PRELIMINARY RESULTS OF THE KEKB QUADRUPOLE MAGNET MEASUREMENTS

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Abstract

The quadrupole magnets for the KEK B-factory have been measured using two harmonic coil systems. The ~900 quadrupole and the ~200 sextupole magnets were measured over a period of 18 months at KEK. One-third of the quadrupoles are recycled TRISTAN[1] magnets and two-thirds are newly fabricated magnets. Preliminary results of the magnetic field measurements are given for the newly fabricated magnets. A unique problem regarding the recycled TRISTAN magnets is also presented.

1 MEASUREMENT OUTLINE

A harmonic coil system consisting of one long coil and three short coils is used. There are two sets of such systems, one for measuring the LER magnets and the other for measuring the HER magnets. The analog signals from the coils are digitized by an integrator (PDI5025). A Fourier transform is performed to obtain the multipole components of the magnetic field. The accelerator control system EPICS[2] is used for data acquisition. The measurement begins by optically aligning the magnet with the harmonic coil system. Two plates welded to the upstream and downstream ends of the magnet yoke are used to hold the optical target, which supplies the reference. A five-axis mover is used for positioning the magnet into alignment with the measurement system. The magnets were measured at the same polarity (F-connection, F for focusing), unless mentioned otherwise. The integrated field strength (B'L) is measured at several different currents for each magnet. Dipole components measured by the short coils are used to calculate the transverse offset between the mechanical and magnetic centers along the beam axis. The alignment error and measurement reproducibility of B'L are estimated by measuring the same magnet (the standard magnet) every 10 days on average over the series measurement period.
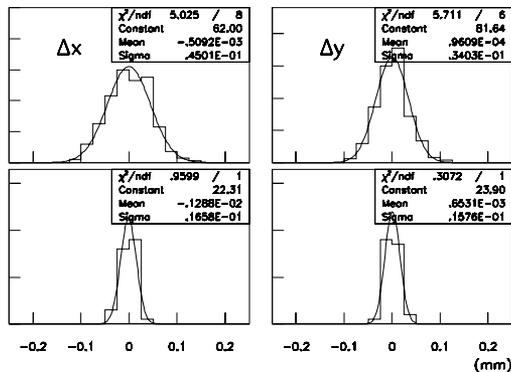
Figure 1: The error in determining the magnetic center is plotted for horizontal and vertical directions in the lower plots. The standard deviation of the distribution is ~15μm for both directions. The upper plots show the offsets between the mechanical (defined by the external fiducial points) and the magnetic centers in the horizontal and vertical directions, respectively, for the QA(LER)I magnets.

The lower plots in Figures 1 and 2 show the error and reproducibility distributions. An effort was made to keep the experimental condition as constant as possible. The temperature of the experimental area varied between 23.5 and 25.5 degree (with 0.5 degree in r.m.s.) while the temperature of the cooling water was kept constant during 18 months. The upper plots of Figure 1 shows the distribution of the offset between the mechanical and magnetic centers for the QA(LER)I magnets. The B'L distribution of the same set of data is shown in the upper plot in Figure 2. Both distributions are significantly broader than the error and reproducibility distributions.
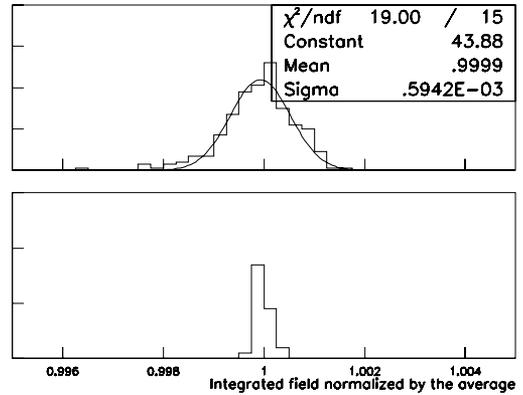
Figure 2: The standard magnet output (B'L) measured over the period of ~1 year is normalized by its average and plotted (bottom). The upper plot shows the B'L from all QA(LER)I magnets measured over the same period as a comparison.

2 NEWLY FABRICATED MAGNETS

The newly fabricated magnets were measured in parallel with production. Rapid feedback was given to the factory production line if a magnet failed to satisfy the specifications. B'L, the multipole components, the offset between the mechanical and the magnetic centers and the median plane are the main parameters checked by the series measurements. Table 1 gives the basic parameters of the newly fabricated magnets.

Magnet	r	L	B'	#
QA(LER)I	55	0.4	10.2	284
QA(LER)II	55	0.4	10.2	132
Qrf(LER)	83	0.5	6.32	42
QS(HER)	50	0.5	12.7	82
Qrf(HER)	83	1.0	6.32	44

Table 1: Magnet parameters for new magnets. Bore radius, lamination length and the field gradient are represented by r(mm), L(m) and B'(T/m), respectively. The last column gives the number of magnets manufactured.

The r.m.s. of the offsets (Δx and Δy) between the mechanical and the magnetic centers and B'L at the maximum current (500A) are summarized in Table 2. It is found that the r.m.s. of $\Delta x, \Delta y$ and B'L are small enough and satisfy the beam optics criteria[3].

Magnet	$\Delta x (\mu m)$	$\Delta y (\mu m)$	B'L/<B'L>
QA(LER)I	50	30	6.0e-04
QA(LER)II	40	40	7.0e-04
Qrf(LER)	30	30	6.8e-04
QS(HER)	60	50	4.8e-04
Qrf(HER)	50	40	5.2e-04

Table 2: The first two columns give the r.m.s. of the horizontal and vertical offsets Δx and Δy. The r.m.s of normalized (by the average) integrated field strength at the maximum current is given in the last column.

The requirements for the higher order multipoles are also satisfied for all types of quadrupole magnets. Shim corrections have been made for certain types of magnets in order to reduce the multipole components. Figure 3 shows the normalized multipole amplitudes evaluated at r=50 mm for the QA(LER)I magnets. The 6th multipole, the lowest allowed higher multipole, has been reduced after the shim correction.
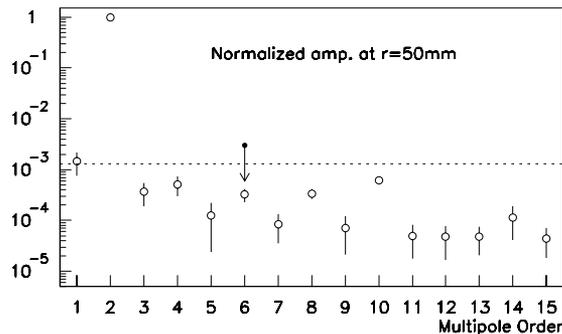
Figure 3: Normalized multipole amplitude plotted as a function of multipole order for the QA(LER)I magnets. The solid circle indicates the 6th multipole before the correction. The requirement for the lowest allowed multipole is indicated by a dotted line. The error bars correspond to one standard deviation of each multipole.

The median plane distribution of the QA(LER)II magnets is shown in Figure 4. The standard deviation is

~0.1 mrad, which is satisfactory from the alignment point of view.
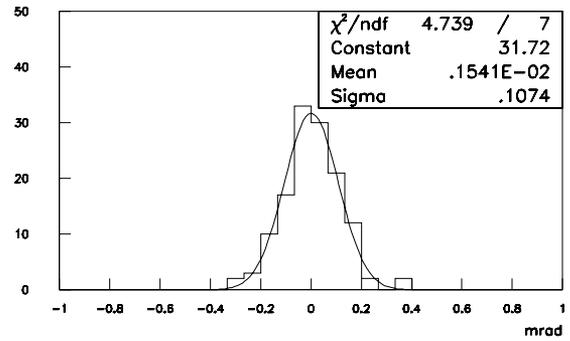
Figure 4: The QA(LER)II median plane distribution.

The series measurements detected several bad magnets.. Figure 5 shows an example of a bad magnet found among the Qs(HER) magnets. The main quadrupole amplitude was ~0.4% smaller than the average. The same magnet showed a larger sextupole component which indicates an unbalanced field. Electrical tests performed later showed that one of the coils was partially shorted. It was found that the coils were wound manually for the first ~10 magnets resulting in uneven winding, which is suspected as a cause of possible damage during transportation from the factory to KEK.
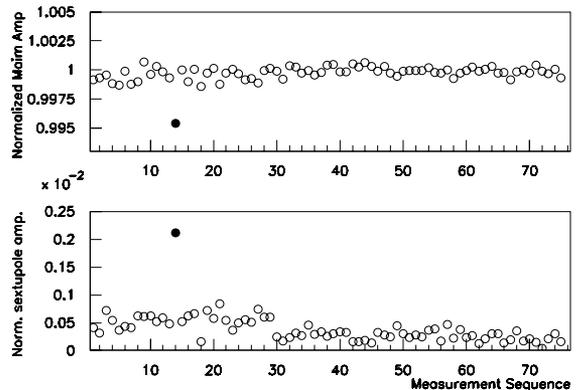
Figure 5: The main amplitude and the normalized sextupole component are plotted against the magnet measurement sequence. The solid circle in each plot (the 14th magnet to be measured) corresponds to the short-layered magnet.

3 RECYCLED TRISTAN MAGNETS

One-third of the quadrupole magnets are recycled TRISTAN magnets[1]. They were used as either focusing (F-type) or defocusing (D-type) lenses at a maximum current of 1500A during TRISTAN operation. These magnets were never demagnetized when they were later removed from the tunnel. They were measured under the same conditions as the new magnets with a maximum current of 500A, since they will be powered by 500A-capacity power supplies at the KEK B-factory. Figure 6

shows the B'L distribution at I=500A. There are two clear peaks; the TRISTAN F-type magnets form the upper peak and the D-type magnets form the lower peak. The difference between the former F-type and the D-type magnets has a current dependence, as shown in Figure 7. The effect of historical polarity is measured to be as large as 0.2% at I=500A. An attempt was made to evaluate and reduce the hysteresis effect with the available 500A power supply. A TRISTAN D-type magnet was initialized with F- and D- connections alternately. The field was measured at each connection to monitor the demagnetization process. Figure 8 shows the main amplitude after initialization at each polarity. The hysteresis effect, i.e. the difference between the F- and D-connections, is slightly reduced after a few initialization cycles at alternating polarity. However the amplitudes at F- and D-connection never converge to a common value. There still remains a significant dependence on the TRISTAN polarity. Thus it has been decided that TRISTAN F-type and D-type magnets should not be connected to the same power supply.
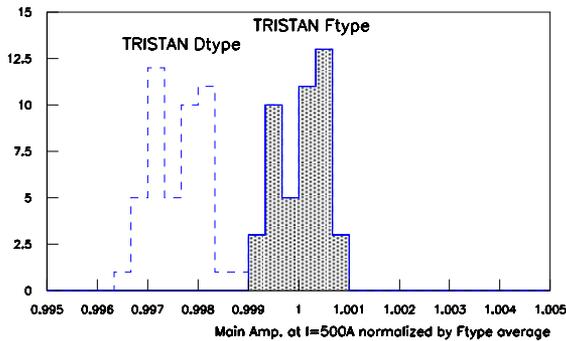
Figure 6: The main amplitude (normalized by the TRISTAN F-type average) distribution at I=500A.
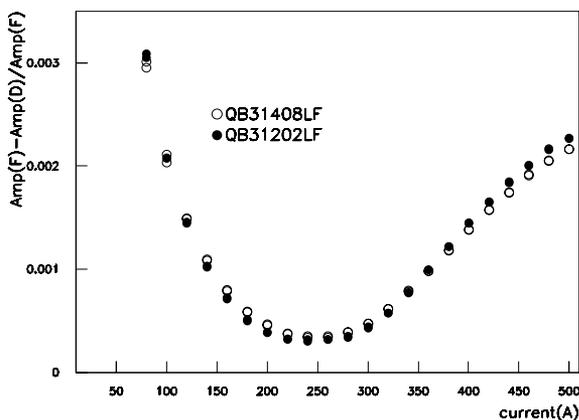
Figure 7: The difference in B'L between the F-and D-connections is plotted as a function of current for two TRISTAN F-type magnets. The hysteresis effect has a minimum at around I=250A. The B'L at I=500A will be ~0.2% smaller than what was measured by the series measurement (with F-connection) if these magnets are used as defocusing magnets in the KEK B-factory tunnel, for example.
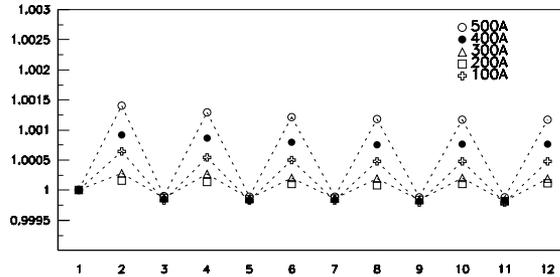
Figure 8: An attempt to reduce the hysteresis effect by alternating the polarity of the initialization. A TRISTAN D-type magnet was used. Even numbers on the horizontal axis indicate that the magnet was connected as D (the same polarity as in TRISTAN), while odd numbers indicate F (the reverse polarity). The amplitude is normalized by the amplitude of the first F-connection for each current. Since the magnet was originally operated as a D-type magnet at a maximum current of 1500A, it retains the D-type hysteresis. The effect could not be removed by the usual 500A initialization loop.

4 SUMMARY

The quality of the newly fabricated magnets and the recycled TRISTAN magnets were checked by the series magnetic field measurements. It was found that the r.m.s. of the offset between the mechanical and magnetic centers and B'L are smaller than the beam optics requirements. The requirements for the higher order multipoles are also satisfied for all types of quadrupole magnets. Several bad magnets were found by the measurements and the problems were taken care of before the installation.

The recycled TRISTAN magnets presented a hysteresis problem, coming from the fact that a proper demagnetization process was not undertaken upon removal from the TRISTAN tunnel. Some hysteresis was expected, but not as large as what has been observed by the field measurements. It has been decided to group them separately with respect to the KEKB power supplies. About 50 recycled TRISTAN magnets were measured with the same polarity as the new magnets (F-connection), independent of the original TRISTAN polarity. A correction is needed to translate the field strength from the series measurements to the actual operation with these magnets. The later measurements of ~250 magnets were performed with the KEKB polarity, in order to avoid any additional error due to the correction. The remaining work, such as the evaluation of the absolute value of the magnetic field, is under way.

REFERENCES

[1] 'TRISTAN electron-positron colliding beam project',KEK Report 86-24 March 1987
[2] T.Katoh *et al.*,'PRESENT STATUS OF THE KEKB Control System',T2-2 ID079,ICALEPCS97
[3] KEKB B-Factory Design Report 95-7