# Magnets, Power Supplies and Alignment

**Koji TSUMAKI**

By the end of 1995, fabrication and installation of the bending, quadrupole and sextupole magnets were completed[1][2]. Last year we constructed the injection and steering magnets, and installed them in the SPring-8 Storage Ring tunnel. Final tuning and alignment for all these magnets have also been carefully performed to achieve the smooth commissioning of the storage ring.

## 1. Magnets and Power Supplies

The injection magnets consist of three DC septum magnets, one pulsed septum[3] and four bump magnets[4]. Three DC septum magnets, two of which are of the same design for cost reduction, are connected in series and are operated by a single power supply. At first, the pulsed septum magnet was designed to be placed in a vacuum vessel. Later we changed the design to place the magnet in a He atmosphere for easy maintenance and cost reduction.

We measured the magnetic strength of the DC septum magnets and reduced the leakage field by adding a silicon steel plate to the septum wall. The integrated field strength of the pulsed septum magnet was also measured by a long coil. We confirmed that the integrated fields along the injection path length are the same as their design value, and that the leakage field is small enough to neglect its effects on the stored beam.

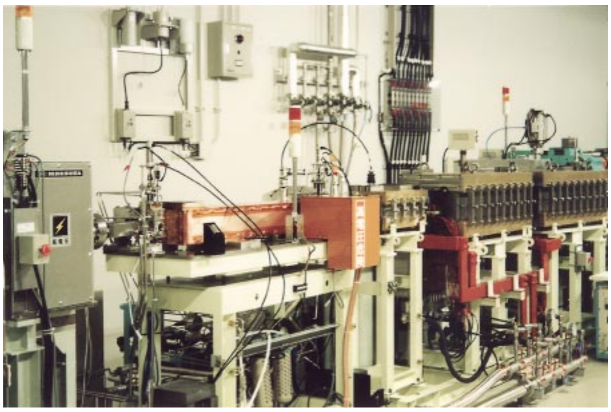

Fig. 1 Injection magnets.

The magnetic field strength and the electric property of bump magnets were also measured to verify the performance. The timing and the control system for these injection magnets were designed, and their control programs were developed.

The delivery of the steering magnets was started in April 1996 and was completed in September. The field measurements were carried out for three types of the steering magnets. The small remnant field was measured and the good performance was confirmed.

The bending, quadrupole and sextupole magnets of the same family were connected in series and the final tuning of power supplies was completed by applying electric currents to the magnets. Current stability was suppressed to $1\times10^{-5}$ for dipoles and $1\times10^{-4}$ for quadrupoles and sextupoles. The control programs for these magnets based on a client/server models were developed[5].

## 2. Alignment

Following the completion of the magnet alignment between girders, the magnet alignment on a girder and the bending magnet alignment were completed in March and April respectively. The steering magnet installation and alignment were started in April and were finished in September. After the alignment we measured the alignment change with time and realigned the magnets having large position deviation. We imposed the following conditions in realigning the magnets. First, we do not correct changes which have a larger wavelength than the betatron wavelength. Second, although the closed orbit distortion is mostly determined by the harmonics near the tune value, we do not apply the harmonic correction by moving several special quadrupole magnets. Instead we correct the quadrupole magnets which have the large position deviation. Because it is natural to correct them from the larger deviation, and the closed orbit distortion does not change greatly even if the optics is changed and the tune is moved to another value. The harmonic correction is simply a role of steering magnets.

The changes in the alignment of the sextupoles and quadrupoles on the girder were measured before and after the chamber installation, after the chamber baking and just before the commissioning using a He-Ne laser and a CCD camera[6]. The alignment accuracy was made worse approximately by 10 μm by the recovery of these magnets after the chamber installation. Other processes did not affect alignment deterioration. After these corrections we achieved approximately 15 μm of final alignment accuracy.

The magnet positions between the girders were surveyed after 10 months of the girder alignment[7]. The relative position accuracy for horizontal direction was deteriorated from 40 μm to 60 μm. We corrected 29girders and obtained 50 μm of the relative accuracy as the final value.

The levels between the girders were measured in April, August and January[6]. The measured results showed that the floors, under which an under path and five drainpipes were passing through, moved up and down depending upon the changes of the atmospheric temperature. The floor levels in the RF sections were also changed due to the temperature change of the klystron pit under the floors. Besides that, there were many level changes which seemed to be nonuniform subsidence of the ground. We corrected the levels of 21 girders and obtained the relative accuracy of 40 μm as the final value. The summary of the final alignment accuracy is shown in Table 1.

Table 1 Alignment accuracy of quadrupole and sextupole magnets (Measured value).

| | σx | σy |
|---|---|---|
| Between girders (absolute) | 0.53 mm | 0.16 mm |
| Between girders (relative) | 0.05 mm | 0.04 mm |
| On a girder | 15 μm | 15 μm |

The circumference of the ring was measured and the ring was 1.8 mm longer than the design value.

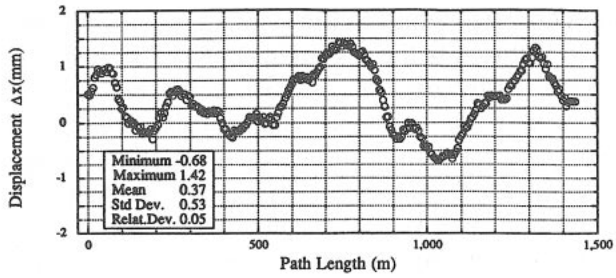


Fig. 2 Alignment results for horizontal direction.

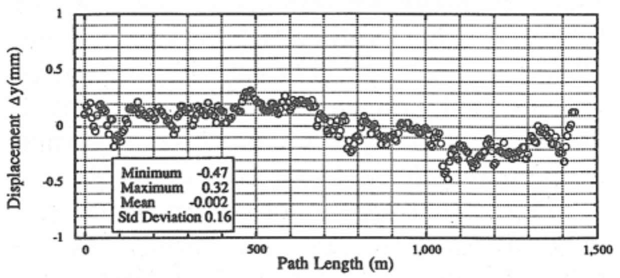


Fig. 3 Alignment results for vertical direction.

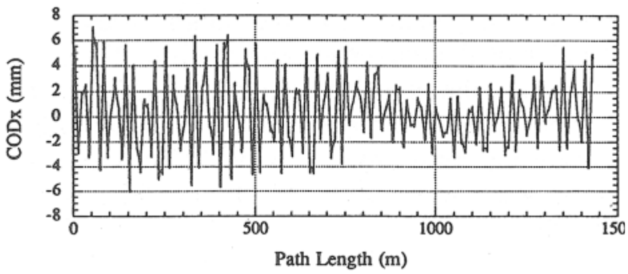


Fig. 4 Calculated closed orbit distortion for horizontal direction based on the alignment data.

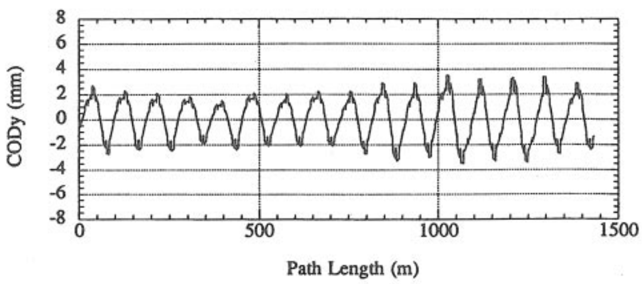


Fig. 5 Calculated closed orbit distortion for vertical direction based on the alignment data.

We calculated the closed orbit distortion based on the alignment data. Figures 4 and 5 show the calculated closed orbit distortions which correspond to the final alignment results, and figure 6 is the dynamic aperture with these closed orbit distortions. Since the sensitivity against errors of the storage ring is very large, the magnet position errors generate a large closed orbit distortion. When we studied the commissioning process by simulation, we found that the electron beams could not circulate a ring even a single turn with high probability[8]. Therefore, we designed the detuned modes which are less sensitive to the alignment errors, and we even studied step by step commissioning process via the detuned lattices[9]. Figures 4,5 and 6, however, show that we can circulate a beam with final lattice without first turn steering and even store it without the closed orbit correction by turning on the sextupoles and switching on the RF.

These small closed orbit distortions and large dynamic aperture are mainly due to following reasons. First, we found out that it is possible to reduce the effective sensitivity if we can align the magnetic centers of quadrupole magnets precisely on a straight line in each straight section[10][11]. Second, we were able to achieve the high accuracy magnet alignment by the high accuracy transfer of the magnetic centers to the fiducial points[1], the development of an alignment system using a laser and a CCD camera[2], and by the long time continuos efforts of all those who were involved in the alignment activities.

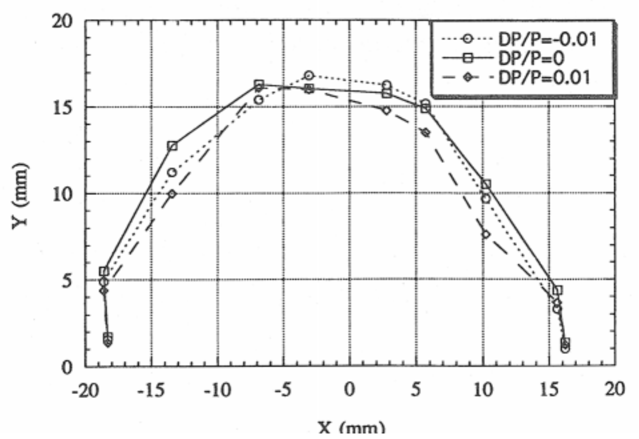


Fig. 6 Dynamic aperture without correction of closed orbit distortion. The momentum deviation is ±1%. If the closed orbit is corrected, the dynamic aperture becomes larger and approaches the ideal one.

## References


[1] J. Ohnishi et al., IEEE trans. on Magnetics 32,4 p3069(1996).

[2] S. Matsui et al., Proc. of the Fourth Int. Workshop on Accelerator Alignment, KEK, Tsukuba, Japan, Nov.,p174(1995).

[3] T. Shimada et al., To be published.

[4] K. Kumagai et al., IEEE trans. on Magnetics 32,4 p2538(1996).

[5] H. Takebe et al., Proc. of the 4th European Particle Accelerator Conference, London, U.K., p1827(1994).

[6] S. Matsui et al., To be published in the Fifth Int.Workshop on Accelerator Alignment.

[7] C. Zhang et al., To be published in the Fifth Int.Workshop on Accelerator Alignment.

[8] R.Nagaoka et al., Proc. of the 7th Symposium on Accelerator Science and Technology, Osaka, Japan, Decem., p296(1989).

[9] K. Tsumaki et al., Proc. of the 7th Symposium on Accelerator Science and Technology, Osaka, Japan, Decem., p290(1989).

[10] K. Tsumaki et al., Proc. of the IEEE Particle Accelerator Conference, San Francisco, U.S.A., May, p1698(1991).

[11] H. Tanaka et al., Nucl. Instr. and Meth., A313, p529(1992).