Transient Characteristics of a Solid Sector Bending Magnet for Use in Compact Storage Ring

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Abstract

In a solid sector bending magnet, the magnetic field is disturbed due to eddy currents induced in the solid iron core during excitation. A solid 30 degree sector magnet was fabricated and the magnetic field distribution within its good field region was measured for various excitation rates. The influence of eddy currents was evaluated by comparing the transient distributions with static ones. It could be shown from the results that the magnetic field generated by eddy currents was almost the dipole component while the quadrupole and the sextupole components were nearly independent of accelerating time.

1. INTRODUCTION

Since a solid sector bending magnet can generate a higher magnetic field compared with a conventional laminated one, choice of the solid sector type is preferable to make a storage ring compact. However the solid sector type has a serious problem that the magnetic field is disturbed due to eddy currents induced in the solid iron core during excitation. Therefore bending magnets of this type are usually adopted in a storage ring with full or medium energy injection.[1][2]

In this paper, the influence of eddy currents during acceleration was investigated in order to discuss the possibility of applying solid sector bending magnets to an acceleration ring with low energy injection.

2. MEASUREMENT OF MAGNETIC FIELD

2.1 Method

A solid 30 degree sector magnet with 1.5 Tesla and n-index of 0.75 was fabricated. Main parameters of the magnet are summarized in Table 1. The magnetic field at eleven points within its good field region were measured simultaneously. The good field region is from -50 mm to +50 mm and the measuring pitch is 10 mm.

Measurement of the magnetic field was carried out using a probe shown in Figure 1. The probe consists of eleven Hall sensors on a board. Current leads and voltage leads for each Hall sensor were wired using printed-circuit technique in order to avoid picking up induced voltage and to make accurate setting of sensors. In addition to these Hall sensors, a thermocouple(CC), a thermister and a heater were mounted on the board to control Hall sensors' temperature constant.

Figure 2 shows the magnetic field measurement system. The output voltage of eleven Hall sensors was measured and saved in two analysing recorders whose sampling time was synchronized by a function generator. The acquired data were analysed into each magnetic component with the least squares method built in a PC. Excitation pattern of the DC source for the magnet was given by another PC. Six excitation patterns (accelerating times of 30, 50, 100, 200, 300 and 500 seconds) were employed in our test.

Table 1 Main parameters of the bending magnet

Type	solid sector type
Material of iron yoke	low carbon steel
Bending angle (degree)	30
Magnetic field (Tesla)	1.5
n-index	0.75
Pole gap length (mm)	56

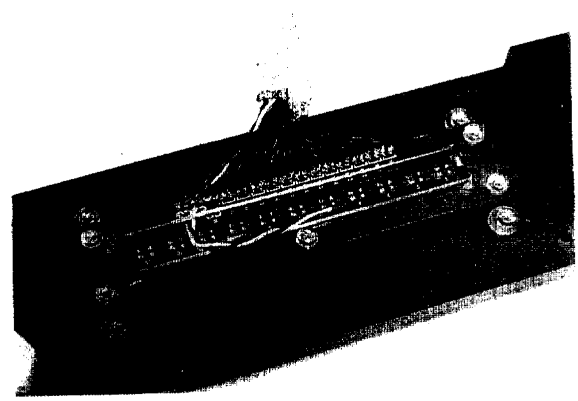

Figure 1 Probe for magnetic field measurement

2.2 Magnetic Field at the Cross Section

The magnetic field was measured at various locations. Figure 3 shows the typical measurement results at the cross section of the magnet. Figure 3(a), 3(b) and 3(c) present the magnetic field distributions at 15 degrees from the magnet's edge (center of the magnet), at 1 degree from the magnet's edge (near the edge) and outside, 70 mm from the magnet's edge, respectively. In Figures 3(a), 3(b), 3(c), the thick solid line with open circles shows the static results and other lines indicate transient ones.

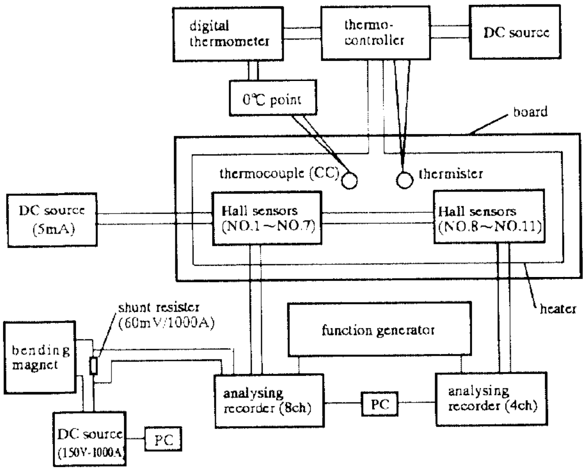

Figure 2 Block diagram of measurement system

In Figure 3(a), 1.5 Tesla at x = 0 and n-index of 0.75 are in good agreement with the designed values. The magnetic field strength becomes smaller as accelerating time shortens. Moreover, the magnetic field distributions are removed nearly parallel to the static one. This indicates that the dipole component reduces but the quadrupole component remains approximately constant as mentioned below.

In Figure 3(b), the magnetic field strength becomes lower and the distributions are also disturbed.

In Figure 3(c), the magnetic field reduces and n-index is almost zero. Since both ends of measured curves are downward, appearance of a negative sextupole component is considered.

2.3 Each Component of the Magnetic Field

The influence of eddy currents was evaluated by comparing the transient distributions with static ones. The magnetic field is expanded in the dipole, the quadrupole, the sextupole and the higher components on the median plane by the following equation:

$$B = B_0 + (dB/dx)\,x + (1/2)(d^2B/dx^2)\,x^2 + \cdots, \qquad \cdots(1)$$

where B_0 is the dipole component. The n-index is expressed using the quadrupole component as

$$n = -(\rho/B_0)\,(dB/dx), \qquad \cdots(2)$$

where ρ is the bending radius. The sextupole component in Figure 4(c) is expressed as

$$m = (1/B_0\,\rho)\,(d^2B/dx^2). \qquad \cdots(3)$$

The higher order components over octupole were ignored here because they were negligibly small.

Each component was calculated as a function of accelerating time. Figure 4(a), 4(b) and 4(c) present results of the dipole, the quadrupole and the sextupole components, respectively.

In Figure 4(a), ΔB is the difference between the transient magnetic field strength and the static one, and corresponds to the dipole field component induced by eddy currents. The result of $\Delta B/B$ indicates that eddy currents have much influence on the dipole component as accelerating time becomes less than 100 seconds.

The results in Figure 4(b) show that n-index of the transient magnetic field is nearly the same as that of the static one independent of accelerating time. This means that a ring's tune variation due to eddy currents seems to be small during beam acceleration.

The sextupole component presented in Figure 4(c) is very small and includes measurement errors, especially for shorter accelerating times. It is considered that the sextupole component is nearly independent of accelerating time same as the quadrupole component and is easily compensated by sextupole magnets located in a storage ring.

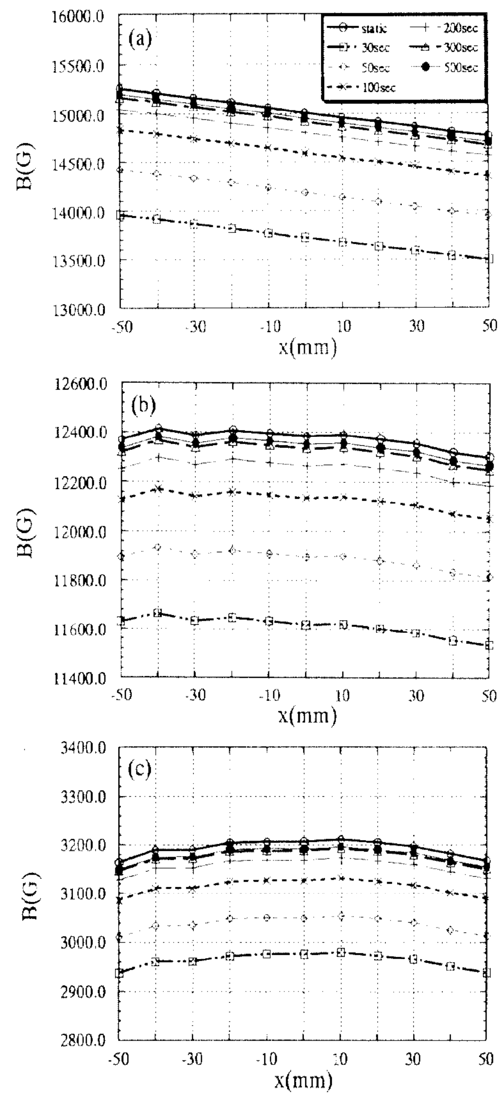

Figure 3 Magnetic field at cross section, (a) 15 deg. from magnet's edge, (b) 1 deg. from magnet's edge, (c) outside of magnet.

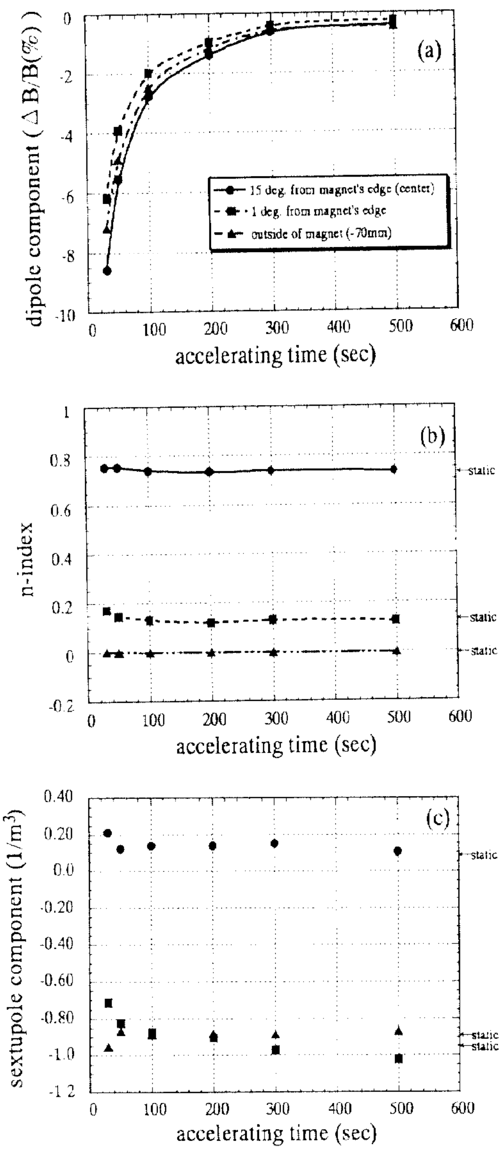

Figure 4 Each component of the magnetic field, (a) the dipole component, (b) the n-index, (c) the sextupole component.

3. TRANSIENT MAGNETIC FIELD ANALYSIS

3.1 Method

Transient magnetic field analysis was carried out using a linear two-dimensional FEM code. The cross section used in this analysis was exactly the same as the actual one but the length was considered as infinite. However, this infinite approximation had hardly any influence on the calculated results because the pole length was large enough compared with the pole width. The relative permeability was kept constant at 1000 regardless of the magnetic field strength in the iron core. The excitation patterns of DC source used in this analysis were also the same as actual ones.

3.2 Results

Figure 5 shows the computed dipole component as a function of accelerating time. In Figure 5, solid line with circles presents computed values and squares mean measured values. The computed values are almost in agreement with the measured ones, though some errors are observed in the case of the shorter accelerating time. This indicates that the linear two-dimensional analysis can be applied to evaluate the dipole component within allowable errors. Since the quadrupole component strongly depends on the magnetic field distribution in the iron core, it is impossible to apply this code to calculate the quadruplole component. If a non-linear transient FEM code could be available, it can be applied to analyse the quadrupole and higher components.

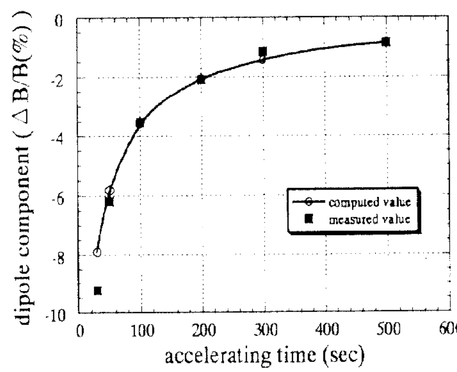

Figure 5 Comparison between analysis and experiment (dipole component)

4. CONCLUSION

The dipole component of the magnetic field was affected largely by eddy currents as accelerating time shortened. On the other hand, the quadrupole and the sextupole components of the magnetic field were hardly affected by eddy currents. Therefore, when the accelerating time is not so short, excitation patterns of quadrupole magnets in a storage ring can be determined, only considering the dipole component reduction due to eddy currents. We conclude from the above results that excitation current tracking between the two components is possible and solid sector bending magnets can probably be applied to a compact storage ring with low energy injection.

5. REFERENCES

[1] T.Tomimasu et al., Proc. 6th Symp. on Accelerator Science and Technology, Tokyo (1987) p.53

[2] M.Yokoyama et al., Proc. 8th Symp. on Accelerator Science and Technology, Saitama (1991) p.16