LEAKAGE FIELD MEASUREMENTS OF DC SEPTUM MAGNETS FOR THE SPRING8 STORAGE RING

K. Tsumaki, K. Fukami, K. Kajimoto, N. Kumagai, H, Yonehara, SPring-8/JASRI, Hyogo, Japan
T. Shimada, JAERI, Tokai, Ibaraki, Japan

Abstract

We have improved DC septum magnets to reduce leakage field effects on injected and stored electron beams. Saddle-shaped magnet coils were changed to symmetrical coils concerning a median plane. Thickness of the shield of septum plane was increased. Leakage fields were measured by a Hall probe and effects on electron beams were studied.

1 INTRODUCTION

In 1997 electron beams were first injected to the SPring-8 Storage Ring and stored immediately. In the injection process we found that an injection beam was kicked upward by DC septum magnets. We corrected an injection beam orbit by three steering magnets located just upper stream of the septum magnets. But we could not fully correct the injection orbit. Thus we tilted one of the septum magnets to compensate the error kick. This kick comes from the error fields generated by saddle-shaped coils of septum magnets. As injected beams do not pass through the center of the septum magnets, they feel the fields that kick them upwards.

After correcting the injection angle, we studied the effects of septum magnet leakage fields on stored electron beams. Effects of pulse septum magnets were not observed but the stored electron moved about 1 mm when the bump orbit was formed. This is considered to be due to leakage fields of dc septum magnets. For top-up operation it is desirable to suppress this movements as small as possible.

We decided to improve the septum magnets owing to the problems described above. In this paper we describe the improvements of septum magnets, their leakage fields measurements and effects on electron beams.

2 IMPROVEMENT OF DC SEPTUM MAGNETS

2.1 Improvement for Injection Beam

Arrangement of injection magnets is shown in Fig. 1. There are one pulse septum magnet (septum 8) and three dc septum magnets (septum 5, 6, 7). Injected beams were kicked 0.3 mrad by these dc septum magnets. This is due to the coil asymmetry of the magnets concerning a median plane as shown in Fig. 2(a). Electron beams pass through the outer part of the magnets and at both ends of the magnets horizontal field exists except the center of the coils. Then beams are kicked upward by these fields. To avoid this, we need to make the magnet that has a symmetrical coil concerning a median plane. Magnet coils are improved as shown in Fig. 2(b).

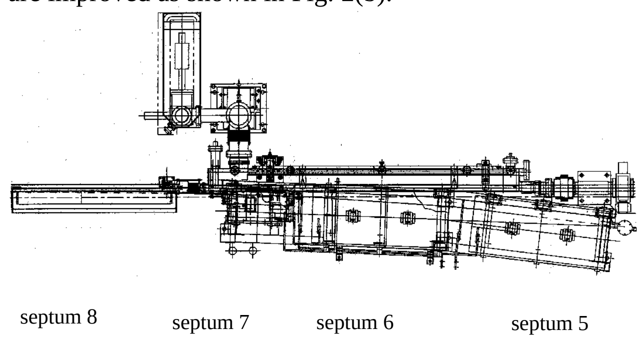
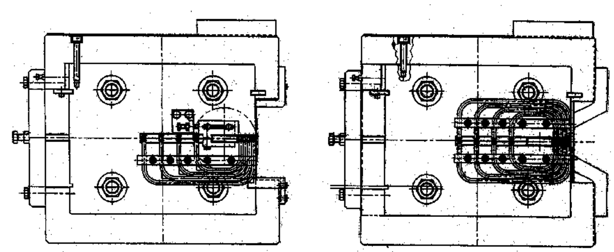


Figure 1: Arrangement of injection magnets.



(a) Before improvement (b) After improvement

Figure 2: DC septum magnet before and after improvement.

2.2 Improvement for Stored Electron Beam

The septum plane was covered with silicon steel plates to reduce the leakage field effects on the stored electron. But the thickness of steel plate was not enough and the both ends of the coils were not covered with shield plates. Thus we made field clumps at both ends of magnets and silicon steel plates were extended to the clumps. Shield thickness was determined by measuring leakage field strength.

2.3 Tolerance of Leakage Fields

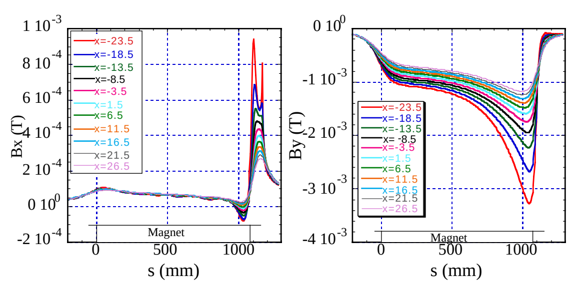
We set a goal of 0.54×10^{-4} T*m for vertical and 0.064×10^{-4} T*m for horizontal integrated leakage fields, which correspond to the orbit change of 10 % of the beam size at insertion device section.

3 LEAKAGE FIELD MEASUREMENTS BY HALL PROBE

Magnetic fields were measured by three-dimensional Hall probe that was set on a three-axes pulse drive movement equipment. Leakage fields were measured parallel to the beam line from septum wall to 50 mm points from septum wall.

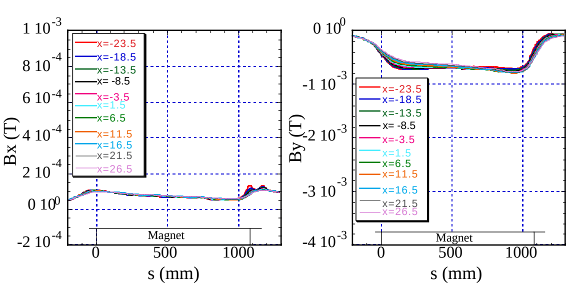
The magnetic shields for septum 7 consist of three sections: Downstream shield is a 0.5 mm thick plate, middle part has 1 mm thickness (0.5 mm x 2) and upstream shield has 2 mm thickness (0.5 mm x 4), while the shield for septum 5 and 6 are single long plates, the thickness of which is 2 mm (0.5 mm x 4). Measurements were done with these shields. Results for septum 6 is shown in Fig. 3. Since measured leakage fields did not satisfy the tolerances, we increased the shield thickness. For septum 7 we changed the shield plates so as not to make the boundary between the plates that makes the leakage of the fields; thickness of the thinnest part is 1 mm at downstream section and shield thickness gradually increases and it becomes 4.5 mm at the end of the magnet. For septum 5 and 6, thickness of the septum shield was increased to 3 mm (0.5 mm x 6).

Leakage fields were measured with these shield plates. Results for septum 6 are shown in Fig 4. These leakage fields were integrated along the beam line. Figures 5 and 6 show the integrated leakage fields for initial thin shield and final thick shield. Stored electron orbit change is due to the field difference between the central orbit (x = 0) and bump orbit (x = -14.5). Then it is important to reduce this difference.



(a) Horizontal (b) Vertical

Figure 3: Leakage fields of septum 6 magnet before increasing the shield thickness. x = 0 is the central orbit.



(a) Horizontal (b) Vertical

Figure 4: Leakage fields of septum 6 magnet after increasing the shield thickness.

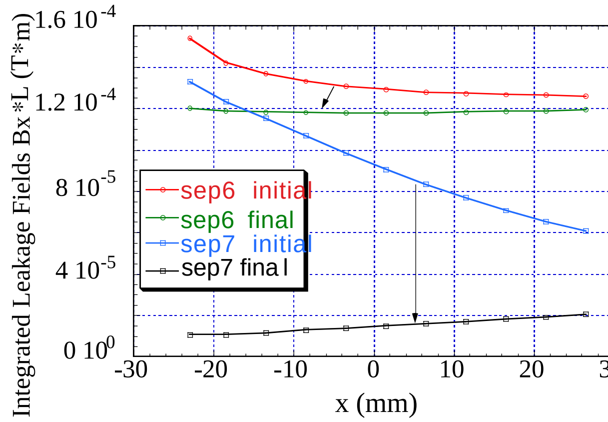


Figure 5: Horizontal component of integrated leakage fields. The central orbit is x = 0 and the bump orbit is x = -14.5.

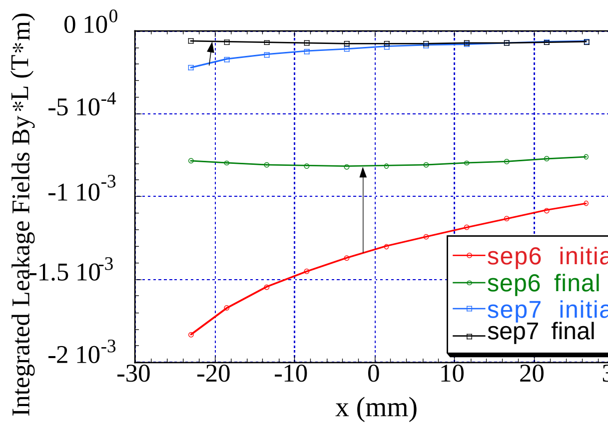


Figure 6: Vertical component of integrated leakage fields.

The difference of integrated fields between the bump and central orbit is summarized in Table 1. Total leakage fields ΔByL and ΔBxL correspond to the orbit change of 6 % of horizontal beam size and 5 % of vertical beam size, respectively.

Table 1: Difference of integrated field strength.(unit: T*m)

	septum 5	septum 6	septum 7	Total
ΔByL	-0.45×10^{-4}	0.07×10^{-4}	0.06×10^{-4}	-0.32×10^{-4}
ΔBxL	-0.005×10^{-4}	0.006×10^{-4}	-0.03×10^{-4}	-0.029×10^{-4}

4 LEAKAGE FIELD EFFECTS ON ELECTRON BEAMS

The orbit change of stored electron was measured by changing the bump height. The bump orbit was formed by four steering magnets and the closed orbit was measured by changing the septum magnet current; bump height was changed from 10 mm to -10 mm and for every 5 mm bump height change, septum current was changed from 0 to 2460 ampere and the closed orbit was measured.

Closed orbit distortion (cod) is expressed as follows when four steering magnets form the bump orbit.

$$cod(x,I,t) = cod_0+cod_{sep}(x,I)+cod_{st}(x)+cod_{sext}(x)+cod_t(t) ,$$

where cod_0 , $cod_{sep}(x,I)$, $cod_{st}(x)$, $cod_{sext}(x)$, $cod_t(t)$ are the original cod, cod generated by the leakage field of septum magnets, cod generated by the four steering magnets, cod generated by the nonlinear effect of sextupole magnets that are located in a bump area and time dependent variation of cod, respectively. The value we want to obtain is $cod_{sep}(x_b,I)-cod_{sep}(x_0,I)$ that correspond to the difference of integrated fields between central orbit and bump orbit. Here x_b is the bump orbit and x_0 is the central orbit. To obtain $cod_{sep}(x_b,I)-cod_{sep}(x_0,I)$, we subtract $cod(x_0,I,t)-cod(x_0,0,t)$ from $cod(x_b,I,t)-cod(x_b,0,t)$. Then,

$$\{cod(x_b,I,t)-cod(x_b,0,t)\}-\{cod(x_0,I,t)-cod(x_0,0,t)\}=$$
$$\{cod_{sep}(x_b,I)-cod_{sep}(x_0,I)\}-\{ cod_{sep}(x_b,0)-cod_{sep}(x_0,0)\}+cod_t \ .$$

Assuming the second and third term of the right side is small, we can obtain $cod_{sep}(x_b,I)-cod_{sep}(x_0,I)$. Obtained results are shown in Figs. 7 and 8. Calculation of cod was done so as to give the equal standard deviation with the experimental results. From the calculation of cod leakage fields are obtained as $\Delta ByL=3.31\text{x}10^{-4}$ T*m and $\Delta BxL=0.31\text{x}10^{-4}$ T*m, which correspond to the orbit change of 61 % of horizontal beam size and 48 % of vertical beam size.

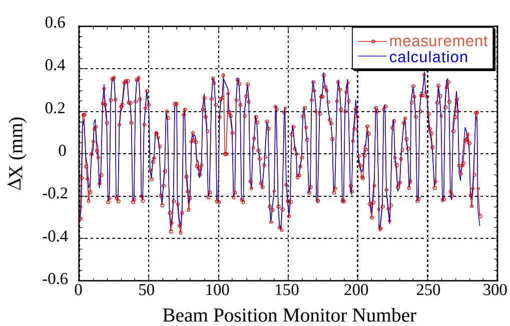


Figure 7: Measured and calculated cod for horizontal direction.

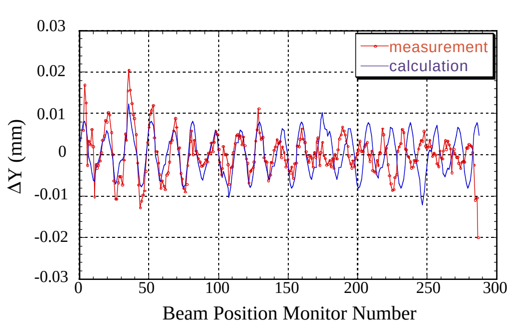


Figure 8: Measured and calculated cod for vertical direction.

5 DISCUSSION

Estimated leakage fields obtained from the beam measurement are six and five times larger than our goal and they were about ten times larger than Hall probe measurement results. We can consider two reasons for these differences. First is the change of leakage fields due to environments. We reduced the difference of leakage fields between the central orbit and bump orbit by reducing the position dependence of integrated field along the beam line perpendicular to the beam orbit as well as reducing the strength of integrated fields. Magnetic field measurement by a Hall probe was done with ideal condition: There was no vacuum chamber, no distributed NEG pump, no cable, and no vacuum gauge. But actually those equipment are arranged around the septum magnets. There is a possibility that the field distribution is changed owing to these equipment and field balance is lost. The second is the error of measurement by electron beams. Small cod is generated when four steering magnets form a bump orbit. There are 12 sextupole magnets on a bump orbit, which give nonlinear effects on stored electron beams. These effects also generate a closed orbit distortion. There is also time dependent fluctuation of cod. These effects are superimposed and can not be separated each other, which makes it difficult to evaluate the leakage fields by stored electron. Field measurement around the chamber may give the important information whether the fields were changed or the measurement by stored electron gives large errors.

6 CONCLUSIONS

We have improved the DC septum magnets. The saddle-shaped magnet coils were changed to the symmetrical coils concerning a median plane. Thickness of the magnetic shield plates was increased to reduce the leakage field effects on the stored electron beams. We have measured the leakage fields by a Hall probe and studied the effects on stored electron beams. Measurements by a Hall probe showed that the integrated leakage fields is $0.32\text{x}10^{-4}$ T*m for vertical and $0.029\text{x}10^{-4}$ T*m for horizontal component. These values give the orbit changes of less than 10 % of their beam sizes at insertion device sections. But the cod variations give $3.31\text{x}10^{-4}$ T*m and $0.31\text{x}10^{-4}$ T*m leakage fields for vertical and horizontal component, respectively, which correspond to the orbit change of 61 % and 48 % of horizontal and vertical beam size at insertion device section.

7 ACKNOWLEDGEMENTS

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