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Manufacture and Arrangement of Bending Magnets of SPring-8 Synchrotron

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1. Introduction

The booster synchrotron of the SPring-8 has a circumference of 396.12 m with a FODO lattice of 40 unit cells. The synchrotron ring contains 64 bending magnets. Basic ability have been test for a preceding magnet. Manufacture of bending magnets have been finished on July in 1995. Field measurements have been performed for all magnets. Based on this results, we discussed sorting of 64 bending magnets in the synchrotron ring to suppress horizontal closed orbit distortion (C.O.D.). Horizontal C.O.D. was calculated by means of the code "SYNCH". In case of the magnets are arranged consideration the phase of betatron oscillation, the C.O.D. decrease to about 1/7 in comparison with the C.O.D. without the above mentioned consideration.

2. Field Measurement

Energy of a electron is increased from 1 GeV to 8 GeV in 0.4 sec by the synchrotron. Following the ramping of the energy, the excitation current of bending magnets were increased by eight times. To estimate the hysteresis of bending magnet, excitation was measured for three preceding magnets. The excitation were measured by means of NMR probe at the center of the pole. It was verified that the magnetic field was nearly in proportion to excitation current within 0.2 % of linearity. Field distribution were measured with a hall-probe for two excitation current (are equivalent to 1 GeV and 8 GeV). Horizontal field distribution and integrated field are shown in Fig.1 and 2, respectively. For three preceding magnets, the variation of the former and the latter were less than 2×10^{-4} and 1×10^{-3} for the range of $\pm$ 30 mm, respectively.

The integrated field was measured for three excitation current (are equivalent to 1 GeV, 4 GeV and 8 GeV) by means of long-flip coil for all bending magnets. The coil has 12 mm width, 3600 mm length and 3 turn. It is flipped by 180 deg during 5 ~ 20 sec. The integrated field was measured along straight line. Consequently, the measurements were performed at 18 mm in the direction of the outside of electron orbit at edge of the pole because sagitta of bending magnet is 35.6 mm. Since the measurement was performed for a half year, a reference magnet was measured in every measurement of a sample magnet to keep long term stability. The deviation from the

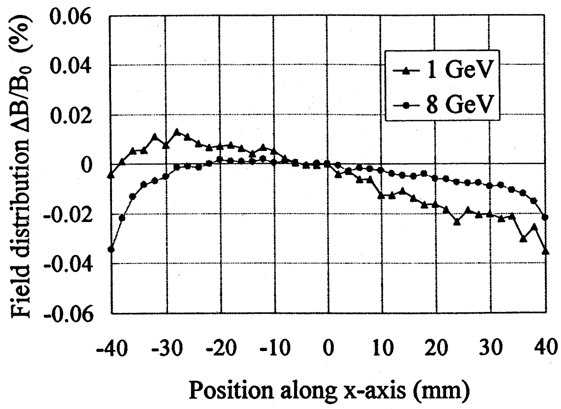

Fig.1 The cross sectional distribution against horizontal position at the center of the pole.

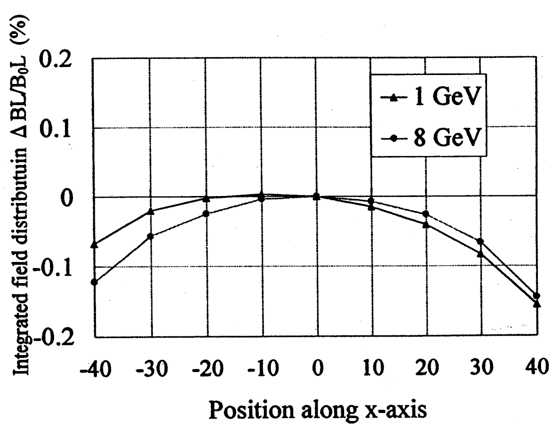

Fig.2 The integrated field distribution against horizontal position.

average for all bending magnets were obtained as an instrumental error. The instrumental error was less than $\pm 8 \times 10^{-4}$ for three excitation current. Histogram of the instrumental error for 1 GeV was shown in Fig.3. The instrumental error were divided into eight classes of "A" ~ "H".

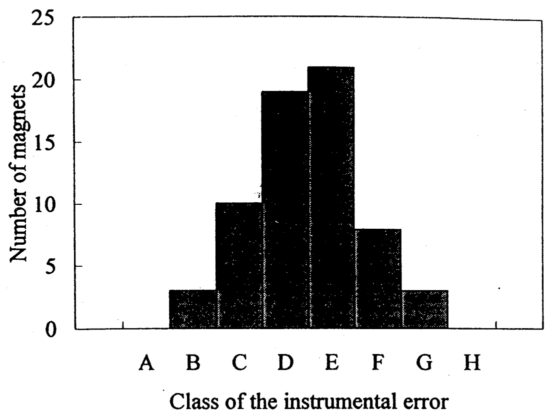

Fig.3 Histogram of the instrumental error of integrated fields. The symbols of "A" ~ "H" indicate the class of instrumental error. Where, A: -0.08 ~ -0.06 (%), B: -0.06 ~ -0.04 (%), C: -0.04 ~ -0.02 (%), D:-0.02 ~ 0 (%), E: 0 ~ 0.02 (%), F: 0.02 ~ 0.04 (%), G: 0.04 ~ 0.06 (%) and H: 0.06 ~ 0.08 (%).

3. Arrangement of the magnets

All bending magnets are excited serially make use of one power supply. Thus, horizontal C.O.D. is generated by the field error of bending magnets. The instrumental error is equal to the field error of bending magnets. Let the direction of electron beam as the s coordinate axis, horizontal C.O.D. x(s) is shown as [1],

$$x(s) = \frac{\sqrt{\beta(s)\beta(s_1)}}{2\sin\pi\nu}\cos\{\pi\nu+\mu(s)-\mu(s_1)\} \times (\Delta B/B)\,\theta \qquad (3\text{-}1)$$

where, s_1 is position of the field error, $\beta(s)$ is beta function (m), $\mu(s)$ is phase advance (rad), ν is horizontal tune, $\Delta B/B$ is the field error and θ is bending angle (rad). From eq. (3-1), a sign of x(s) changes as phase advance to be 180 deg. We assume that the field error is generated at the center of the magnet. If two magnets with same instrumental error were arranged at distance is equivalent to 180 deg, kicked electron by first magnet is returned to design orbit by second magnet. The C.O.D. is canceled except for an interval of two magnets.

3-1 Arrangement of two pairs of magnets

Since horizontal tune is designed to be 11.73, the phase advance of betatron oscillation to be ~ 105 deg every one cell. A number, k, of cells is equivalent to about 180 deg phase advance are k = 2,5,12,15,19,22,29,36,39 cells. Distance of two magnets should be short because the C.O.D. remain for an interval of two magnets. It is wished that the phase advance is closer to 180 deg. In this reason, two magnets were arranged with separation distance 5 cells (call first pair).

In order to cancel remained C.O.D., a pair of magnet with opposite sign were put (call second pair). There are two bending magnets every one cell in a normal cell because of a FODO lattice. Let the position of the magnet of upstream in n th cell and that of downstream in n th cell are (n,u) and (n,d), respectively. The first pair were put (n,d) and (n+5,d) and the second pair were put (n+1,u) and (n+6,u). Since the phase advance is approximately 26 deg from (n,d) to (n+1,u), the remained C.O.D. decreases to less than 1/2.

To confirm the above mentioned discussion, the C.O.D. was calculated by SYNCH with following three cases.

(1) One magnet with $\Delta B/B = -0.05$ % was put at (4,d).

(2) First pair of magnets with $\Delta B/B = -0.05$ % were put at (4,d) and (9,d).

(3) Add second pair of magnets with $\Delta B/B = +0.05$ % were put at (5,u) and (10,u) to case (2).

In case of (1), maximum of the C.O.D. was 0.33 mm and root mean square (r.m.s.) of the C.O.D. was 0.18 mm. In case of (2), r.m.s. of the C.O.D. decrease to 0.09 mm. However, maximum of the C.O.D. was 0.45 mm for the interval of two magnets. Thus, the C.O.D. was remained for the interval. In case of (3), maximum and r.m.s. of the C.O.D. were obtained to be 0.16 mm and 0.04 mm, respectively. It was confirmed that the C.O.D. was decreased to about 1/3 for the interval of the first pair due to insert the second pair.

3-2 Arrangement of all magnets

Electron beam size is maximum at 1 GeV and become minimum at 8 GeV [2]. To suppress the C.O.D. at 1 GeV, 64 magnets were arranged based on the result for 1 GeV. For example, two magnets which were taken from class of "B" in Fig.3 (first pair) were put at the position of (3,d) and (8,d). The second pair were selected from class of "G" and were put at the position of (4,u) and (9,u).

Horizontal C.O.D. was calculated at the

upstream of every quadrupole magnets (location of monitors) by "SYNCH". The C.O.D. against the monitor number was shown in Fig.4 by the solid line. Maximum and r.m.s. of the C.O.D. were 0.35 mm and 0.10 mm, respectively. For comparison, the C.O.D. was also shown in Fig.4 by the dotted line when the magnets were put according to the order of production of magnets. In this case, maximum and r.m.s. of the C.O.D. were 1.71 mm and 0.69 mm, respectively. These results show that the C.O.D. was decreased to about 1/7 by discussion of section 3-1.

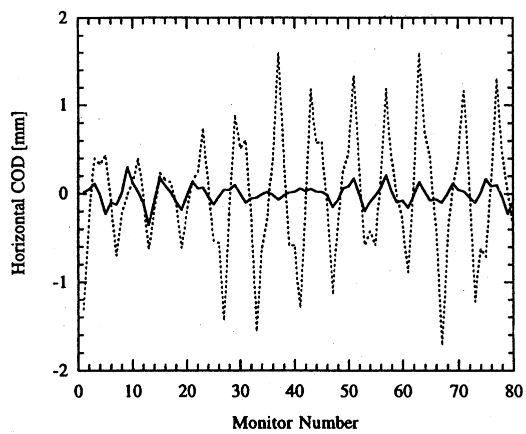

Fig.4 Horizontal C.O.D. against the monitor number. Monitor number 1 indicates the position of the inlet of first quadrupole magnet from the injection point of electron beam. Eighty monitors are equivalent to a circumference of the synchrotron. The solid line indicate the C.O.D. for the magnets are arranged consideration the phase of betatron oscillation. The dotted line indicate the C.O.D. without the above mentioned consideration.

4. Conclusion

Integrated field were measured for all bending magnets of synchrotron. The variation of integrated field was less than $\pm 8 \times$ 10-4. We decided the arrangement of bending magnets based on the result to suppress horizontal C.O.D.

References

1) OHO '88 (1988) pIII-2.
2) JAERI-memo 04-289 (1992).