Magnets for TRIUMF'S KAON Factory

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Abstract

The KAON Factory will require over 2000 magnets to transport protons from the existing 500 Mev cyclotron through three storage rings and two synchrotrons and deliver them to the experimental area at 30 Gev.

The magnet requirements are summarized and the results of measurements on prototypes for the 50 hz Booster magnets are compared with design values.

This paper will address three topics. The results of our prototype work, some of the more difficult design aspects of other magnets and the tolerances required to achieve production magnets uniform to ± 2 parts in 10^4.

I. INTRODUCTION

The KAON Factory Proposal has been presented several times [1-3]. It will require 1448 magnets in the rings and a further 548 in the transfer lines, the experimental hall and secondary beam lines. The ring magnet parameters are shown in Table 1. The advent of synchrotrons at TRIUMF required the design of ac magnets for the first time so a prototype 50 Hz dipole and quadrupole, Figs. 1 & 2, were built for the Booster ring

II. PROTOTYPE MAGNETS

A. Dipole

Parameters for the dipole and quadrupole prototypes were presented in Chicago [4]. The dipole was designed, fabricated and made ready for testing in a time interval of 18 months. The lessons from the manufacture were:

- The prototype serves as a test for the manufacturing procedures as well as testing the electrical and magnetic properties of the magnet.
- Modifications to laminations by cutting them with a laser cutting machine to shape the pole ends and make slits was very successful.
- It is necessary to set up special equipment to measure flatness to better than ± 0.5 mm over the 3 m length, the best way to measure the pole end profiles is with a template.
- The steel packing factor was estimated to be 97.9%, and the epoxy thickness 0.0004 in.

The magnet was set up and tested at the maximum rated current though not at the correct ratio of ac to dc current. The power supply stability did not permit measurements at the 10^{-4} level with ac excitation. The inductance varied 0.5% with excitation current and affected the tune of the power supply resonant circuit [5]. Measurements were made with dc current only, ac current only and combinations of both with the ac frequency at 32 Hz and 50.1 Hz.

The effective length was very close to the POISSON values. Figure 3A shows the values at peak, dc and minimum fields, the variation observed with excitation may be due in part to the power supply. The transverse field also agreed with the predicted values. Figure 3B.

Coil eddy current losses are 20% higher than estimated for the coil pancake in the highest field region adjacent to the magnet gap.

Core losses are not easy to measure directly but from the temperature rise it was determined that it is not necessary to cool the core or to put slits at the end of the poles adjacent to the coils.

Small effects observed in the field measurements due to eddy currents, in the coil and the end laminations, appear to have an insignificant effect on the overall field characteristics.

The measurements were made using a Hall probe with a fast sampling digital multimeter which allowed the field to be measured every 1.0 ms so we obtained 20 values per excitation cycle at 50 Hz [7]. We believe that this is the first time that this technique has been used for production measurements.

B. Quadrupole

The magnet is shown in Fig. 2 and has indirectly cooled coils. The cooling circuit is a square stainless steel tube sandwiched between an inner and an outer saddle winding using 8 parallel ribbon conductors.

The yoke manufacture presented no problems and gave a packing factor estimated at 96% from steel weight measurements.

The stainless cooling array cannot be wound by normal coil winding techniques but has to be bent one turn at a time and welded together. The ribbon conductors have a tendency to twist at the bends and care must be exercised to avoid inter-turn shorts.

The magnet measurements are incomplete. A Morgan coil system based on a printed circuit coil array is being made for this measurement.

III. KAON FACTORY MAGNET DESIGN CHALLENGES

Preliminary designs have been made for most of the magnets listed in Table 1, these have been used for estimating purposes and for specifying power supplies and space requirements. The Driver ring magnets will be the

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Table I. Magnet parameters for the rings.

DIPOLES

Ring	Effective Length (m)	Vertical Aperture (m)	Max. Field (T)	Pole Width (m)	Quantity
A dc	1.00	0.092	0.882	0.24	24
B 50 Hz	2.99	0.108	1.118	0.28	25
C dc	1.00	0.070	0.834	0.18	96
D 10 Hz	4.89	0.100	1.381	0.28	96
E dc	3.90	0.052	1.731	0.25	96

One extra B-ring magnet is included for power supply purposes

QUADRUPOLES

Ring	Type	Effective Length (m)	Bore Radius (m)	Pole Tip Field (T)	Max. Gradient (T/m)	Quantity
A	F and D	0.3	0.067	0.284	4.25	51
B	F	0.46	0.071	0.604	8.51	24
	D	0.36	0.071	0.890	12.53	24
C	F and D	0.2–0.4	0.065	0.64	9.78	96
	SS	0.2	0.050	0.52	10.39	40
D	F and D	0.94–1.69	0.074	0.98	13.24	96
	SS1	1.09–1.24	0.052	0.98	18.84	12
	SS2	0.68–0.94	0.061	0.98	16.06	28
E	F	1.4–1.8	0.043	0.521	12.12	48
	D	0.82	0.062	0.99	15.96	48
	SS1	1.1–1.6	0.035	0.842	24.06	12
	SS2	0.7–1.3	0.049	0.942	19.22	20

SEXTUPOLES

Ring	Effective Length (m)	Bore Radius (m)	Pole Tip Field (T)	Maximum Gradient (T/m^2)	Quantity
A F	0.2	0.073	0.021	3.937	12
D	0.2	0.073	0.015	2.760	12
B F	0.2	0.073	0.079	14.89	12
D	0.2	0.073	0.056	10.44	12
C F	0.2	0.086	0.103	13.93	24
D	0.2	0.058	0.050	14.94	12
D F	0.2	0.086	0.834	112.8	24
D	0.2	0.058	0.407	121.0	12
E F	0.2	0.070	0.553	112.9	24
D	0.2	0.058	0.407	121.0	12

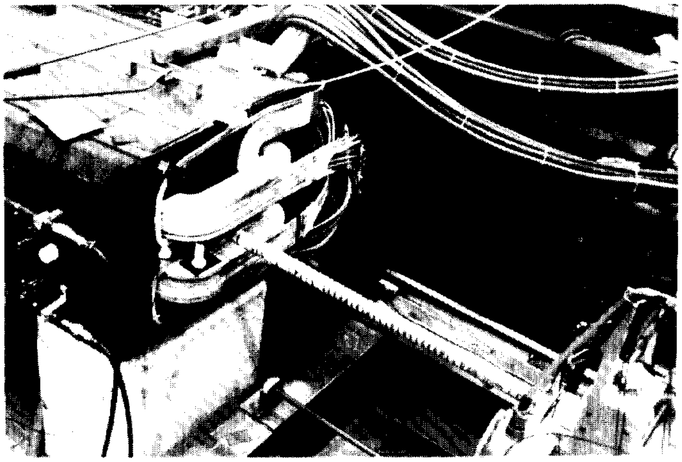

Figure 1: Prototype dipole during magnetic testing.

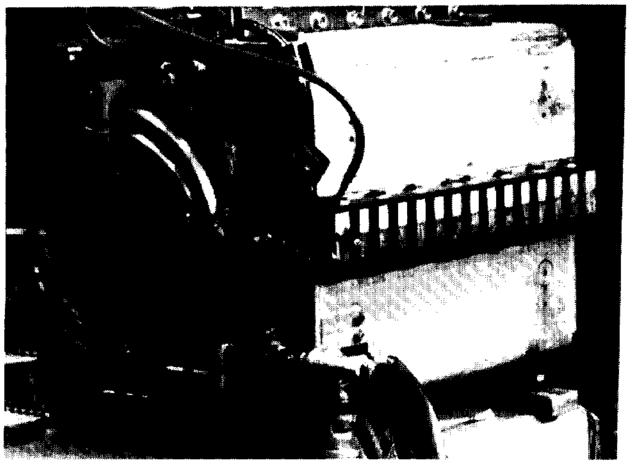

Figure 2: Indirectly cooled prototype Booster ring quadrupole.

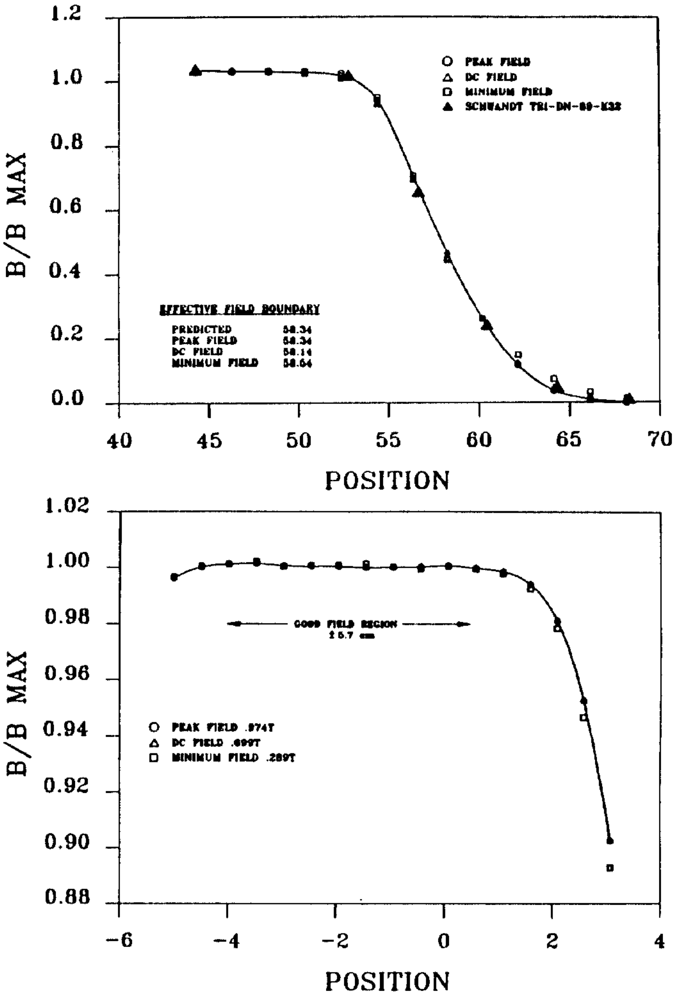

Figure 3: a) Effective length and 3b) transverse field profile measured at 3000 A dc and 860 A rms ac @50.1 Hz.

major cost component and also the critical path item. The quadrupoles will have their coils away from the median plane. These magnets have a specified pole tip field of 0.98 T so the coils will experience high leakage fluxes near the pole corners which will generate eddy current losses in the copper. A study with TOSCA [8] has shown that the magnet should track with the dipole and that the harmonics are within tolerance.

There are several families of quadrupoles in which varying strengths will be obtained by keeping the pole tip field constant and varying the length. In this way tracking errors should be reduced to a minimum. Sextupoles have been specified with large bore to length ratios which will require the use of a three dimensional code for the physics design.

IV. TOLERANCES FOR MAGNET UNIFORMITY

The specification for magnet uniformity is generally ± 0.02% for the integral of field times effective length. An evaluation of manufacturing parameters for the E-Ring dipoles including the effect of variation of the steel permeability shows that the magnets must have some built-in adjustment to achieve this tolerance. Without considering steel permeability variations it can be shown that length, gap and field uniformity tolerances combine to produce a variation of 2.9 parts in 10^4.

The variation of the field due to steel permeability depends upon the flux density in the magnet yokes. A POISSON evaluation based on the variation of permeability permitted by CERN for low carbon steel [9] showed that prior to any sorting of the steel variations of 89 parts in 10^4 could be expected

The results for two steels at varying flux density in the yokes are shown below-

Yoke flux	Δ B/B due to permeability tolerance	
Density T	C-1010	very Low Carbon
1.66	0.0089	0.0128
1.40	0.0079	0.0073
1.20	0.0071	0.0065

This variation can be reduced by a factor of six by sorting according to coercivity [10].

Ac magnets will have similar variations in the steel characteristics, no B-H data is available but the core losses for M17 steel can vary within 10% at 1.5 T. For these reasons all magnets will need some means of adjustment to set the field within tolerance at a common current.

V. REFERENCES

[1] M.K. Craddock, "The TRIUMF KAON Factory", these proceedings

[2] "KAON FACTORY STUDY - Accelerator Design Report", TRIUMF, 1990.

[3] M.K. Craddock *et al.*, "TRIUMF KAON Factory Pre Construction Study" *Proc. 1989 Particle Accelerator Conf.*, Chicago, pp 450-452.

[4] A.J. Otter, C. Haddock and P. Reeve, "Prototype Designs and Loss Measurements for the Dual Frequency Booster Synchrotron for TRIUMF's KAON Factory" *ibid.*, Chicago, pp 390-392.

[5] K.W. Reiniger, "Power Supply System for the TRIUMF KAON Factory", these proceedings.

[6] P. Schwandt, "An Improved Magnetic Design For the Booster Ring Dipoles", TRI-DN-89-K32, April 1989.

[7] C. Haddock *et al.*, "Prototype Booster Magnet Measurements " TRI-DN-89-K60, August 1989.

[8] D. Orrell "Designs for a Quadrupole in The Driver Ring", TRI-DN-89-K79, October 1989.

[9] "Steel Sheets for SC Magnets", CERN Technical Specification AT/MA 90-02, I-1835/AT.

[10] H.Laeger *et al.*, "Production of the Soft Magnetic Steel Laminations for the LEP Dipole Magnets", IEEE Trans. Magnetics, vol 24, No 2, March 1988, pp 835-838.