CONF-760829--38

1976 Applied Superconductivity Conf., Stanford University, Palo Alto, Calif. 8/17-20/76 BNL 2170,

AGS SUPERCONDUCTING BENDING MAGNETS*

K.E. Robins, W.B. Sampson, A.D. McInturff, P.F. Dahl, F. Abbatiello, J. Aggus, J. Bamberger,
D. Brown, R. Damm, D. Kassner, C. Lasky and A. Schlafke+

ABSTRACT

Four large aperture superconducting bending magnets are being built for use in the experimental beams at the AGS. Each of these magnets is 2.5 m long and has a room temperature aperture of 20 cm. The magnets are similar in design to the dipoles being developed for ISABELLE and employ a low temperature iron core. Results are presented on the "training" behavior of the magnets and a comparison will be made with the smaller aperture versions of this design. The magnet field measurements include end fields and leakage fields as well as the harmonic components of the straight section of the magnet.

I. INTRODUCTION

A new high energy unseparated beam (HEUB) line from the AGS, incorporating four large aperture dipoles capable of deflecting 30 GeV/c secondary particles a total of 20°, is presently being constructed. All four magnets have been wound, and three have undergone preliminary tests in their cryostats. Two are now being installed in the AGS experimental area, and the remaining two will be added shortly. The refrigerator[1] operates satisfactorily, and has served temporarily as a facility for testing prototype ISABELLE magnets.[2]

The dipole design, shown in Fig. 1, has been presented in considerable detail elsewhere.[3] The ISABELLE ring magnets are essentially smaller aperture versions of the same basic design. Each dipole is 2.5 m long, and has a room temperature aperture of 20 cm diameter. The winding consists of a single layer of braided conductor impregnated with soft metal, 2 cm wide and 0.06 cm thick, containing 95 wires of 0.3 mm diameter with 517 NbTi filaments in a copper matrix surrounded by a cupro-nickel jacket. The conductor is grouped in blocks of approximately equal width, forming a current density distribution varying azimuthally as the cosine of the angle from the median plane, by appropriately interleaving spacers braided from copper wires. (The original design called for spacers braided from stainless steel, but experience with the 4.25 m long ISABELLE magnets indicated the desirability of replacing these with copper braids which are incorporated in the turns themselves, in order to minimize the thermal barriers between turns in the low current density sections and ensure azimuthal normal zone propagation during quenching.) The laminated cylindrical iron shield is at liquid helium temperature. It is constructed in two halves with the split on the median plane. The coil is inserted in the shield by a shrink fitting technique after the two shield halves have been welded together and integrally honed -- a technique developed during the actual construction of the coils. Sextupole and decapole field correction coils are incorporated in the design, in the form of 1-block approximations to cos 3θ and cos 5θ distributions, located internal to the main winding and wound from series connected strands cabled from the same basic composite wire as in the main conductor.

Various magnet design and measured parameters are listed in Table I.

Table I

Magnet Parameters

Warm bore	20 cm
Coil i.d.	25 cm
Winding thickness (conductor width)	2.03 cm
Iron i.d.	29.8 cm
Iron thickness	25.7 cm
Lamination length	2.5 m
Magnetic length	2.29 m (HEUB I) 2.30 m (HEUB IV)
Magnet weight	~10^4 kg
Inductance	0.28 mH
B/I ($\mu = \infty$)	15.4 G/A
B/I (4.0 T)	15.15 G/A
Design field	4.0 T
Magnet current (4.0 T)	2650 A
Current density (including insulation - 4.0 T, 4.3 K)	19.0 kA/cm^2
Stored energy (4.0 T)	1.04 mJ
Heat load (magnet + dewar + leads)	~ 100 ±25 W

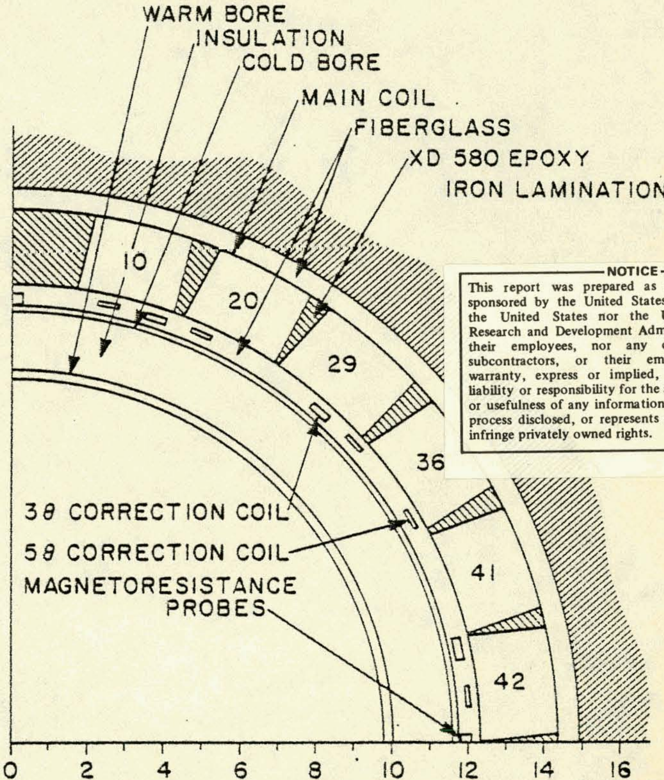

Fig. 1. Magnet cross section.

Figure 2 shows one magnet being installed in its cryostat, and Fig. 3 the magnet ready for testing. The refrigeration system has also been described elsewhere.[3] It has operated in excess of 1300 W, or considerably greater than the expected heat load of the four magnets. (The system was designed to provide sufficient capacity for superconducting quadrupoles -- subsequently eliminated due to limitation on resources --

---

Manuscript received August 16, 1976.

*Work performed under the auspices of the U.S. Energy Research and Development Administration.

+Brookhaven National Laboratory, Upton, New York 11973

CONTRACT NO. E(30-1)-16

as well as the dipoles.) The cryostat design uses a single leg support for the magnet with all services connected through a "conning tower" in the center of the vessel at the top.

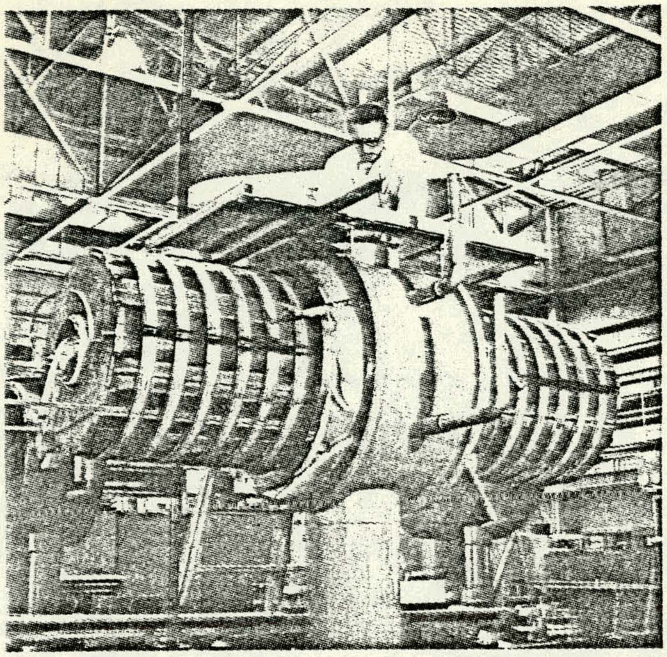

Fig. 2. Magnet being installed in cryostat.

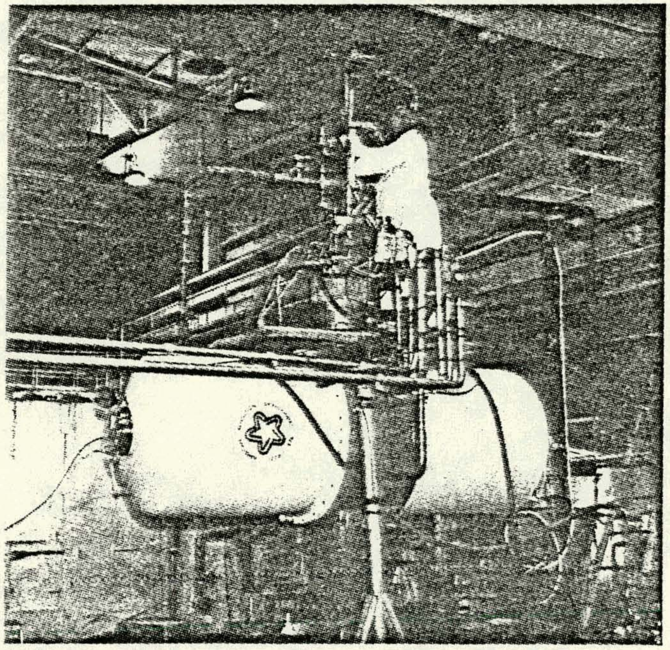

Fig. 3. Magnet ready for tests.

II. QUENCH PERFORMANCE

Three of the four magnets, HEUB I, II and IV (designating the order of coil winding), have undergone preliminary tests in their cryostats, utilizing a general purpose Claude cycle refrigerator of nominally 200 W capacity. HEUB II, tested first, attained 3.27 T on the first quench, and 3.52 T on the second quench which resulted in a short between coils and conductor damage. This magnet has been disassembled and repaired. Next to be tested was HEUB I, followed by HEUB IV. Their initial quench performance is shown in Fig. 4. In both cases the design field was attained or exceeded after few quenches: HEUB I reached 4.0 T and HEUB IV 4.14 T on the 5th quench, at which point no further quenching was attempted, although the magnets appeared to be still training, until magnet installation in the beam line is completed. Further training is also expected on the basis of the conductor short sample characteristics (short sample field limit ~ 25% above the design field) and the performance of the ISABELLE model dipoles[2] which are based on similar conductor and construction technique. Note that at 4.0 T the stored energy is approximately 1 mJ, and was dissipated completely in the magnet during these tests. At operating field levels simulated power supply failure runs confirm the magnets ability to sustain deexcitation at the rate of $\dot{B} \sim 10$ mT/sec without quenching, using an energy extraction system consisting of a power diode and external resistors placed in parallel with the magnet.

At 4.0 T the iron saturation, in terms of deviation of the current-field curve from linearity, is approximately 2%.

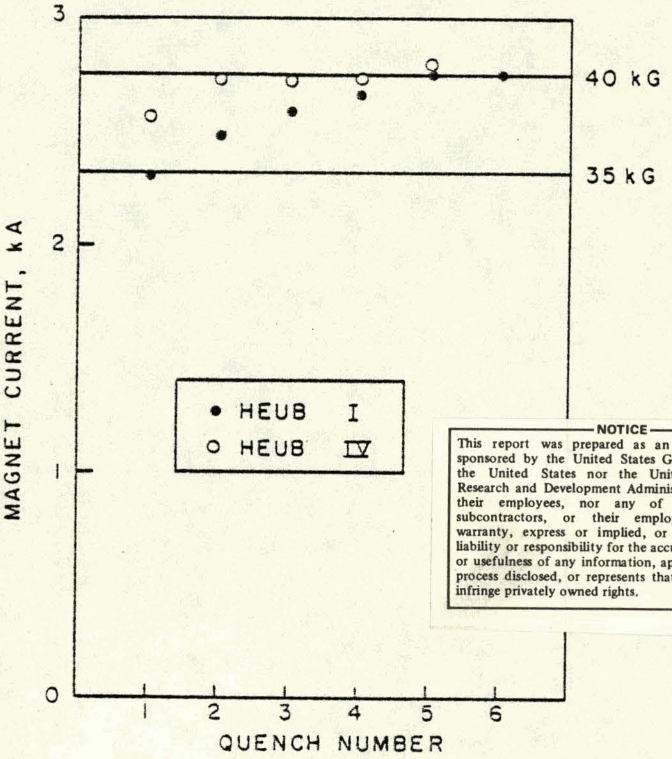

Fig. 4. Magnet quench performance.

III. FIELD QUALITY

Preliminary measurements of harmonic field components in the two-dimensional straight section of the magnets as well as integral harmonics have been measured with a set of rotating 6.8 cm diameter harmonic coils of the Morgan type.[4] The uncorrected quadrupole, sextupole and decapole harmonics are tabulated for various fields in Table II for HEUB I and HEUB IV. The coefficients are defined as usual by the expansion of the field on the median plane

$$B = B_o \, (1 + b_1 x + b_2 x^2 + \dots) \quad .$$

The variation of the uncorrected sextupole and integral sextupole term with field is also shown in Fig. 5a.

Table II

	HEUB I				HEUB IV				
	1.0 T	2.0 T	3.0 T	4.0 T	1.0 T	2.0 T	3.0 T	4.0 T	Units
b_1	1.25	1.28	0.96	0.1	0.08	0.12	0.13	0.38	$10^{-4}/\text{cm}$
b_2	5.1	4.9	-0.5	-14.0	6.2	6.1	0.9	-10.4	$10^{-5}/\text{cm}^2$
b_4	2.5	1.3	1.5	-	4.6	3.5	12.0	5.0	$10^{-8}/\text{cm}^4$
$\int b_1$	-	-	-	-	2.0	2.1	2.0	2.0	$10^{-4}/\text{cm}$
$\int b_2$	-	17.5	12.3	1.6	17.0	16.5	11.7	0.9	$10^{-5}/\text{cm}^2$
$\int b_4$	-	-	-	-	23.0	26.0	38.0	30.0	$10^{-8}/\text{cm}^4$

The dipoles are not corrected by end shaping. However, they are equipped with a set of sextupole as well as decapole correction windings, as noted. The sextupole winding consists of 84 0.3 mm superconducting wires connected in series and the decapole winding (not expected to be used normally) half this number of wires. The correction current required for complete cancellation of the sextupole term as a function of dipole field is shown in Fig. 6. The maximum current required occurs in the region of 2.5-3.0 T and exceeds the available correction current (the (also shown) by at most 25% here. Therefore, in this field region a residual sextupole term remains with the correction winding powered, as shown in Fig. 5b. Its peak value, however, is well within the acceptable beam line tolerance. The current requirements for cancellation of the decapole term are somewhat less; consequently cancellation of this harmonic is possible over the full field range, if it should be desirable.

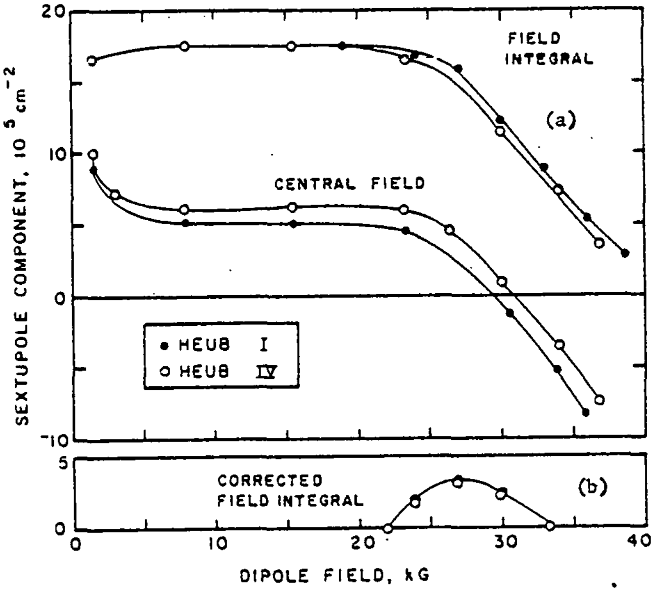

Fig. 5. Variation of sextupole component with field: uncorrected component (a), and corrected component (b).

The magnetic lengths of the two magnets, measured with both a Rawson type fluxmeter and a harmonic coil, agree to better than 1% (Table I).

IV. CONCLUSION

Two of the dipoles have been completed and performed well throughout their initial tests. They appear to meet all the beam line requirements, including performance, field precision and reproducibility. The excellent quench tolerance exhibited, in particular, is of paramount importance from a beam line operational point of view. The two remaining dipoles are presently being assembled, and installation of all four magnets should be completed by November 1976.

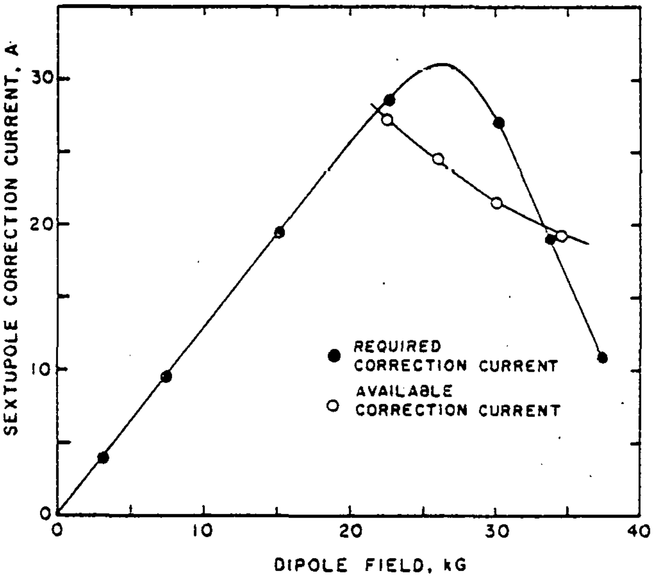

Fig. 6. Variation of sextupole correction current with field.

V. ACKNOWLEDGMENTS

The authors would like to thank the many individuals involved in the design, construction, and testing of the HEUB system. Special thanks are due to the following individuals for their efforts: G. Stenby and M. Stone (coil construction); and R. Kehl, N. Franklin and H. Hildebrand (cryogenics). In addition, we also wish to thank H. Hahn, J. Spiro and M. Barton for their constant encouragement and support.

References

1. J.A. Bamberger, J. Aggus, D.P. Brown, D.A. Kassner, J.H. Sondericker, and T.R. Strobridge, these Proc.
2. A.D. McInturff, W.B. Sampson, K.E. Robins, P.F. Dahl, R. Damm, D. Kassner, J. Kaugerts, and C. Lasky, these Proc.
3. G. Morgan, J. Aggus, J. Bamberger, D. Brown, P.Dahl, R. Damm, H. Hahn, D. Kassner, C. Lasky, G. Parzen, A. Schlafke, and W.B. Sampson, IEEE Trans. Nucl. Sci. NS-22, No. 3, 1164.
4. G.H. Morgan, Proc. 4th Intern. Conf. on Magnet Technology, Brookhaven, 1972, p. 787.