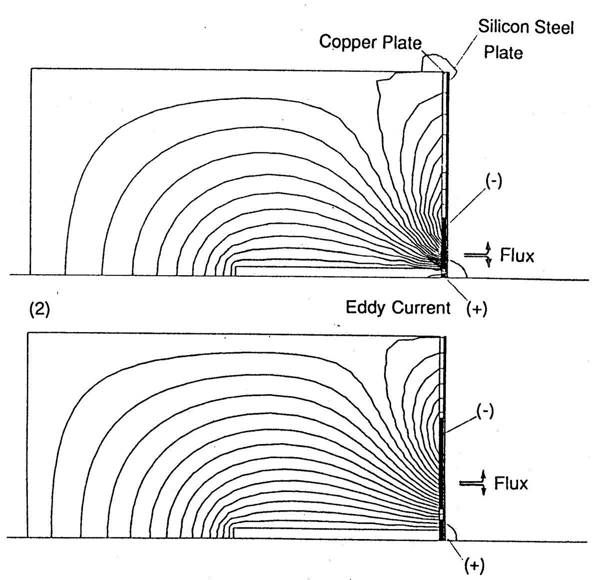

Fig.10 Change of distribution of the magnetic fields due to diffusion of eddy currents. Magnetic fluxes which go through the central part of silicon steel prate are increased with the distribution changes of the eddy currents.

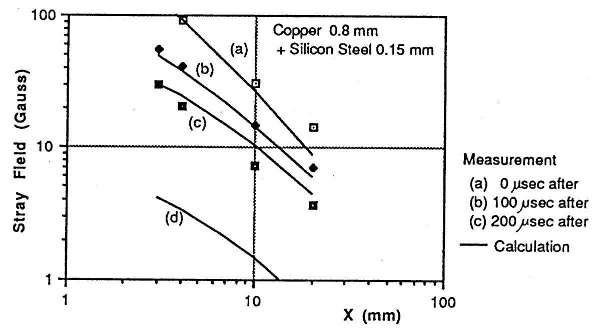

Fig.11 Time variations of distribution of stray fields on the median plane. Conditions are the same as Fig.6 except that the septum is the copper plate of 0.8-mm thickness combined with a silicon steel plate of 0.15-mm thickness.The condition of curve (d) is described in the text.

A Suggestion of Septum Magnet Design

Fig.12 shows the peak strength of the stray fields against the thickness of copper septum(wall). It decreases exponentially with thickness. Fig.13 shows the peak strength of the stray field against the pulse width of an exciting current. It also decreases as the pulse width reduces. We can find the condition that the stray field is smaller enough for the tolerances from Fig.9-(1). A design of the septum magnet in a case that a field strength is 5000 gauss in a gap is suggested by using Fig.12 and Fig.13. Following conditions are required in order not to make the silicon steel plate saturated:

Pulse width : 40 μsec (required for flatness at the peak current),
Thickness of the copper plate : 0.85 mm,
Thickness of the silicon steel plate : 0.15 mm.

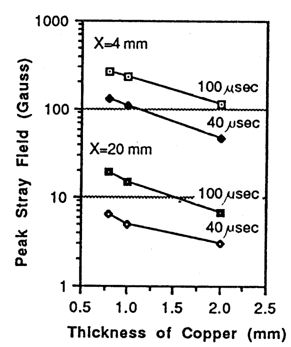

Fig.12 Peak strength of the stray fields on x=4 mm against some thickness of copper septum (wall). Peak strength of the source field is 3770 G.

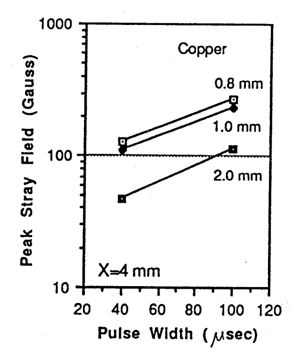

Fig.13 Peak strength of the stray fields against the pulse width of an exciting current. Peak strength of the source field is 3770 G.

Conclusion

We have measured performances of a pulsed septum magnet whose external field are shielded by eddy currents in the copper septum (wall), and analyzed the shield mechanism by comparing measured data with field calculations of TRIM. When a thin silicon steel plate is placed outside the copper septum, stray fields are reduced to be small enough for the tolerances unless the silicon steel plate become saturated magnetically. And we found a required thickness of copper and steel plate confront to the strength of a gap field. On the basis of experimental results we could find a design plan for the actual magnet.

References

[1] JAERI-RIKEN SPring-8 Project Team, SPring-8 Project Part I Facility Design 1991 [Revise]
[2] N.Marks and M.W.Poole, IEEE trans.on Mag. Vol.MAG-17, No.5, P1579 (1981)