DC SUPERCONDUCTING MAGNETS*

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Abstract

Most of the large superconducting magnets have been tested or will be tested soon. These magnets are briefly reviewed, and a comparison table of main interesting parameters is presented.

Probably the first superconducting magnet that could be called a large workhorse magnet and to be used in a high energy physics experiment was the 10 in. bubble chamber magnet[1] built by C. Laverick at Argonne in 1964. This magnet was certainly out of the small laboratory magnet class and was wound with homemade twisted cable. Performance of this and previous magnets was more or less "cut and try" because a suitable stability theory had not yet evolved.

Shortly thereafter, Stekly built a dipole magnet[2] with a 12 in. bore about 5 ft long. The magnet was stabilized according to the now famous "Stekly criteria" and engineered in much the same manner as large magnets today. Its stored energy of 5 MJ was large for its time and for awhile it held the record as the world's largest superconducting magnet.

In 1966 we began construction on the Argonne 12 ft bubble chamber magnet.[3-4] This was the first of the really large magnets but was a large extrapolation only in size. The design was very cautious as the modest current density of 775 A/cm^2 indicates. Iron was used for the flux return path and field shaping. The magnet could have been built utilizing conventional water-cooled copper but would have required 10 MW of power. During the design of the 12 ft magnet, we were worried about low temperature phase transformation of tin in lead-tin solder, effects of thermal cycling on the various components in the magnet, and overall long-term reliability. One reason for the low current density was to use enough copper to support the hoop stress load without the use of stainless steel for reinforcing. This way we didn't have to concern ourselves with differential contraction problems within the winding. The magnet was tested to full field in December of 1968 and has been operational ever since.

Shortly after construction began on the 12 ft magnet, Al Prodell and his group at Brookhaven started building the magnet for the 7 ft bubble chamber.[5] This magnet although smaller was more of a "supermagnet" than the ANL 12 ft. The Brookhaven magnet operated at a higher current density, 2,600 A/cm^2, used no iron for a return path, had stainless steel reinforcing in the winding, and the maximum field was limited only by the short sample characteristic of the superconductor. This magnet was successfully tested to full field in December of 1970.

During the construction of the Argonne and Brookhaven magnets, CERN decided to build a superconducting magnet for the big European bubble chamber.[6] F. Wittgenstein and coworkers undertook this job. This magnet is not just large, but is huge, with a stored energy of 800 MJ; ten times that of the Argonne 12 ft. The design had to be done very carefully because of the enormous forces and the large amount of material to be cooled down. The 2,000 tons of iron is used for shielding the magnet and does not shape the field or increase the field appreciably. This is currently the largest magnet in the world. It has been cooled to superconducting temperature, and they expect to test to full field during October 1972.

At Rutherford Lab they had plans for a 70 kG magnet to be used with the bubble chamber. During the superconducting study program, P. Smith developed the theory of twisting the superconductors within the copper matrix to improve stability and reduce trapped flux.[7] This was an important contribution to the overall theory of superconducting stability. Unfortunately the chamber project was cancelled, but the fine development work lives on for the rest of us to enjoy.

Sometime during this period the idea evolved for winding a magnet from hollow conductor and cooling it by forcing supercritical helium through the hollow conductor. This method was strongly supported by M. Morpurgo from CERN, and he built the Omega magnet[8] based on this principle. One coil of Omega has been tested, and it is expected to test both coils to full field by the end of 1972.

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Fig. 1 Large Magnet Parameters

	BEBC CERN	NAL BC	12 Ft ANL	7 Ft BNL	Omega CERN
Stored Energy, MJ	800	400	80	72	50
Central Field, Tesla	3.5	3.0	1.8	3.0	1.8
Operating Current	5,700	5,000	1,800	6,000	5,000
Overall Current Density, A/cm^2		2,000	775	2,600	
Coil Weight, kG	120,000	73,000	45,000	19,000	
Test to Full Field	Oct. 1972	Sept. 1972	Dec. 1968	Nov. 1970	End 1972
Power Required if Magnet Were Water Cooled Copper, MW	57	100	10		
Cost, U. S. Dollars, Millions	4	2	2.5	1	2.1
Use of Iron	Shielding	None	Return Path	None	Return Path
Weight of Iron Tons	2,000		1,600		1,400

The design of the magnet for the National Accelerator Laboratory bubble chamber[9] was started in June of 1970. When we started this magnet, we had the advantage of everyone's past experience, both the good and the bad. We didn't have to worry so much about the properties of lead-tin solder at low temperatures, and we knew by then that superconducting magnets do behave in a predictable manner and that the mechanical problems are similar to a conventional room temperature magnet. We had also learned that thermal cycling is not a serious problem so long as reasonable care is taken and all stresses are kept well below the yield point of the materials involved. With this background, we were free to concentrate on the real problems of magnet design and the magnet was built quickly and economically. This magnet is presently being cooled and is due to be tested to full field by the end of September 1972.

The table in Fig. 1 gives some of the interesting parameters of large magnets with above 50 MJ stored energy. These magnets have all been completed and at least partially tested. Every indication is that they will do the job they were designed for with a minimum of maintenance and service costs.

All the magnets listed in the table of Fig. 1 were for use in high energy physics. Most large magnets in the forseeable future will be for other uses such as fusion reactors, MHD, etc. The golden age when you could wind a big superconducting solenoid, and then talk about it as important, seem to be past. Future magnets will generate complicated field shapes, at higher fields, with support and stability problems that will tax the ingenuity of the designers to the utmost.

References

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