Magnet girder for the SPring-8 Storage Ring

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Abstract

We designed a magnet girder for the SPring-8 Storage Ring paying special attention to its rigidity and positioning equipment. 144 girders were fabricated and installed in a storage ring tunnel. Smooth and accurate positioning was successfully achieved. The details of the magnet girder design are described.

1 INTRODUCTION

Electron beams in the third generation synchrotron radiation sources are strongly focused by quadrupole magnets to obtain low emittance beams. Resultantly field strength of quadrupole and sextupole magnets are higher than the first or the second generation radiation sources. Due to these strong field magnets, the sensitivity against errors of the third generation synchrotron radiation sources is higher than the common storage ring. For example, sensitivities of the SPring-8 storage ring against the random quadrupole misalignment are 126 and 84 for horizontal and vertical direction respectively. Therefore it is needed to reduce the sensitivity, while keeping the small emittance.

To meet this requirement we proposed a new alignment method[1]; We treat the quadrupole and sextupole magnets between the bending magnets as a unit and align their magnetic center on a straight line precisely. Kicks due to misalignment of quadupole magnets then cancel each other within a unit. Actually girder plays a role of unit.

In this alignment method the girder is not simply a base of a magnet but has an important meaning; The girder is like a long single magnet in which the opposite polarity magnets are mounted precisely. In this case the required characteristics for the girder is that the magnets on a girder can be adjusted precisely and the girder has a high rigidity not to deteriorate the alignment accuracy after aligning the magnets on a girder.

We designed girders to meet these requirements and alignment was done successfully. Closed orbit distortion without orbit correction is small and betatron oscillation coupling after orbit correction is also small. In this paper we describe the details of the magnet girder for the SPring-8 Storage Ring.

2 ALIGNMENT METHOD AND REQUIRED PERFORMANCE

Magnet lattice for the SPring-8 Storage Ring is the Double Bend Achromat (Chasman Green) type. Different from the FODO lattice, quadrupole and sextupole magnets are placed in a short distance between bending magnets. If we can align the magnetic center on a straight line with high accuracy and phase advance in the unit is small, magnetic force that distorts electron orbits can be cancelled.

Magnet lattice has 10 quadrupole and 7 sextupole magnets and three straight sections in a cell. We decided to place the magnets on three straight girders corresponding to three straight sections in a cell and align the magnetic center on a straight line. By this alignment the magnetic force that generates closed orbit distortion is canceled within a girder even if the girder alignment is not accurate. Alignment between the girder is done by constructing the network as usually done for magnet alignment.

To realize this alignment method the girder is required to have enough rigidity not to deteriorate its straightness after aligning the magnets. We determined the tolerance of girder straightness to be ± 10 μm that is enough small compared with the tolerance of magnet alignment. It is also important to have positioning equipment by which the smooth and accurate positioning can be done. If we take enough time for alignment, we may align the magnet to some extent. However we had 144 girders and approximately 1000 magnets to align. We needed to accomplish alignment efficiently in a short time. Therefore simple and accurate adjustment equipment was required. We set the adjustability accuracy of ± 50 μm for magnet girder positioning equipment and ± 10 μm for magnet positioning equipment.

3 DESIGN PRINCIPLE

Girders for string test had been constructed before the new girder design started. We tested this girder and following results were obtained[2].

- Horizontal girder rigidity is not sufficient.
- Friction of slide plane of girder is large and smooth positioning is difficult.
- Positioning equipment for magnet pushes a magnet directly, which distorts magnets.
- Vertical and horizontal movement are coupled for the vertical positioning of magnet.

Taking these results into account, we designed a new girder with following design principle.

- Increase the horizontal girder rigidity.
- Reduce the friction of slide planes.
- Avoid to push the magnet directly.
- Employ the adjustment equipment which does not couple the horizontal and vertical movement.
- Employ the six-legged girder to increase the natural frequency of girder.

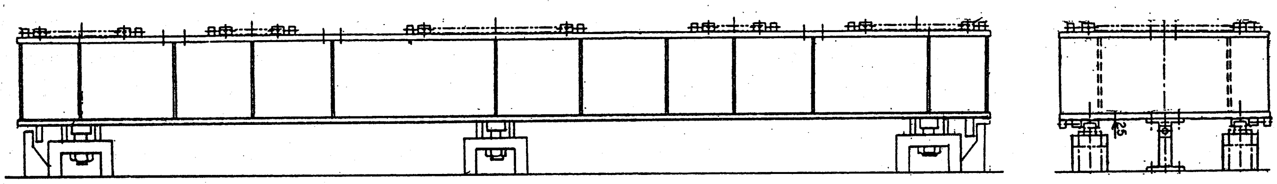

Fig. 1 Magnet girder for the SPring-8 Storage Ring.

4 GENERAL STRUCTURE

As shown in Fig. 1, a girder has a box structure and six legs. Positioning of the girder is done by equipment shown in Fig. 2 and 3. Vertical positioning is done by rotating six bolts that are used as support of girder. Horizontal positioning is done by rotating the bolts that locate the same position as the vertical positioning equipment. Longitudinal positioning is done by two pieces of equipment that are set in both ends of the girder.

Magnet positioning equipment is shown in Fig. 4. Magnet is placed on a board and by pushing this board magnets are positioned for horizontal and longitudinal direction. Vertical positioning is done by rotating bolts.

Three girders in a cell are named A, B and C. A and C girder are the same and the length is 3950 mm. Length of B girder is 5034 mm. In addition to these girders we have made 8 girders for the magnet rearrangement of the 30 m long straight sections in the summer of 2000. The structure is the same as the old girders but the length is 7930 mm long.

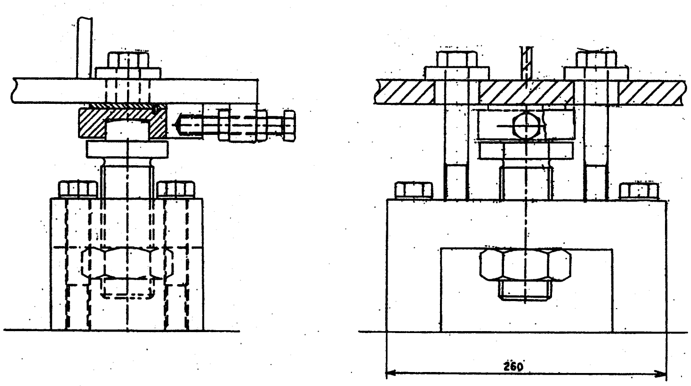

Fig. 2 Positioning equipment of magnet girder for horizontal and vertical direction.

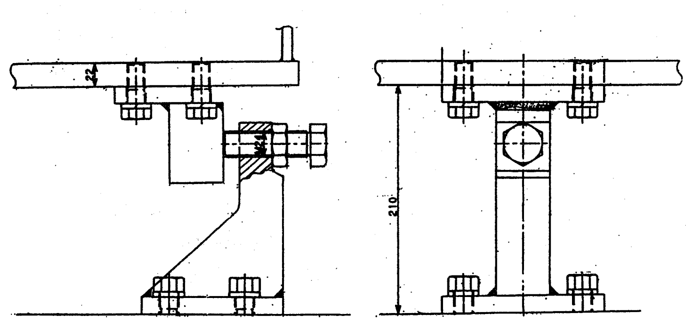

Fig. 3 Positioning equipment of magnet girder for longitudinal direction.

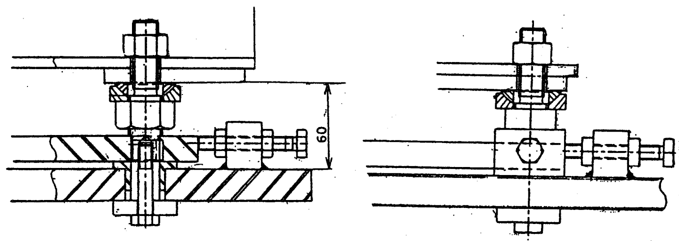

Fig. 4 Positioning equipment of magnet.

5 RIGIDITY

Main frame of the girder for string test consists of two boards that are connected each other at five points. The girder legs are bolts on which girder can slide but due to large friction the girder was bent at the center leg. If we move the girder after aligning the magnets on the girder, magnetic center deviates from the straight line. To prevent the deviation, we need to reduce the friction and increase the girder rigidity. To keep the deviation from straight line, following relation must be satisfied[2],

$I/\mu > 1.2\times10^6$ [cm^4],

where I is the second moment of area and μ is the friction coefficient.

However the obtained value from the string test girder is,

$I/\mu = (1.01 \pm 0.19)\times10^5$ [cm^4].

We need to increase the girder rigidity and reduce the friction.

Friction coefficient of normal steel is 0.2~0.3 but if we employ the low friction material such as oiles bearing, we can make the friction of slide plane to be less than 0.1. Assuming 0.1 as a friction coefficient, the second moment of area for girder must satisfy,

$I > 1.2 \times10^5$ [cm^4].

We decided to employ the girder that has the cross section as shown in Fig. 1. The second moment of area for a beam is proportional to its width and the third power of its height. This means that to increase the horizontal rigidity it is more effective to increase the horizontal width of girder. But the magnet cable restricts the width of girder. Girder height is also restricted because the height of the magnet center was already determined to be 1200 mm. Only side and bottom board thickness are remained as a parameter. We calculated the maximum deviation from the straight line against the positioning(Fig. 5). As was expected, thickness of the side board slightly affects the horizontal rigidity of the girder. We chose 25 mm thickness as a bottom board. Next we calculated the vertical deflection. Deflection is 13 μm and 21 μm for 20 mm and 10 mm thick side board respectively. Since the vertical bend keeps its shape constant, we do not need to pay attention to vertical rigidity as horizontal. Deliberating with the manufacture maker we determined 12 mm as the side board thickness.

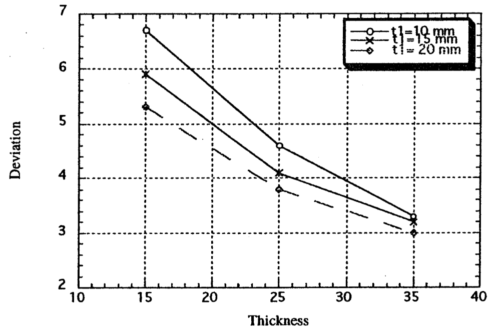

Fig. 5 Deviation from the straight line of magnet girder as a function of bottom board thickness. Parameter t_1 is side board thickness.

6 POSITIONING EQUIPMENT

6.1 Girder positioning equipment

The string test girder has a bar setting up under the girder. The bar is pushed by a bolt and the girder slides on the head of bolts directly. When we tested the adjustability, the girder didn't slide initially even if we pushed the bar but the magnet moved to the opposite direction. When pushing was continued, the girder suddenly began to move with the sound. The reason is that the large friction prevents the girder to slide on bolts and rotating moment works for girder. If the pushing force exceeds the friction force, it suddenly begins to slide with the sound. In this case fine adjustment is difficult. We set a cap on a bolt and low friction material is applied to the slide plane of the cap. To reduce the rotational moment we shorten the distance between the slide plane and a point of action. After improvement smooth and accurate movement of girder was achieved.

Vertical adjustment of string test girder was done by rotating bolts. In this case rotating force is transmitted to the girder. We then made the head of the bolt round and put the cap on the bolts to reduce the rotating force to the girder.

Adjustment accuracy of girder for longitudinal direction is the order of mm. We employed the simple structure as shown in Fig. 3.

6.2 Magnet positioning equipment

Positioning of the magnet of string test girder was done by pushing an intermediate girder of magnet. We measured the movement of magnet and intermediate girder of magnet. The amount of movement of magnet and intermediate girder is different and even within the intermediate girder movement of four corner is different each other. This means the distortion of intermediate girder. Maximum distortion was 60 μm. To avoid the distortion of magnet, we changed the adjustment method from pushing the intermediate girder to pushing the newly setting board on which the magnet was placed. Low friction material was applied to slide plane between the girder and the board. By these improvement the amount of movement of magnet and board became the same and no distortion of magnet was achieved.

For vertical positioning old girder used the leveling block that consisted of two wedge and sliding the wedge to the horizontal direction the height of edge changed according to the horizontal position of wedge. This structure has the intrinsic disadvantage that the horizontal and vertical movement couples each other. In fact for heavy magnet when adjusting the vertical direction, magnets moved not only the vertical direction but also the horizontal direction. We changed the leveling block to the simple bolts as shown in Fig. 4. Magnets still moved for the lock of bolts. We then rotated the lock nuts from both sides so as to keep the same position. Lock to the girder was done by rotating the bolt with same torque.

7 SUMMARY

We tested the girder for sting test cell. We found that the girder had not enough rigidity for the alignment. Adjustment equipment for magnet was also required to improve for fine adjustment of magnets. On the basis of these test results, we designed a new girder that has high rigidity. Low friction materials was applied to the slide plane. With these improvement the girder kept its straightness within ±10 μm during alignment.

Adjustment method for magnet was changed from pushing the magnets directly to pushing the board on which the magnet was placed. By this improvement the distortion of magnet was prevented and smooth and accurate adjustment was achieved.

With these improved girder magnet alignment for SPring-8 Storage Ring was successfully accomplished.

ACKNOWLEDGEMENTS

We would like to thank Dr. N. Kumagai for valuable discussions. Thanks are also due to Dr. S. Matsui for his help of the measurement of magnet fiducial point and S. Sasaki calculating the mechanical strength of bolts of girder.

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