Magnet Rearrangement for 30 m Long Straight Sections in the SPring-8 Storage Ring

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Abstract

In the summer of 2000, we constructed the four 30-m long straight sections in the SPring-8 Storage Ring. Magnets were rearranged to make long free spaces. New girders were designed, manufactured and installed to the SPring-8 storage ring tunnel. Magnets placed on the girders were aligned on a straight line using CCD camera and laser. A long undulator was installed in one long straight section and the vacuum chamber of the other three sections were shielded by the metal with high permiability. Magnet power supplies were also made and installed in power supply rooms and cabling was done for the rearranged magnets.

1. INTRODUCTION

The SPring-8 Storage Ring is the 8 GeV synchrotron radiation source with 1436m circumference and consists of 44 double bend achromat cells (Chasman Green cell) and 4 straight section cells. The straight section cells are the same as the normal cell except no bending magnet exists in a cell. These straight section cells[1] were prepared to install long undulator by rearranging the magnets in these sections after operating the storage ring during two or three years with the initial magnet arrangement.

The SPring-8 Storage Ring had been operated since 1997 and expected performance was achieved. It was then determined to rearrange the magnets and make the four long straight sections in the summer of 2000. Beam optics was reexamined and tough optics for momentum deviation was obtained[2]. Together with the beam optics study, study of the hardware was started. We prepared the baseplate and made new girders. Alignment method was studied and the new laser system was developed[3]. Carefully thought-out plan was scheduled to accomplish the rearrangement in a short period[4]. In June 17, the rearrangement was started and finished August 27. The beam commissioning was started on August 28 and the beam was successfully stored in the same day.

2. OUTLINE OF MAGNET REARRANGEMENT

2.1 Magnet rearrangement

There are four long straight sections in the SPring-8 Storage Ring as shown in Fig. 1. The magnets were removed and rearranged to make magnet-free long straight sections as shown in Fig. 2. In one section, vacuum chamber was also removed to install a long undulator but the other sections were remained to be free space for the future installation of undulator.

We needed to remove 16 quadrupole, 11 sextupole, 1 skew and 16 steering magnets and 2 girders for one straight section and rearrange 12 quadrupole, 2 skew and 12 steering magnets. Two girders and a skew magnet were newly made. Resultantly 4 quadrupole, 11 sextupole, 4 steering magnets and old girders were carried out from the storage ring tunnel for one straight section. For the whole ring 64 quadrupole, 44 sextupole, 64 steering and 4 skew magnets and 11 girders were removed.

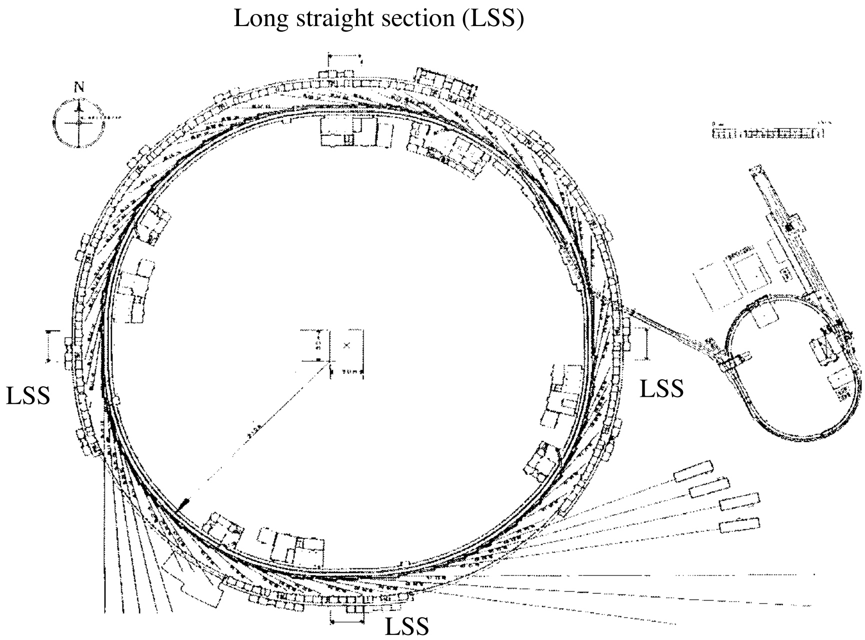
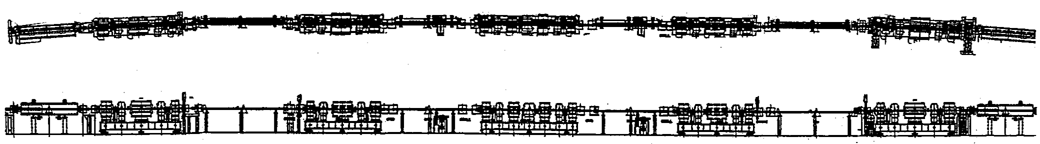
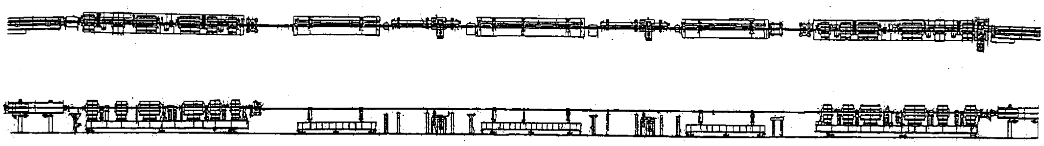


Fig. 1 The SPring-8 Storage Ring, an injection linac and a synchrotron.



(a) Before rearrangement



(b) After rearrangement.

Fig. 2 Magnet rearrangement of the 30m-long straight section.

2.2 Procedure of magnet rearrangement

Since the time for the construction was two and a half months, the parallel working was done for four long straight sections. Procedure is shown in Fig. 3.

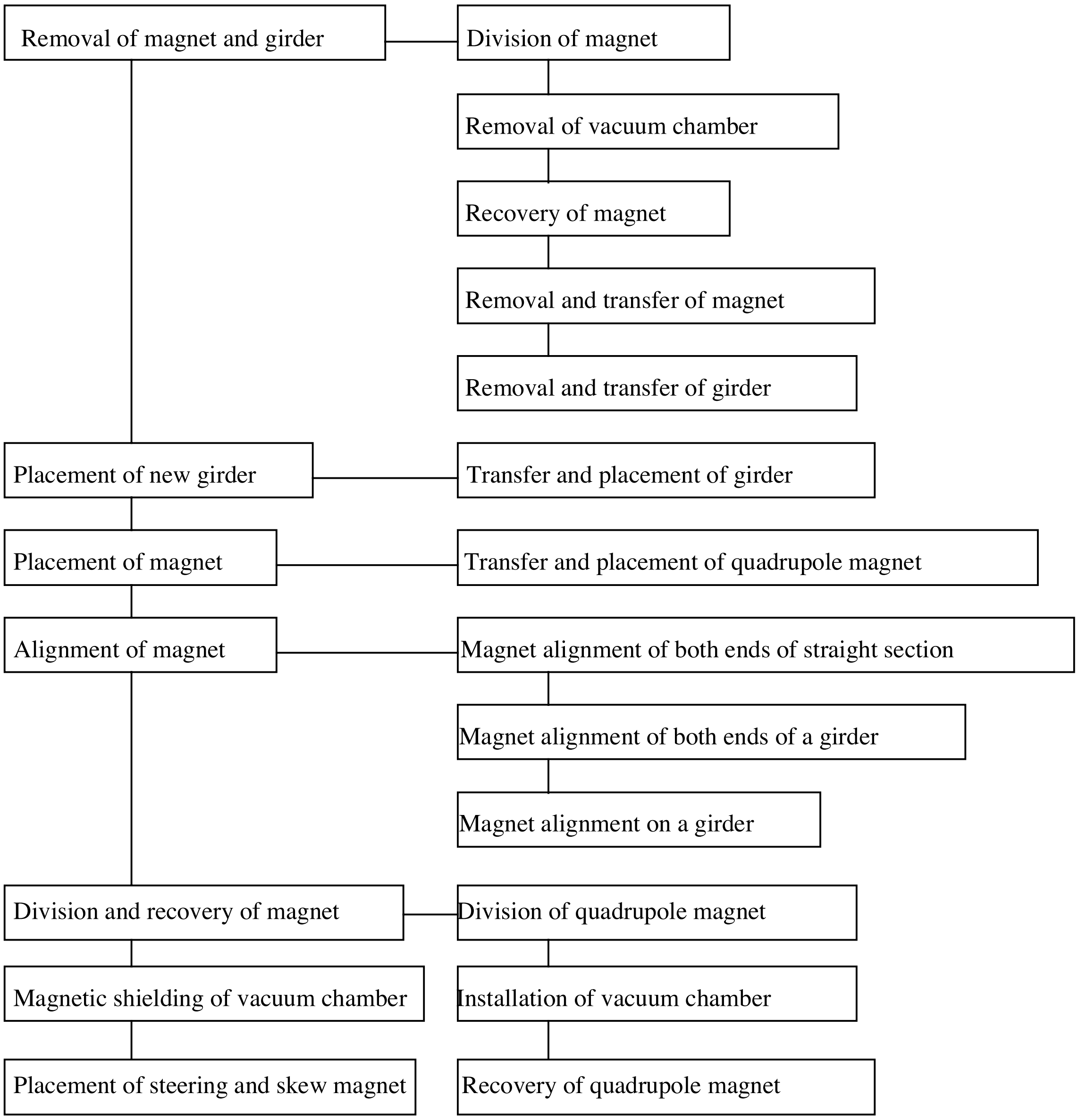


Fig. 3 Procedure for magnet rearrangement of 30m-long straight section.

(a) Removal of magnet and girder

First, the upper parts of the magnets are separated and vacuum chambers are removed. After that magnets are recovered. Before and after recovery, magnet tilt angle is measured to confirm that the magnets are not deformed and no dust is on the surface of the separated plane. Magnets are then removed from the girder and carried to the keeping place. After that, girders are also carried to the keeping place. For three long straight section cells where the long undulator is not placed, girders are left unchanged and the vacuum chamber is reconstructed on the girder.

(b) Placement of new girder

As shown in Fig. 2 long girders are placed at the both ends of the free space. First, the legs of girder are set on the baseplates. The position is adjusted to a marking line drawn on the baseplate. The heights of the legs are adjusted to become the same level as the other girder height by comparing the height with the fiducial point on the wall. After adjusting the levels of legs, the girders are set on the legs.

(c) Placement of magnet

The magnets removed from girders are placed on the girders again and adjusted to the marking drawn on girders.

(d) Alignment of magnet

Six magnets named QL1~QL6 are placed on the girder of upper side of the straight section and QL7 ~QL12 are placed on the girder of the down side. First, position of QL1 and QL12 is determined by measuring the position of neighboring quadrupole magnets. Next, QL6 and QL7 are adjusted to align on a straight line that is obtained by connecting QL1 and QL12. Finally, residual magnets are aligned on a straight line.

(e) Division and recovery of magnet

After separating the magnets, vacuum chamber is installed and the magnets are recovered. Special attention is paid to the magnet recovery because of the possibility of magnet deformation especially for heavy magnet. The magnet is hung by the four ropes and the tensions of four ropes are adjusted to become equal to avoid deformation of magnets. The tilt of fiducial plane before and after recovery is checked.

(f) Magnetic shielding of vacuum chamber

Three straight sections are entirely free space and an electron beam is easy to be affected by the external magnetic field. The chamber is then shielded magnetically by the thin metal plate.

(g) Placement of steering and skew magnet

After quadrupole placement, steering and skew magnets are placed.

(h) Setting of power supply and cable

According to the removal of magnets, power supply cables are also removed. New power supplies are manufactured and set in the power supply rooms. Cables are set in the power supply rooms and the tunnel.

3. MAGNET GIRDER

3.1 Baseplate

In the SPring-8 Storage Ring, all girders and bending magnets are placed on baseplates, the faces of which are flattened by a machine. These baseplates made it possible to do the efficient alignment work and keep the high accuracy of alignment without being affected by a crack of concrete.

Three baseplates are needed for a girder but two existed baseplates are available. We made one new baseplate for a girder, and in the whole ring we made eight baseplates[5]. As shown in Fig. 4 floor was dug and a baseplate was set and fixed by the non-contractile mortar.

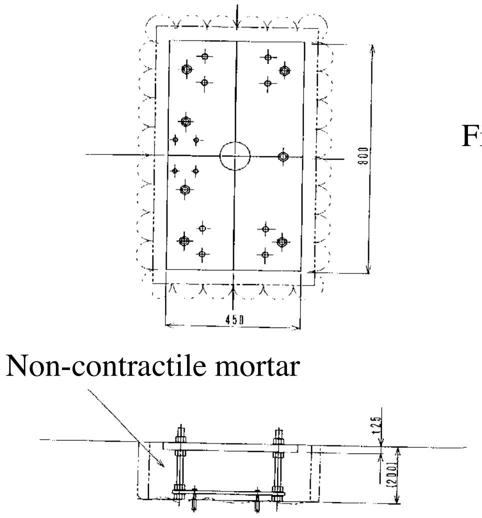


Fig. 4 Baseplate for a magnet girder.

3.2 Required performance and design principle

In the SPring-8 Storage Ring, the magnets aligned on a straight line are regarded as a unit and a closed orbit is suppressed to a small value by aligning the magnetic center precisely [6]. Girder actually plays a role of unit.

The quadrupole and sextupole magnets in a cell were divided to three kinds of units and placed on corresponding three kinds of girders to realize this alignment method[7]. Girders must have had enough rigidity so that they could be regarded as units. This time we adopted same policy to new girders. Distance from QL1 to QL6 is about 8 m and we decided to place these six magnets on a same girder though the girder becomes longer than existed girders and rigidity becomes weaker. The reason is the following. Magnetic strength of QL3 and QL4 is larger than the other magnets. Contribution of these two magnets to the orbit deviation is larger than other magnets. But polarities of these magnets are different from each other. Two magnets cancel the driving force of orbit deviation each other if the magnetic center is aligned precisely. Contrary to this, if magnets are placed on different girders and the magnetic centers of each magnet are not on a line, cancellation between two magnets does not work.

In a normal cell, quadrupole magnets were placed just above the six legs to reduce the deformation of girder and avoid the effect of vibration. This time, some magnets are placed between the legs and easy to be affected by vibration. We added the equipment between the legs and fixed the girder to reduce the vibration.

3.3 General structure

A girder for a long straight section is shown in Fig. 5. Length and weight are 7930 mm and 3.5 ton, respectively. Structure of the girder is box type and positioning can be done for horizontal, vertical, and longitudinal direction. On the girders there are equipments for magnet adjustment that can adjust magnet for three directions.

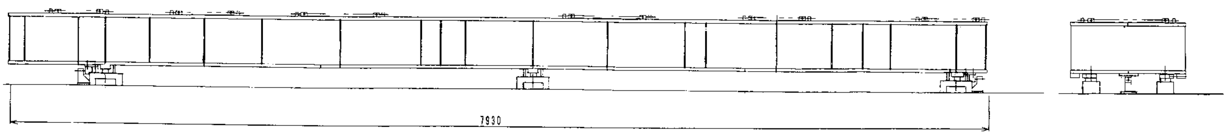


Fig. 5 A girder for a long straight section.

3.4 Positioning equipment

Vertical and horizontal positioning are done by the equipments set up at six legs and longitudinal positioning is done by the equipments at the both ends of a girder. Figure 6 shows the positioning equipment of the girder for horizontal and vertical direction. Positioning for horizontal direction is done by rotating a bolt that is fixed to the girder. Low friction material is set to reduce the friction between the leg head and the girder bottom plate when adjusting the girder position. Vertical adjustment is also done by rotating the bolt. Figure 7 shows the positioning equipment for longitudinal direction. Since the tolerance for longitudinal alignment accuracy is large and fine tunability is not needed, it has simple structure.

Figure 8 is the positioning equipment for magnets. Positioning for horizontal direction is done by pushing the plate, on which the magnet is set, to avoid the deformation of magnet. Low friction material is also applied to the plane between girder and board. Vertical adjustment is done by rotating the bolts as shown in Fig. 8.

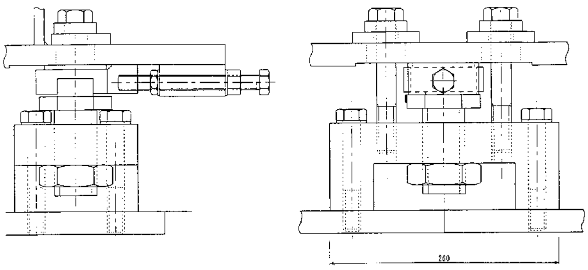


Fig. 6 Positioning equipment of magnet girder for horizontal and vertical direction.

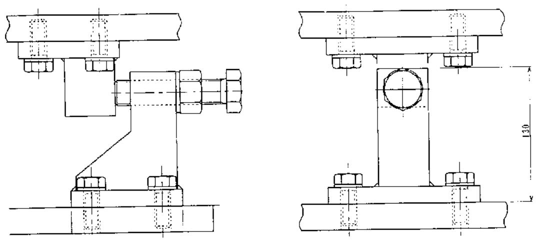


Fig. 7 Positioning equipment of magnet girder for longitudinal direction.

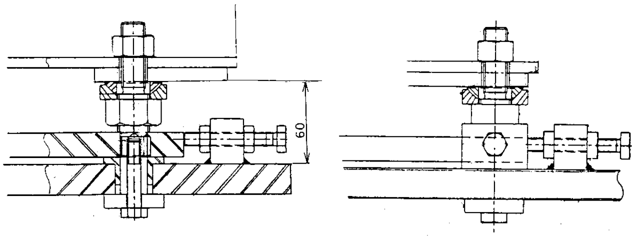


Fig. 8 Positioning equipment of magnet for horizontal and vertical direction.

3.5 Rigidity

When the girder is pushed by a bolt for the horizontal positioning, a girder is bent and deviates from the straight line. This deviation for previous girder is less than 10 μm. But this time the girder length and total weight of magnets increased, which makes the larger deviation from the straight line for girder. If we employ the same structure, the deviation becomes 10 time larger than the previous one. To increase the horizontal rigidity the width must be widened. But the only 10 cm can be widened due to the restriction of magnet cable arrangement. Maximum deviation is 90 μm as shown in Fig. 9. We therefore needed to monitor the deviation of girder while positioning the girder.

Deformation of girder for vertical direction increases with the length of girder. To reduce this we need to increase the height of girder. The height of girder is however difficult to increase because of the height of the magnet center does not change. By reducing the range of adjustment, we increased the girder height from 350 mm to 400 mm. Vertical deformation of girder is shown in Fig. 10.

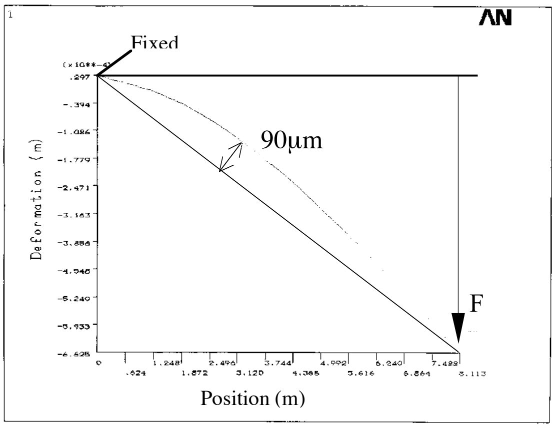


Fig. 9 Deformation of girder for horizontal direction.

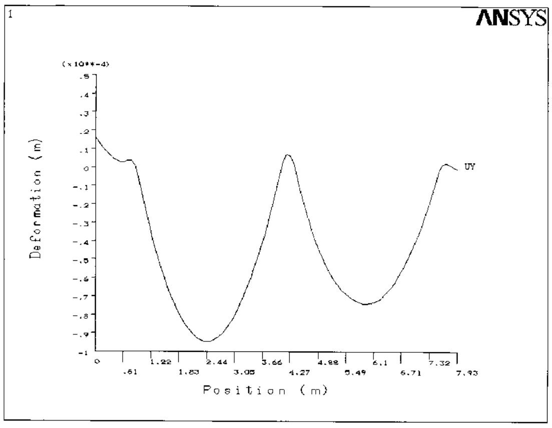


Fig. 10 Deformation of girder for vertical direction.

3.5 Resonance characteristics

Since vertical emittance of the SPring-8 Storage Ring is less than 4 pm, even the small vertical vibration leads to the effective emittance growth. In previous girder, magnets were placed just above the legs where the effect of vertical vibration is small compared to the other points. But this time magnets were placed between the legs where the vibration amplitude is larger than the other was. We calculated the natural frequency of new girder. Results are shown in Table 1. Main oscillation modes are shown in Fig. 11. Frequencies of main modes are less than 100 Hz and we tried to increase these frequencies by fixing a girder at the center of two legs.

Table 1 Oscillation frequency of magnet and magnet girder. unit : Hz

	horizontal	vertical
1	23.4	44.9
2	32.6	49.4
3	47.6	60.8
4	49.4	65.9
5	58.3	69.8
6	61.4	78.9
7	92.8	87.5
8		92.5
9		92.8

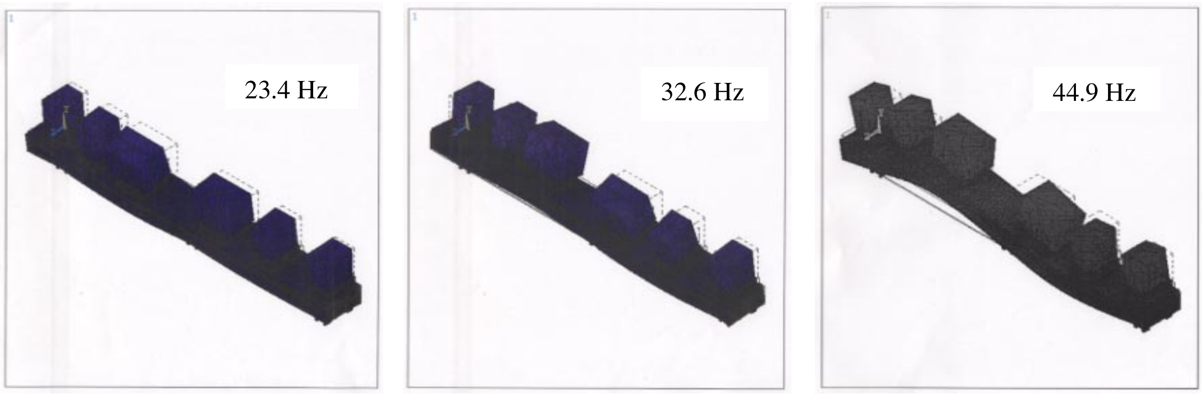


Fig. 11 Girder oscillation mode for horizontal and vertical direction.

4. MAGNET ALIGNMENT

4.1 Alignment for magnets of both ends of straight section

First we need to align the magnet QL1 and QL12. To determine the magnet position of QL1 and QL12, we measured the girder position over five cells around long straight section beforehand by constructing the network shown in Fig. 12[8]. Measurements were done for four long straight sections by laser tracker SMART 310. One of the results is shown in Fig. 13. In the figure the magnets from C girder of cell 29 to A girder of cell 31 are removed to make the free space. Positioning of QL1 and QL6 on the LA girder were done by measuring the position with SMART 310. Fiducial points in this case are B girder of cell 41. Positions of QL7 and QL12 on LB girder were adjusted as the same way with LA girder. Accuracy of positioning for QL1 and QL12 is less than 70 μm.

Levels were also measured as shown in Fig. 14[9]. Since the levels of B girder of cell 6 was too high, it was lowered about 0.25 mm. After that, levels of QL1 and QL6 were adjusted to the quadrupole magnet on B girder of upstream cell. Levels of QL7 and QL12 were also adjusted to the B girder of downstream cell.

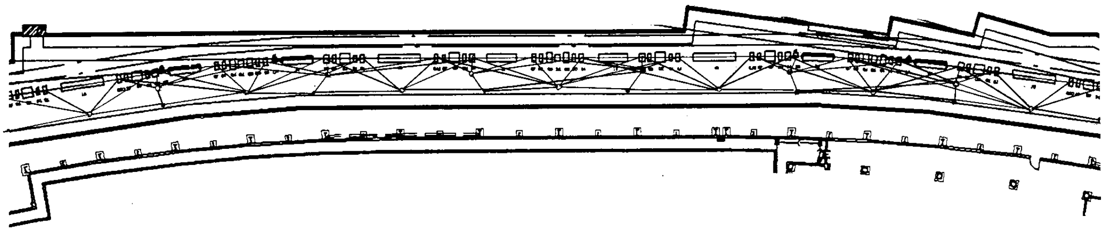


Fig. 12 Control network for the measurement of girder position.

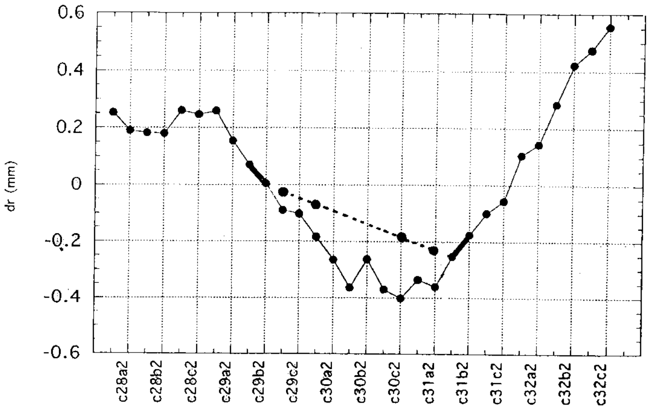


Fig. 13 Girder position before rearranging the magnet.

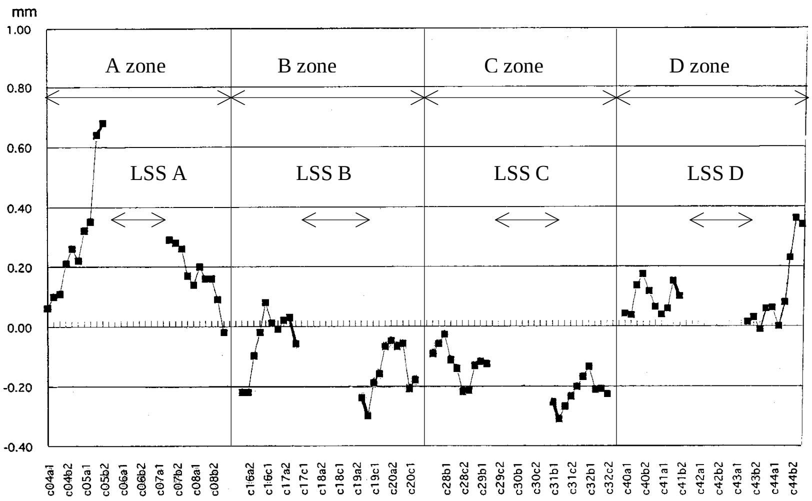


Fig. 14 Level of magnets around four long straight sections.

4.2 Alignment for magnets of end of a girder

QL6 and QL7 are aligned on a line made by connecting QL1 and QL12. Distance between QL1 and QL12 is about 40m and alignment tolerance is 0.1 mm. Since we can not obtain this accuracy with laser tracker SMART 310, we developed a laser system that consists of He-Ne laser and CCD camera. Using this system QL6 and QL7 magnets are aligned as shown in Fig. 15 [3].

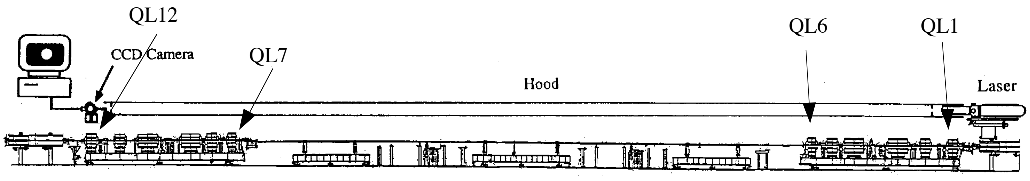
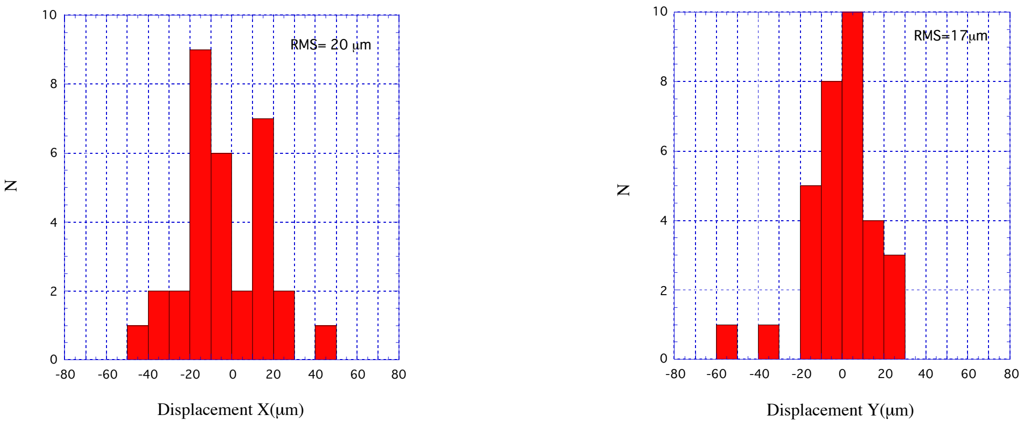


Fig. 15 Alignment of QL6 and QL7 using laser and CCD camera system.

4.3 Magnet alignment on a girder

Magnets on a girder are aligned on a straight line made by connecting the magnets on the both ends of a girder. Measurement were done by He-Ne laser and CCD camera system that had been developed for the SPring-8 Storage Ring magnet alignment[10]. For carrying out the alignment efficiently, magnets were pre-aligned with the accuracy of 50 μm using laser tracker SMART 310[11] and final alignment was done using the He-Ne Laser and CCD camera system[12]. Results are shown in Fig. 16.



(a) Horizontal (b) Vertical

Fig. 16 Alignment results for the magnets on girders.

5. MAGNETIC SHIELD

Most of the long straight sections were shielded by magnets from the external magnetic fields. After removing the magnets these sections are exposed to the external magnetic fields. We then shielded these sections magnetically[13]. As shown in Fig. 17, the chamber was rolled threefold by thin amorphous metal, thickness of which is 25 μm and relative magnetic permeability is 45000. The chamber near the steering magnets was not shielded to avoid the absorption of steering magnetic field and resultant error field generation at the edge of the shielding metal. Magnetic fields of inside and outside of the shielding were measured by a three axial Hall probe. Magnetic fields inside the shielding reduced to about 1/10 of the outside field strength as shown in Fig. 18 and the effectiveness of shielding was confirmed.

Fig. 17 Magnetic shielding of the vacuum chamber.

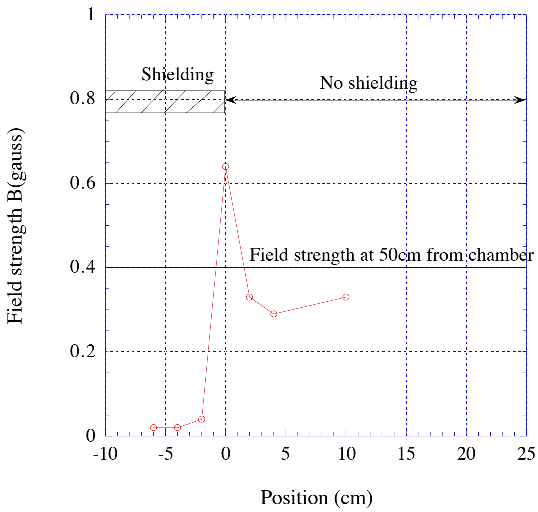


Fig. 18 Magnetic fields inside and outside of the chamber.

6. POWER SUPPLY

Thirteen magnet power supplies were newly made for one straight section[14] and for whole ring it amounts to 52 power supplies. Cables for removed magnets were cleared away and new cables were laid.

Magnet arrangement in long straight section is mirror symmetry and two magnets that situated the symmetric position are serially connected. In addition to this, some quadrupole and sextupole magnets were reconnected to the new power supplies to control these magnets independently from normal cell magnets as shown in Fig. 19. Control programs for these magnet power supplies were rewritten and tested[15].

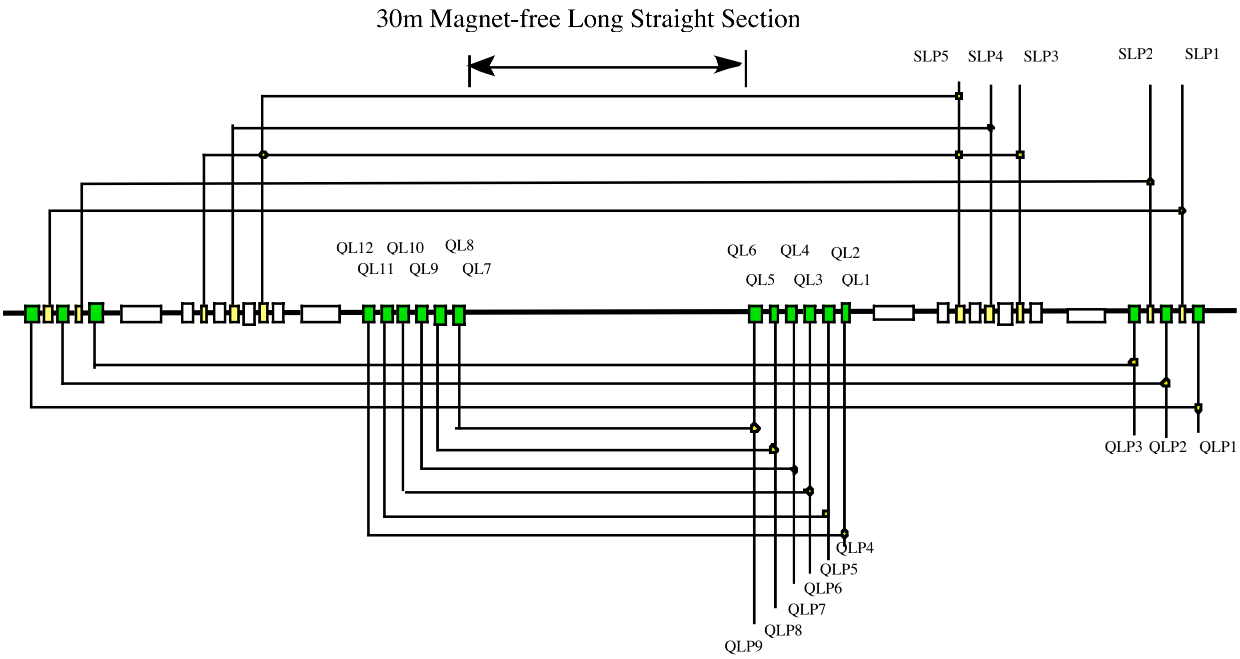


Fig. 19 Magnet arrangement and magnet power supply connection.

7. CONCLUSION

We rearranged the magnets of four long straight sections to make long free spaces (Fig. 20). Eight baseplates and girders were made and the magnets were placed on the girders. Magnets on the girders were aligned with the accuracy of 20 μm and 17 μm for horizontal and vertical direction, respectively. Chambers in long free spaces were shielded with the amorphous metal to avoid the effect of external magnetic fields. Power supplies for the long straight section magnets were newly made and the new cables were set and connected.

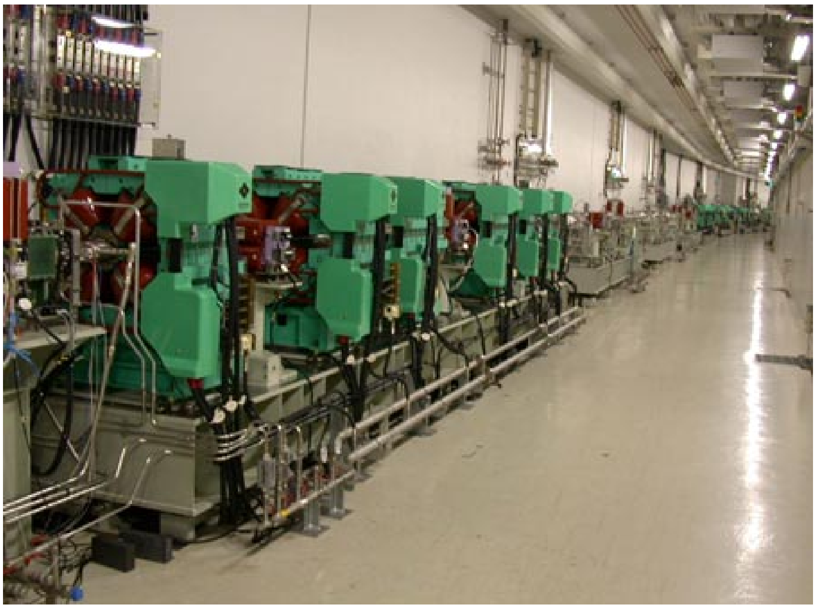


Fig. 20 Long straight section after magnet rearrangement.

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