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THE ARGONNE SUPERCONDUCTING MAGNET FOR POLARIZED PROTON TARGETS*

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Summary

A d.c. superconducting C-frame magnet for use with polarized proton targets has been assembled and tested at ANL. This magnet has a vertical field of 25 k Gauss, uniform to within 4 parts in 10^4 over a 10 cm diameter, 2 cm high cylinder located at the center of the magnet's 10 cm high room temperature air gap. The magnet consists of two sets of coils each containing a main coil and a correction coil. Each set of coils is mounted on its own coil form and in its own liquid helium dewar with only a small bellow communication line between them. The field is shimmed by adjustment of the correction coil current and by mechanical adjustment of the position of the top set of coils relative to the bottom set.

Introduction

A polarized proton target is a material, typically, a hydrocarbon containing unpaired electrons in which a large fraction of the free proton spins are dynamically aligned in the direction of an applied magnetic field. They are used in high energy physics experiments to determine the spin dependent parameters of nuclear collision events. The degree of target polarization is given by $P = (N_+ - N_-)/(N_+ + N_-)$ where N_+ is the relative population of free proton spins aligned in the direction of applied field and N_- is the relative population aligned in the opposite direction. Targets with polarization as high as 80% have been built at Argonne and CERN using He^3 cooling. This is accomplished by placing the target material, typically 10 cc in volume, in a microwave cavity in a highly uniform magnetic field and cooling the cavity to a temperature as low as 0.4° K. The microwave frequency is then selected so as to induce the "forbidden" electron-proton transitions, i.e., the spin quantum numbers for the electron and proton change by one. Saturation of these resonances near 70.6 GHz at 25 kG causes the polarization of the protons to approach the polarization of the electrons which is close to 90% at typical operating conditions. Saturation of the higher frequency "forbidden" transition causes the N_+ population to increase (positive polarization). Saturation of the lower frequency "forbidden" transition causes the N_- population to increase (negative polarization).

The first successful operating polarized proton target (PPT) employing a superconducting magnet was built at Harvard[1] in 1964. Subsequently superconducting magnets PPT have been built at Liverpool[2] and Saclay [3,4]. Argonne's target magnet is unique in the size of its field uniformity volume, the access provided by the C-frame construction and the 10 cm air gap. The magnet has a vertical access angle of ±20° and an unobstructed azimuthal angle of 280°.

* Work supported by U.S. Atomic Energy Commission
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Magnet Design

The magnet was designed to have a 10 cm room temperature air gap and to achieve a central field of 25.3 kG with field uniformity of ± 10G in a cylindrical volume 10 cm in diam. by 2 cm high. In addition a vertical access angle of ± 20° and a large unobstructed azimuthal angle were required. The requirements of field and field uniformity are necessary for the achievement of high target polarization. The gap and access are required to satisfy the experimental users of the target.

The requirements of the large vertical access angle, large gap and large field uniformity dictated the use of a pair of main coils displaced at an angle larger than the "Helmholtz Configuration" angle and a smaller pair of "bucking" correction coils. The coils are electrically connected in series with the field of the correction coil "bucking" the main coil field. Shunt leads are attached to the correction coil so that an external correction current can be supplied for the purpose of shimming the field. Figure 1 shows a drawing of the magnet and preliminary layout of the magnet dewar. Detailed characteristics of the magnet are given in Table I. The conductor, supplied by AIRCO, is a rectangular composite of Nb-Ti and Cu of dimensions 0.1" x 0.065", containing 132 superconducting filaments, with a ratio of Cu to superconductor of 2.6:1. The filaments are twisted at the rate of 1 twist per inch and the electrical insulation is Ebanol or black copper oxide, which enables good thermal conduction from turn to turn. The interlayer insulation is 5 mil mylar and does not allow liquid helium to circulate through the winding, which therefore operates in a "conduction cooling mode". To ensure the mechanical integrity of the coils and the winding tolerances necessary for the field uniformity, the coil forms were machined out of a single stainless steel billet, and the winding process was carefully controlled for number of turns, packing uniformity, and dimensions. Figure 2 shows the stainless steel coil form with the main coil winding.

Magnet Dewar and C-Frame Support

The magnet dewar design presented a special problem. It not only had to be a good liquid helium dewar (specified heat leak of 4 Watts), but also had to transmit the attractive force (30 tons) to the C-frame support structure. This was accomplished by means of a thin wall stainless steel tube, doubled back on itself for additional heat path. The cold end of the tube was attached to the coil form and the room temperature end attached to a 6 cm thick x 82 cm diameter aluminum support plate. The support tube which is also part of the helium vessel and support plate are shown in the bottom left of Figure 3. The top left of Figure 3 shows the copper radiation shield completely surrounding the magnet helium vessel.

The dewar was designed and fabricated by Cryogenics Consultants Inc. and had a heat leak of 4.5 Watts when measured at ANL.

The assembled magnet is shown in Figure 4. The C-frame support was fabricated from welded thick stainless steel plates. It was designed to deflect 45 mils with an attractive pull of 30 tons. The bottom magnet dewar is rigidly attached to C-frame support by 36-1/2 in. diam bolts. The top dewar is set on three fine threaded adjusting jacks. This allows fine adjustment of the relative position of the top coils for magnetic field uniformity shimming. After position adjustment the top dewar is attached to support by 36-1/2 in. threaded studs.

Magnet Measurements and Field Uniformity

The volume uniformity region of the magnet was mapped by using an NMR Gauss meter. The NMR probe was mounted on a non-magnetic carriage which allowed movement of the probe in three directions (X, Y, Z) and vernier position readout. The measurements were compared with detailed computer calculations of the field, and appropriate adjustments were made in the relative position of the top coil and amount of external correction current added to correction coil to achieve "better" field uniformity. This process continued until the optimum field uniformity was achieved. The "final" uniformity achieved by this process was ± 10 G in a cylindrical volume 10 cm diam. by 2 cm in height centered in the air gap. Although the magnet was designed to require zero external correction current. It was found that best results were achieved with external correction current of 6 A in top coil and 6 A in bottom coil.

Acknowledgments

We wish to express our appreciation to B. Cork and T. H. Fields for thier continuous support of this project. Also instrumental to success of the project were F. P. Catania, O. Fletcher, E. E. Smith, F. Onesto, T. Kasprzyk, C. T. M. Chang, S. T. Wang, and F. W. Johanson for the design and construction of the power supply.

References

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(2) P. J. Hayman "The Liverpool Polarized Proton Target", Proc. Inter. Conf. on Polarized Target and Ion Sources, Saclay, 1966, 273.

(3) H. Desportes and B. Tsai, "A High Homogeneous Field Superconducting Magnet for a Polarized Target" Proc. Inter. Magnet Symposium, Stanford, Sept. 1965, p. 509.

(4) H. Desportes, Proc. of the 2nd Inter. Conf. on Magnet Technology, Oxford, 1967, p. 603.

Table 1

Superconducting Magnet Characteristics

	Main Coil	Correction Coil	Complete Magnet (4 coils)
Inside Diameter (in.)	11	5.2	
Outside Diameter(in.)	19.5	9.2	
Length per Coil (in.)	4.25	1.	
Axial Coil Separation (in.)	9.5	6.	
Conductor (Stablized Nb-Ti) (in.)	0.1x.065	0.1x.065	0.1 x 0.065
Number of Layers	61	27	
Turns per Layer	42	10	
Number of Turns	2558	268	5652
Length of Conductor (ft)	10,200	505	21,410
Test Current (Amps)	550	600	500
Central Field (kG)	45	11.2	26.5
Max Field on Conductor (kG)	71	22	67
Amp x Turns	1.407×10^6	0.16×10^6	2.83×10^6
Average Current Density (Amp/cm^2)	12,135	12,537	11,032
Inductance (Henrys)	2.41	0.015	5.11
Stored Energy (kJoules)	365	2.7	640
Vertical Access Angle (degrees)			40
Azimuthal Access Angle (degrees)			280

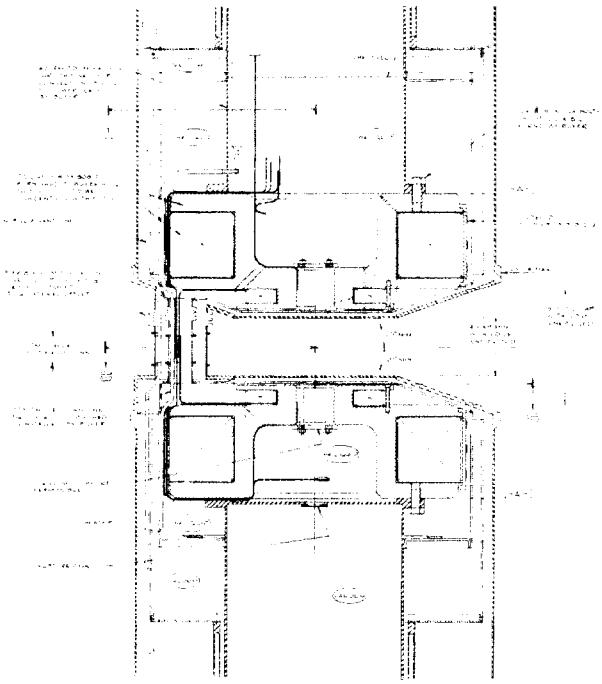


Fig. 1. Drawing of the magnet and preliminary layout of magnet dewar.

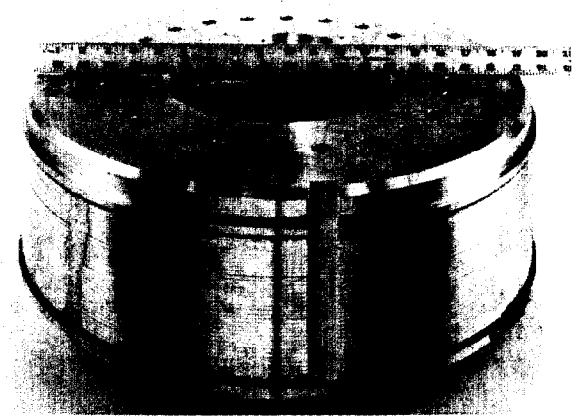


Fig. 2. Stainless steel coil form with main coil winding.

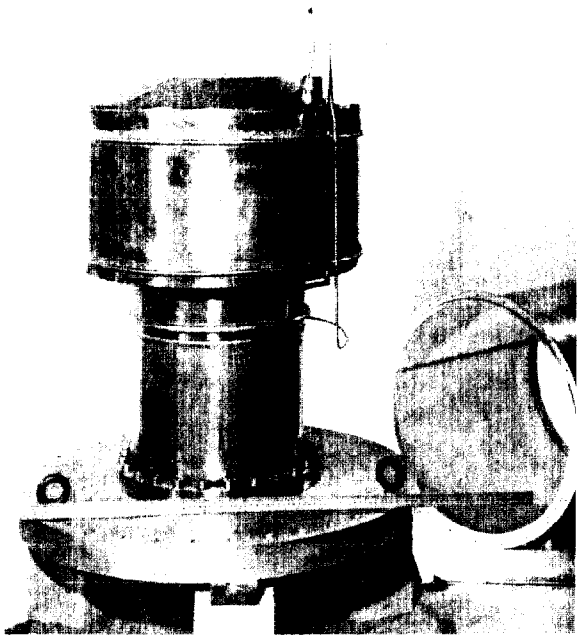


Fig. 3. Inner structure of magnet dewar.

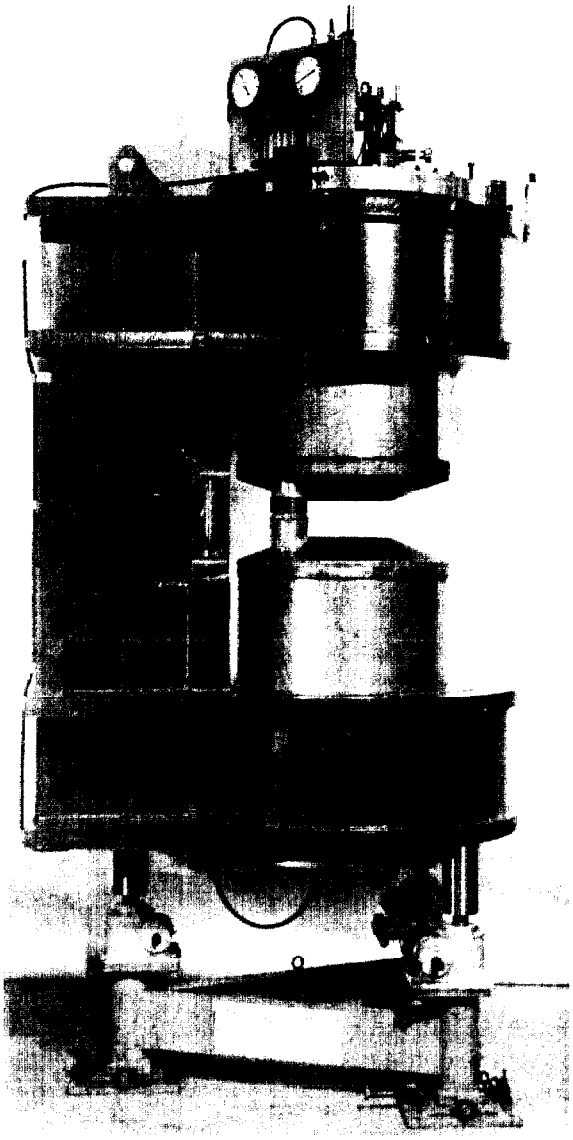


Fig. 4. The superconducting PPT magnet.