RESULTS OF FIELD MEASUREMENTS FOR J-PARC MAIN RING MAGNETS

K. Niki#, K. Ishii, Y. Nemoto, E. Yanaoka, KEK, Tsukuba, Ibaraki, Japan
M. Muto, FFAG DDS Research Organization, Tokyo, Japan

Abstract

The mass production of J-PARC main ring (MR) magnets had been completed in March 2005. These magnets consist of 97 bending magnets, 216 quadrupole magnets with 11 families and 72 sextupole magnets with 3 families. We have been measured the magnetic field for all of these magnets and we finished it in March 2006. The obtained distributions for the BL products of bending magnets and the GL products of quadrupole magnets are within the required tolerance limits, values of which are estimated by the beam optics for COD correction, etc. The measured multipole components for the bending and the quadrupole magnets are consistent with the designed ones.

MR MAIN MAGNETS

The principal parameters of the bending, the quadrupole and the sextupole magnets are summarized in Table 1. Field calculation of these magnets was mainly executed with the code POISSON [1].

The bending magnets have the cross sectional shape of the H-type. The length is about 6m, and the weight is about 34 tons. The bending angle is 3.75 degree and its sagitta is 4.8 cm. In order to make a radial size small, a sector type was adopted. The resultant ampere-turn is 90450 for the maximum field strength of 1.9 T corresponding to the energy of 50GeV. Field saturation occurs above the energy level of 30 GeV, then the saturation factor becomes larger than 10 % at 50 GeV [2].

The turn-number of the main coil of the quadrupole magnets is 24 turns/pole. In addition to this, a correction coil is also equipped to each pole, whose ampere-turn is 5 % of the main coil. All of the quadrupole magnets have the same outward shape, but are classified into 3 kinds of the bore radius and 7 groups of the length. After all, these quadrupole magnets consist of 4 families, 171 magnets located on the arc sections and 7 families, 45 magnets on the straight sections. The quadrupole magnets on the arc section have the same cross sectional shape, the bore radius of which is 65 mm, and the maximum field gradient is 18 T/m for 50GeV, and the current is up to 1.5 kA. The saturation feature is similar to the bending magnets.

The sextupole magnets with 3 families have the identical cross sectional shape and the length. The turn-number of the main coil is 15 turns/pole. The correction coil is also equipped to each pole. The saturation of the sextupole magnets is weak even at 50GeV.

#kazuaki.niki@kek.jp

Table 1: Parameters of MR Main Magnets

Bending Magnet	
Bending Radius	89.381 m
Max. Field	1.9 T (for 50GeV)
Useful Aperture	120 mm (≤ ± 5×10^{-4} at injection)
Gap Height	106 mm
Core Length	5.85 m
Number	96 + 1 (Reference Magnet)
Max Current	3015 A
Quadrupole Magnet (11 families)	
Max. Field Gradient	18.0, 16.9, 16.3, 14.7 T/m (for 50GeV)
Aperture	130, 140, 150 mmϕ
Core Length	0.86 m – 1.86 m
Number	216
Max Current	1507, 1654 A
Sextupole Magnet (3 families)	
Max. Field Gradient	230 T/m^2
Aperture	136 mmϕ
Core Length	0.7 m
Number	72
Max Current	657 A

FILED MEASUREMENT SYSTEM FOR MASS PRODUCTION MAGNETS

Before installing in the MR tunnel, we considered that we should evaluate the magnetic field of all mass production magnets. For this purpose, we developed three kind of the field measurement coil system. They are the 7m-length flip-flop coil for the bending magnet, the 2m-length harmonic coil for the short quadrupole magnet and the sextupole magnet, and the 3m-length harmonic coil for the long quadrupole magnet [3][4]. Using these coil systems, the mass field measurements have been done from Sep. 2004 to March 2006. Including a tuning period, they worked stably in the good precision for two years.

Figure 1 shows the mass measurement bench. In order to control the room temperature, an air conditioned room shielded by the vinyl sheet was made in the factory.

7m-Length Flip-Flop Coil

The length and the radius of the flip-flop coil for the bending magnet are 7 m and 1.909 cm, respectively. The coil bobbin is made of GFRP. This coil is inserted from the end direction of the magnet using a 7m long removal stand. The inserted coil can rotates smoothly supported by four SUS-bearings. To verify the long time stability, we measured the BL products continuously for 12 hours. The stability and resolution of the system were better than the value of the sigma=1.56×10^{-5} at the magnet current of 570A. This flip-flop coil system has an encoder at the other end of the motor assembled. As a result, the sextupole component of the bending magnet can be measured. However following three attentions must be paid. The coil width is much smaller than a magnet useful aperture. Since the flip-flop coil is a π-coil, a multipole component in the even number cannot be measured in principle. The magnet is sector type, while the flip-flop coil is straight. Therefore we have to carefully evaluate multipole components.

2m-Length Harmonic Coil

The 2m-length harmonic coil with a radius of 5.95 cm is a radial type, and used for the quadrupole magnet of 1.46 m and shorter. This coil is also used for the sextupole magnet. The coil bobbin, which is made of AFRP, has a length of 2.55 m. As a support of the rotation, a ceramic air bearing is used. The GFRP plate is settled inside of the bobbin. On this plate, 5 kinds of coil are assembled. The main long coil is used for measuring the whole GL product and the multipole component. 2 short coils are assembled at both end of the bobbin. These coils are used for tuning the alignment of the magnet.

3m-Length Harmonic Coil

The 3m-length harmonic coil with a radius of 5.98 cm is a tangential type, and used for the quadrupole magnet of 1.56 m and longer. The tangential coil has no inner structure, so that the coil sag is smaller than that of the radial type. In our case, the sag of the AFRP bobbin with a length of 3.4 m is about 200 μm. This value is the same size as the maximum alignment tolerance. As our tangential coil is π/2-coil, the inefficient multipoles, for example the 8th and 16th –pole in our case, exist.

Figure 1: Field measurement system.

RESULTS OF MEASUREMENTS

BL, GL and G'L Products

Figure 2(a) shows the distributions of BL products for all bending magnets [5]. The horizontal axis indicates the BL products at the highest energy of 50GeV, and vertical axis indicates that at the injection energy. The values were corrected by the DCCT, which is additionally attached in the power supply. The allowable tolerance from the beam optics calculation is ±0.18% at 3 sigma. The measured values satisfied this requirement. Figure 2(b) shows the results for the checking magnet, which was measured by every 2 weeks to check our measurement system. This figure shows the measurement has a good accuracy.

The distributions of GL products for each families of the quadupole magnet were also obtained. These all spreads are in the tolerances. Only the spread of G'L products for sextupole magnets at 50GeV is not in the tolerance. In order to correct this, the position shuffling of

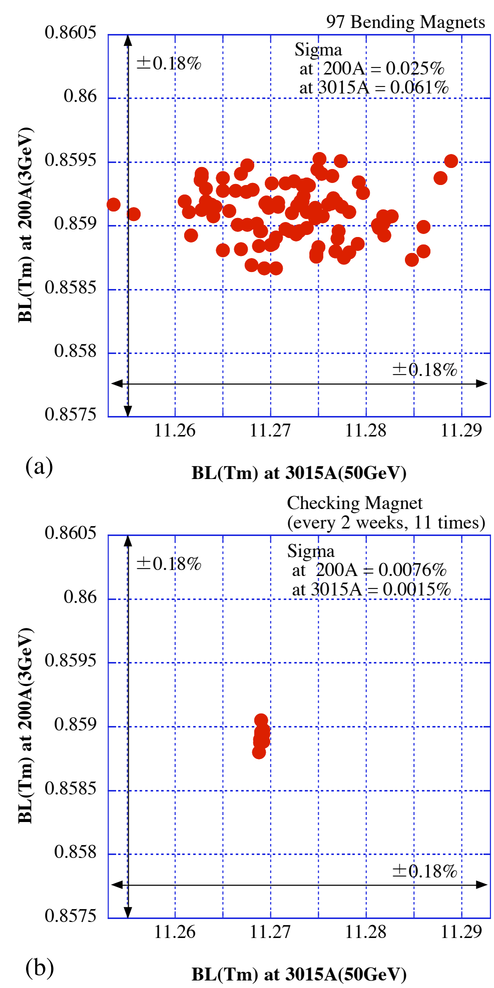

Figure 2: BL products results;
(a) for all bending magnets. (b) for checking magnet.

the sextupole magnet was performed [6]. Furthermore the position shuffling for all other magnets were done to make COD compensation and so on easier, though these spreads were in the tolerances.

Multipole Components

Figure 3 shows the measured multipole components. These are the value at the measured coil radius, and normalized by the main components. The (a), (b) and (c) indicates for the bending magnets, for the quadrupole magnets of two families with the length of 1.26 m and for the sextupole magnets, respectively. The allowed multipole of 6th for the bending magnets and of 12th for the quadrupole magnets are observed, which increase above 30GeV due to the saturation. These quantities and tendencies are consistent with expected ones by the POISSON calculation. The sizes of the other multipoles are small, which are the same order of the measurement systematic error.

The allowed multipole of 18th for the sextupole magnets is obtained with one order larger than expected one. We consider that this is due to the effect of the magnet ends. We also checked that even this sizeable multipole did not cause a serious problem to the beam optics.

SUMMARY

The mass production and measurements for J-PARC MR main magnets have been completed in March 2006. From these measurements, the following results were obtained;

- The spread for the BL products of bending magnets and the GL products of quadrupole magnets are within the required tolerances.
- The multipole components for the bending magnet and the quadrupole magnets are consistent with the designed ones.
- Only the sextupole magnets have larger G'L products spread and larger 18th-pole components.

REFERENCES

[1] M. Muto, *et al.*, Proceedings of the 13th Symposium on Accelerator Science and Technology, Osaka, Japan, Oct. 2001, p.277.

[2] K. Niki, *et al.*, Proceedings of the 14th Symposium on Accelerator Science and Technology, Tsukuba, Japan, Nov. 2003, p.205.

[3] E. Yanaoka, *et al.*, Proceedings of the 14th Symposium on Accelerator Science and Technology, Tsukuba, Japan, Nov. 2003, p.193.

[4] E. Yanaoka, *et al.*, Proceedings of the 2nd Annual Meeting of Particle Accelerator Society of Japan and the 30th Linear Accelerator Meeting in Japan, Tosu, Japan, July 2005, p.585.

[5] K. Niki, *et al.*, Proceedings of the 2nd Annual Meeting of Particle Accelerator Society of Japan and the 30th Linear Accelerator Meeting in Japan, Tosu, Japan, July 2005, p.78.

[6] M. Tomizawa, *et al.*, This Conference.

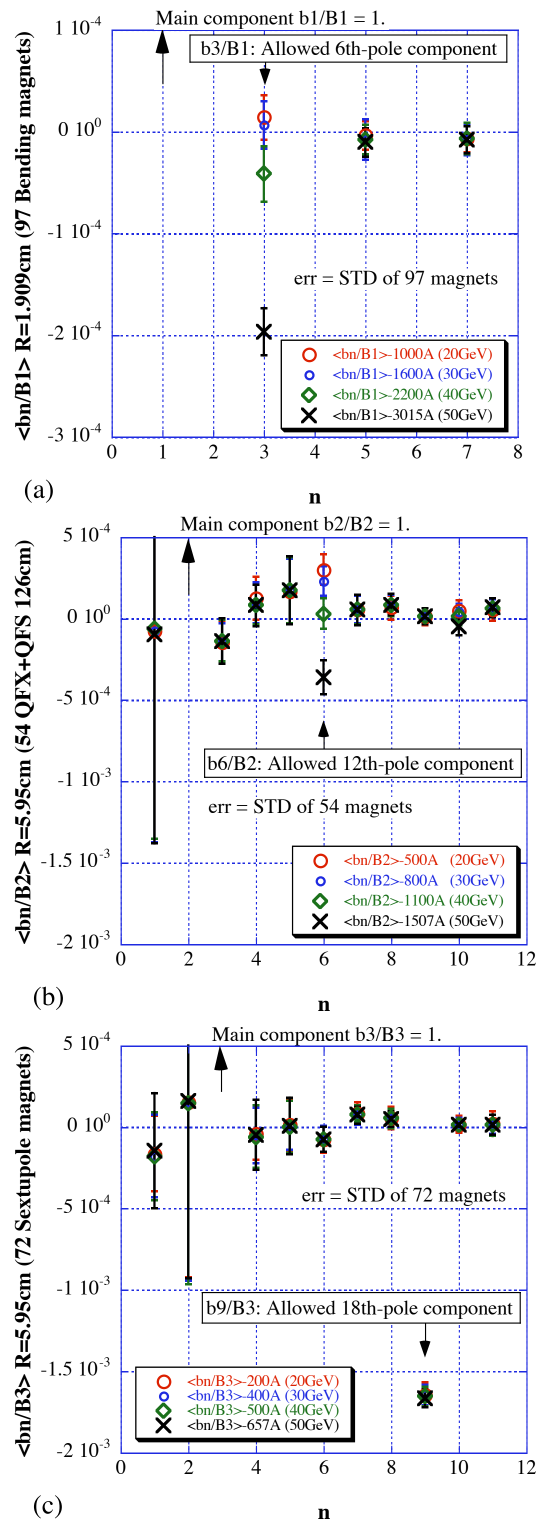

Figure 3: Mutlipole components results;
(a) for all bending magnets.
(b) for the quadrupole magnets with 1.26 m long.
(c) for all sextupole magnets.