MAGNET PROTOTYPES FOR ANKA

D.Einfeld, A.Krüssel, M.Pont[1], Forschungszentrum Karlsruhe GmbH,
Projektgruppe Errichtung ANKA, Postfach 3640, D-76201 Karlsruhe, Germany

Abstract

ANKA is a 2.5 GeV Storage Ring consisting of 16 dipoles with a maximum field of 1.5 T, 40 quadrupoles divided in five families with a maximum gradient of 20 T/m, 24 sextupoles divided in two families with a maximum second order differential of 734 T/m^2, and 44 correctors [1]. A prototype of each different magnet has been built and the magnetic measurements have been performed for quadrupoles and sextupoles. The results of the electrical, mechanical and magnetic measurements are presented here.

1 MAGNETS FOR ANKA

ANKA has 40 quadrupoles grouped in five families, but there are only two physically different quadrupoles which differ with respect to their magnetic length and the number of turns per coil. The quadrupoles are named Q320 and Q390 after their effective magnetic length of 320 and 390 mm respectively. To check the field quality prior to the start of the series production, one prototype of each family was built by the French company Sigmaphi.

There are 24 sextupoles grouped in two families called SH and SV which differ on the number of turns per coil. The effective magnetic length of these magnets is 145 mm. One prototype of each family has also been built by Sigmaphi.

These prototypes were received in March 1998.

The prototypes have been built with steel 1200-100A from EBG, 1 mm thick. The quadrupole and the sextupole yokes have been produced by stacking the laminations and then applying a glueing process. The conductor is hollow Cu from Outukumpu.

The electrical and hydraulic measurements were in good agreement with the calculations that had been initially performed [2]. Regarding mechanical tolerances, quadrupole Q390 and the two sextupoles were within specified tolerances, but for Q320 the dispersion in the interpole distances was too large. This was due to a defect in the stacking tool. The results presented here correspond to a second prototype of Q320, built within tolerances, received in the middle of June 1998.

The prototype of the bending magnet is still under construction and will be delivered at the beginning of July 1998.

2 MAGNETIC MEASUREMENTS

The integrated gradient for both quadrupoles and sextupoles as well as the multipole content were measured using a Danfysik rotating coil system, model 692 [3].

The equipment allows to determine the integrated main harmonic with a relative accuracy of $\Delta b_{2,3}L/b_{2,3}L \leq \pm 3.10^{-4}$ whereas the ratio of the integrated field components b_nL with respect to the main harmonic is determined to $b_nL/b_{2,3}L \leq \pm 3.10^{-4}$.

3 QUADRUPOLE PROTOTYPES

3.1 Quadrupole design

The quadrupoles have been designed for a maximum magnetic field gradient of 20 T/m using the 2-d code POISSON [2,4]. The yoke is made of 4 identical quadrants. Both quadrupoles use the same cross section. The main parameters for these magnets are summarised in table 1.

Table 1: Main parameters for quadrupoles

Parameter	Units	Q320	Q390
Number of magnets		32	8
Nom. magnetic strength	m^{-2}	2.17	2.14
Nom. field gradient	T/m	18.10	17.85
Effective magnetic length	mm	320	390
Nom. integrated gradient	T	5.79	6.96
Aperture radius	mm	35	35
Yoke length	mm	285	355
Number of turns per coil		26	30
Conductor cross section	mm^2	10x10	10x10
Cooling channel diameter	mm	4	4
Number of A-turns	A-turns	9412	9000
Current	A	362	300
Resistance of magnet	mΩ	20.8	26.3
Inductance of magnet	mH	11.8	19.3
Power consumption	W	2725	2367
Number of cooling circuits		2	2
ΔT	deg	15	15
Water flow per circuit	l/min	1.2	1.1

3.2 Magnetic measurements

The first measurements were performed with no chamfer, i.e. with a right angle cut in the yoke at the end

[1] On leave of absence from IFAE-LSB, Barcelona, Spain

of the magnet. Quadrupole Q320 requires a nominal integrated gradient of 5.79 T, which is achieved with a current of 362 A. Due to the finite permeability of the iron as well as to the finite length of the magnet, there is a 5 % difference with the ideal integrated gradient. Q390 requires an integrated gradient of 6.96 T, which is achieved with a current of 300 A and a difference of 3 % with respect to the ideal value.

Different chamfers were tested to achieve an optimum quadrupolar field in the aperture defined by the vacuum chamber. Chamfers with a 45° cut and different lengths (L = 3, 4, 5, 6 and 7 mm) were prepared. There are two ways to decide among the chamfers:

- To minimise the high order harmonics
- To maximise the region were the magnetic field due to the high order harmonics with respect to the field due to the main harmonic is below a given level, for ANKA $b_nL/b_2L \leq 5.10^{-4}$

Figures 1 shows the measured harmonics for the Q390 quadrupole with the different chamfers relative to the main integrated harmonic b_2L. By enlarging the length of the chamfer, the strong negative dodecapole (n=6) component decreases and changes sign for a chamfer of 5 mm. The same behaviour has been observed for the second prototype of Q320.

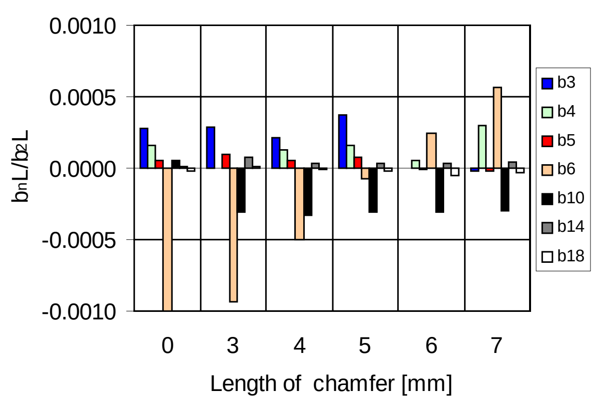

Figure 1: Relative multipole components of Q390 at 300 A using chamfers of different lengths. The normal components are shown

Skew components are not shown as they are smaller than 5.10^{-4} for all the harmonics for both quadrupoles.

Figure 2 shows deviation from the pure quadrupolar field at the walls of the vacuum chamber. Theta is the polar angle with 0 in the horizontal mid plane. For a chamfer around 5-6 mm the relative contribution of high order field components is below 5.10^{-4} around the vacuum chamber.

A chamfer with L=5 mm has been chosen for both quadrupoles [5]. Table 2 shows the measured integrated gradient for Q320 and Q390 with the 5 mm chamfer at different currents.

Table 2: Integrated gradient for Q320 and Q390

Current [A]	gL [T] for Q320	gL [T] for Q390
100	1.72	2.41
200	3.41	4.77
300	5.04	6.97
400	6.09	8.09

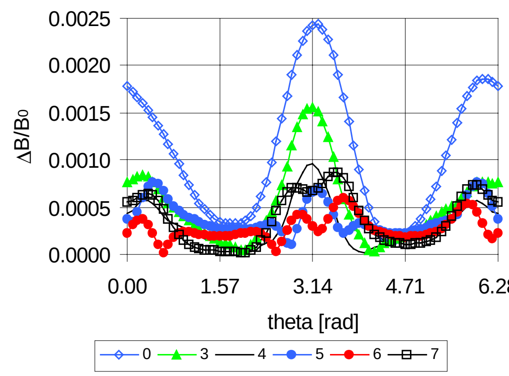

Figure 2: Deviation from the pure quadrupolar field at the walls of the vacuum chamber for quadrupole Q390 with different chamfers at 300 A

4 SEXTUPOLE PROTOYPES

4.1 Sextupole Design

The sextupoles have been designed for a maximum magnetic second order differential of 700 T/m^2 though they will be used at a much smaller strength. Both sextupoles use the same cross section. The 2-d code POISSON [2,4] has been used. The main parameters for these magnets are summarised in table 3.

Table 3: Main parameters for the ANKA sextupoles

Parameter	Units	SH	SV
Number of magnets		8	16
Nom. magnetic strength	m^{-3}	66.1	57.8
Nom. field gradient	T/m^2	551.10	481.7
Effective magnetic length	mm	145	145
Nom. integrated gradient	T/m	79.9	69.8
Aperture radius	mm	37.5	37.5
Yoke length	mm	120	120
Number of turns per coil		20	18
Conductor cross section	mm^2	7 x 7	7 x 7
Cooling channel diameter	mm	3	3
Number of A-turns	A-turns	4000	3420
Current	A	200	190
Resistance of magnet	mΩ	25.5	22.9
Power consumption	W	1020	827
Number of cooling circuits		2	2
ΔT	deg	15	15
Water flow per circuit	l/min	0.5	0.4

4.2 Magnetic measurements

The first measurements on the sextupoles were performed with no chamfer. Sextupole SH requires a nominal integrated gradient of 79.9 T/m, which is achieved with a current of 200 A. On the other hand, SV requires an integrated gradient of 69.8 T/m, which is achieved with 190 A. The difference for both magnets to the ideal value is around 1 %.

Different chamfers were tested to achieve an optimum sextupolar field in the aperture defined by the vacuum chamber. Chamfers with a 45° cut and different lengths (L = 3, 6, 9 and 12 mm) were prepared. The same procedure as for the quadrupoles was applied, with the requirement that $b_nL/b_3L \leq 5.10^{-3}$

Figure 3 shows the measured harmonics for the SH sextupole. By enlarging the length of the chamfer, the negative n=9 component decreases slightly whereas the also negative n=15 component remains more or less constant. The rest of the multipoles are all below 1.10^{-3}. The same is true for the skew components. Equivalent results have been obtained for SV.

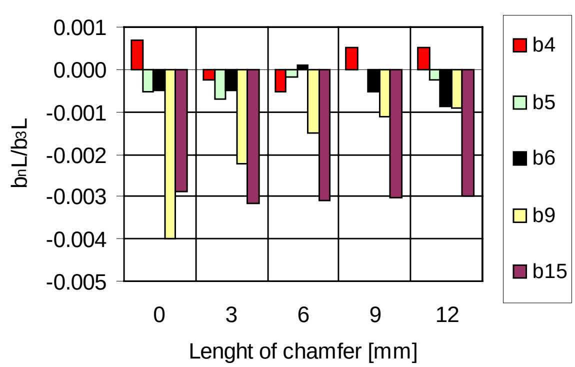

Figure 3: Relative multipole components of SH at 200 A using chamfers of different lengths. Normal components

Figure 4 shows the deviation from a pure sextupolar field at the walls of the vacuum chamber for sextupole SH measured at 200 A. Analysing this plot for the different chamfers and for both sextupoles it is observed that the field due to the high order multipoles is kept to a minimum inside the vacuum aperture for a chamfer with a length around 9 mm.

A chamfer with L=9 mm has been chosen for both sextupoles [6]. Table 4 shows the integrated gradient for SH and SV with the 9 mm chamfer at different currents.

Table 4: Integrated gradient for SH and SV

Current [A]	g'L [T/m] for SH	g'L [T/m] for SV
50	20.0	18.0
100	39.5	35.6
200	77.9	70.2
250	95.2	86.8

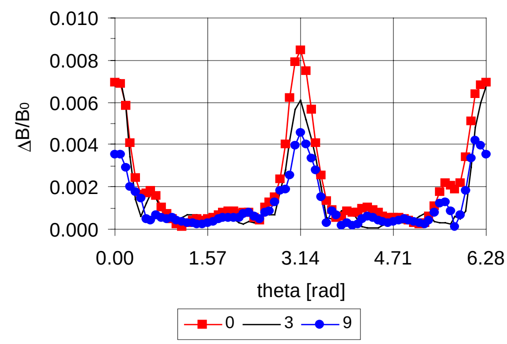

Figure 4: Relative field error at the walls of the vacuum chamber for sextupole SH at 200 A

5 CONCLUSIONS

The prototypes for the quadrupoles and sextupoles of ANKA have been measured. Chamfers of different lengths have been used to minimise the field contribution of higher harmonics to the measured field in the aperture defined by the vacuum chamber. By using a chamfer 5 mm long for the quadrupoles, this contribution is kept below 5.10^{-4} in the full vacuum aperture. For the sextupoles a chamfer of 9 mm keeps the high order harmonics below 5.10^{-3} in the full aperture. Preliminary calculations indicate that the measured multipoles have a negligible effect on the dynamic aperture of ANKA.

Acknowledgements

The authors want to thank especially D.Krämer, F.Radecke, and U.Strönisch from BESSY-II where the measurements were performed for their effort and help to get these prototypes measured.

The authors also want to thank E.Rathjen for performing the mechanical measurements.

REFERENCES

1 G.Buth et al. Status of the 2.5 GeV light source ANKA, this Conference

2 D.Einfeld et al. EPAC 96, June 1996, page 2179

3 Danfysik Model 692 User Manual, Danfysik A/S, (DK)

4 POISSON, User Manual LA-UR-96-1834, Los Alamos 1996

5 M.Pont, A.Krüssel, Technical Report, MAG-98/02

6 M.Pont, A.Krüssel, Technical Report MAG-98/03