IEEE Transactions on Nuclear Science, Vol.NS-24, No.3, June 1977

PROTOTYPE AND PROPOSED "ISABELLE"* DIPOLES†

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SUMMARY

Data are presented on the latest dipole prototypes to update the operational parameters possible for ISABELLE. This data base will constantly expand until the start of construction of the storage rings. The data will include field quality, stray field magnitudes, quench temperature and propagation times, protection capabilities singly and in multiple units, maximum central fields obtained and training behavior. Performance of the dipoles versus temperature and mode of refrigeration will be discussed. The single layer cosine θ turns distribution coils' parameters are better than those required for the operation of the 200 × 200 GeV version of ISABELLE. The double layer prototype has exceeded the magnetic field performance and two dimensional quality of field needed for the 400 × 400 GeV version of ISABELLE.

INTRODUCTION

At the conclusion of the "1975" ISABELLE Summer Study at Brookhaven, the magnet study group made several specific recommendations that could implement and expedite machine construction and still minimize the technical unknowns.[1] The working group had made some specific recommendations which could be divided into two groups, the first group predicated on the possibility that machine construction was eminent and the second, those to be explored assuming a longer time interval before start of construction. This paper is a report of the present status in both groups of recommendations as far as the dipoles are concerned.

A pair of dipoles previously tested individually are presently being run in series with a full scale quadrupole[2] comprising the first subunit of the machine with which series quench and systems operations may be studied.

The shortcomings of the earlier magnets [i.e. low ultimate peak field, low quench velocities, and poor lead (current) arrangement] have been corrected. The standard magnet series MK II, V and VI (two of which have been tested in the forced flow mode) have exceeded the specifications set down at the Summer Study for a 4.0 T, 4.25 m operating dipole (4.8 T at 4.5 K). The harmonic content has steadily improved with each generation. The quench propagation velocity has been improved to the point that the maximum coil temperature difference between II and V was over a factor of two. The training quenches required to reach the 10^{-12} Ωcm strand performance point is less than half.

The first multilayer dipole constructed surpassed the design field required for the 5.5 T machine magnet with its ultimate performance in excess of 6.2 T at 4.3 K. It was able to absorb its own energy during quench.

PARAMETERS

The major design aspects of the single layer dipoles have been presented in earlier papers.[3,4] Only minor design changes have occurred between MK II, III, IV, V and VI which have lead to reduced $\dot{B}$ effects, faster quench front propagation, higher end field quality (integral), and better training performance. Table I lists all of the current dipole magnets (excluding the Nb_3Sn dipoles) and the important parameters.

As noted, each series of dipoles (usually a pair) are designed to specifically eliminate an undesired characteristic of the preceding without losing any of its strong points.

QUENCH PERFORMANCE

The training and ultimate strand performance of each set of magnets that have been obtained to date is given in Table I.

HARMONICS

The harmonic data are presented for the various magnets in Figs. 1, 2, and 3 for the major impurities.

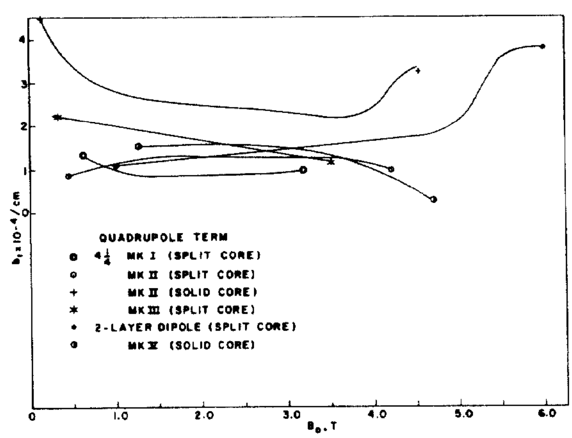

Fig. 1. Quadrupole component of the various magnets as a function of B(0,0), which is probably the upper bound.

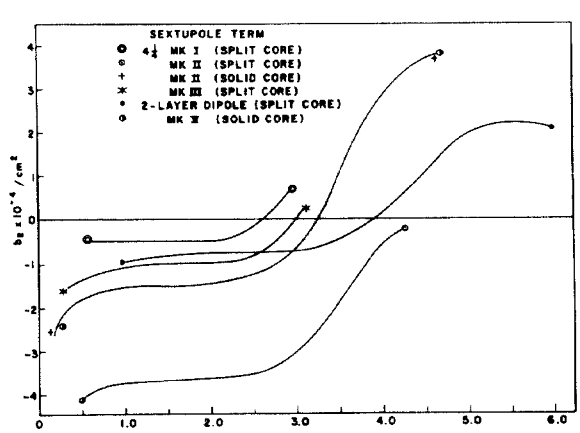

Fig. 2. Sextupole component of the various magnets as a function of B(0,0). Notice the typical shape due to the iron shield saturating.

*A pair of intersecting 200 GeV proton accelerating storage rings utilizing superconducting coils.

†Work performed under the auspices of the U.S. Energy Research & Development Administration.

Table I. Prototype Magnet Parameters

	ISA (4.25 m) SERIES DIPOLES					
	I	II	IIF	III&IV	V&VI	DOUBLE LAYER I
				1 tested	1 tested	
MAGNETIC FIELD						
(T)[a]	3.92	3.97	3.97	3.94	3.95	6.0
Grad. (mT/cm)	0.36	1.0	2.4	0.51	0.51	0.5
B/I (mT/A)$\mu = \infty$	1.246	1.26	1.26	1.255	1.255	2.23
B/I (mT/A) air	0.72	0.73	0.73	0.73	0.73	1.3
Max B(0,0) Achieved	3.6	4.7	4.95[b]	3.75	4.9[c]	6.2[d]
PERFORMANCE H(0,0) T						
First Quench	2.9	4.0	3.95	3.6	4.12[f]	4.96
No. of Quenches	8	22	21	2	9	24
Last Quench H(0,0) T	3.5	4.7	4.9	3.75	4.9	6.2
Min. Temp. (K)	4.25	4.25	4.1	4.25	4.6	4.2
(% 10^{-12} Ωcm) 1st TO LAST QUENCH	54% → 66%	75% → 88%	75% → 98%	68% → 71%	98% → 102%	73% → 97%
CURRENT DENSITY "J" (kA/cm^2)						
(incl. insul.)[a]	24.8	24.8	24.8	24.8	24.8	21.9
(Braid & filler)[a]	30.0	30.0	30.0	30.0	30.0	26.7
Max J in series	24.0	35.5	39.4	27	38.5	29.2
HARMONIC COEFF (2D) H(0,0) = 3.2 T						
$b_2 \times 10^4$ cm^{-2}	-0.46	-2.7	-0.7	-0.2	-0.1	-0.75
$b_4 \times 10^6$ cm^{-4}	0.56	8.0	1.36	3.9	0.18	17.0
MAX. ENERGY INTERNALLY DISSIPATED (kJ)	294	570	688	333	655	216
MAGNETIC LENGTH (cm)	410.7	405.6	405.6	408.8	408	98.6
10 K RESISTANCE (mΩ)	270	250	250	255	255	105
INDUCTANCE (mH)	78	73	73	75	75	48
MAGNETIZATION						
Time Const. (1/e) sec.	18.5	38	38	18.5	38	38
Loss/cycle (J/$\oint$) $\dot{B}$ = o	292	288	288	288	288	139.6
ISA $\oint$ (composite)	324	320	320	324	320	167.5
ISA $\oint$ (meas) W/m		1.36		1.30		
REFRIGERATION MODE	Pool	Pool	Forced Flow	Pool	Forced Flow	Pool
QUENCH TIME CONST.[e] (sec)	est. 0.80+	0.250	0.250	0.688	0.180	0.350
REASON FOR TERMINATION	Opened Turn	Finished	Finished	Shorted Turn	Partially Finished	Ran Out of Liquid

[a]Design; [b]4.1K; [c]4.63K; [d]Still Training; [e]1/e Current decay with 5 mΩ across magnet during superconducting to normal state transition; and [f]5.6 K. The magnet performance is determined by the actual short sample of each wire strand from which the braid was fabricated.

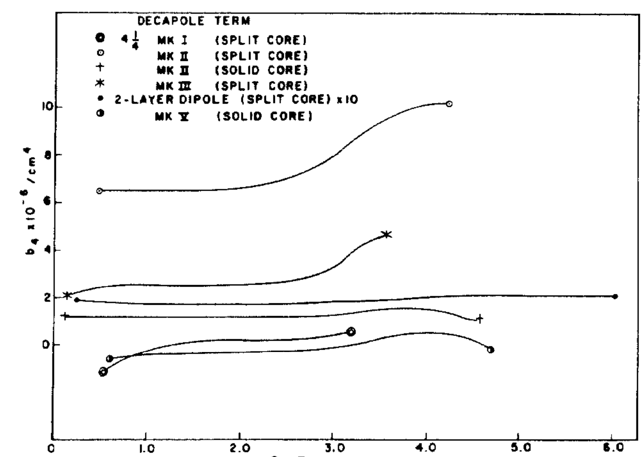

Fig. 3. Decapole component of the various magnets as a function of B(0,0).

The quadrupole term is affected by the accuracy of the alignment of the search coil to the main dipole but the data represents the upper bound on the value for the coil. The very low values for MK I vs MK V may be a reflection of the increase in sophistication and evolution of the measuring apparatus. The magnets from MK III on are integrally corrected in each end locally to about the same accuracy as the straight section or better. With the correction coils (sextupole and decapole) powered these terms can be reduced from 1/50 to 1/100 of their uncorrected values.

The rate of magnetic field change has an effect on the harmonics $[b_2(\mathrm{up}) - b_2(\mathrm{down})]/2$ of 1×10^{-5}/cm^2 for MK-III to 0.8×10^{-5}/cm^2 for MK V. The high field magnet was 1.1×10^{-5}/cm^2. These values were obtained with a 30 mT/sec ramp rate of the dipole field.

The B/I characteristics of the various magnets as measured are given in Fig. 4.

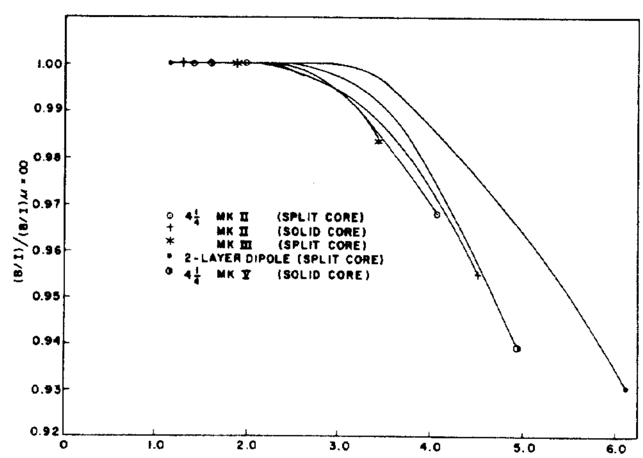

Fig. 4. Saturation characteristics for the various dipoles constructed as a function of B(0,0). The non-split core is 2.5 cm larger radially.

MAGNETIZATION

The losses of the magnets MK II - VI are 1.25 ± 0.05 W/m of magnet. The magnetization loop[4] and harmonic content variations shows the mechanical deformation of the coils to be less than 50 microns except in the case of the double layer magnet where the data has not yet been obtained.

QUENCH CHARACTERISTICS

As the string of dipoles and quadrupoles for series operation becomes longer and the magnets quench, the high temperature helium gas velocities as well as the ability of the magnet to absorb energy all become critical. Using the protection scheme now envisioned[5] one to as many as three magnets will have to absorb their own energy; this allows a minimum of circuitry and high current penetrations to the dewar system. The latest magnets have a (1/e) decay of their current with an internal dump of 0.160 sec and maximum temperature below 50 K, therefore minimizing local thermomechanical stresses. The double layer magnet quenches radially - either outer to inner coil or vice versa in approximately 0.05 sec after the initiating coil starts to go normal, therefore indicating a high probability that a full length version could dissipate all of its energy internally. The minimizing of the coil temperature and the resulting gas temperature is covered in another paper in this conference.[5]

EXTERNAL FIELDS OF MAGNETS IN SPLIT Fe SHIELD

The dipole external field data was obtained for both single and double layer magnets with the split Fe shield with a 40.7 cm outer diameter. The hall probes were located 0.5 cm from the outer iron surface.

Table II. External Field of Dipoles

Central Field		1.0	2.0	3.0	4.0	5.0	6.0	T
Single Layer	Midplane	5.6	17.1	30.2	52.1	70.0[a]	-	mT
	Pole	1.0	4.5	7.0	14.0	-	-	mT
Double Layer	Midplane	0.6	14.0	21.0	38.5	58.0	90.0	mT
	Pole	-	2.0	4.0	8.5	25.0	58.0	mT

[a]Estimated (4.7 T meas.)

CONCLUSIONS

The remaining questions that need to be answered as far as the dipoles for the "ISABELLE" ring are concerned have to do with systems operation and its interaction with the refrigeration system and operation within beam optics tolerances. Improvements in the dipole magnets will probably evolve higher metal densities or packing fractions, higher turns densities, and better superconductor strand performance. The double layer structure will evolve into a more homogeneous structure enabling higher fields and field quality. Figure 5 is a photograph of the half-cell under construction as the first basic machine subunit.

Fig. 5. Half-cell of ISABELLE including MK IIF, V and QUAD I right to left repectively, with the tunnel visible on the left over the quadrupole.

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ACKNOWLEDGMENTS

It is obvious the author list does not include the names of all of the individuals who have directly and indirectly contributed to the present status of the ISABELLE dipoles. The authors would like to express their special thanks to the dewar fabrication team, cryogenics team, braid and magnet fabrication teams of the ISABELLE Division of BNL. The BNL heavy shop and the Airco superconductor unit deserve a special vote of thanks.