THE SUPERCONDUCTING MAGNET FOR THE PROPOSED 25-FOOT CRYOGENIC BUBBLE CHAMBER*

A.G. Prodell Brookhaven National Laboratory Upton, New York

A preliminary proposal has been made for the construction of a 25-ft cryogenic bubble chamber for use at the 200 GeV accelerator at the National Accelerator Laboratory. This chamber, which is to be designed by Brookhaven National Laboratory, is to have an air-core superconducting split-pair magnet capable of generating an average magnetic field intensity of 40 kG over the bubble chamber volume. The superconducting air-core design makes more accessible the component parts of the bubble chamber assembly and gives large savings in magnet costs and power for operation.

To eliminate the need for a magnet helium Dewar and to achieve a magnet coil configuration that is compact and mechanically strong, it is proposed that the 25-ft chamber magnet conductor be a hollow stabilized superconducting conductor cooled by an internal flow of helium.

Hollow stabilized superconducting conductors have recently been fabricated which consist of a number of superconducting filaments embedded in the wall of a tube of copper of square, or rectangular cross section. These conductors may be cooled by an internal flow of helium which is maintained at a temperature of 4.5° K and at pressures above its critical pressure of 2.23 atm. By maintaining the pressure of the helium fluid above 2.23 atm, the formation of two phases within the conductor is prevented. The one-phase positive fluid flow through the conductor insures that cooling is continually brought to all parts of the magnet conductor. The total volume of helium in contact with the conductor is less than that required to cool the magnet by pool boiling. Thus liquid and gas storage requirements are minimized with the hollow superconducting design.

The normal conductor material in which the superconducting filaments are bonded not only stabilizes the superconductors but also aids in supporting the electromagnetic forces to which the magnet is subjected. The amount of normal conductor to be bonded to the superconductor for stabilization for a given magnet current depends on the rate of heat transfer from the conductor to the helium coolant and on the resistivity of the normal conductor. The resistivity of the normal conductor is a function of its purity, of the stress in the conductor, and of the magnetic field intensity at the conductor.

The 25-ft bubble chamber magnet is designed for 3×10^7 ampere-turns to generate a central field of 38 kG with an average magnetic field intensity of 40 kG over the chamber volume. At this value of average field, the maximum field at the magnet windings will be 65 kG and the magnet coil will be subjected to total radial pressures of the order of 2800 psi. To aid in supporting the stresses in the magnet windings, to limit deformation of the conductor material, and to reduce the amount of normal conductor required, a reinforcing or stiffener strip of a high strength material such as stainless steel is wound in the magnet coil windings with the hollow conductor. A thin strip of fiberglass epoxy or Mylar tape is also wound in the magnet coil between the

Work performed under the auspices of the U.S. Atomic Energy Commission.

surfaces of the hollow conductor strip and the stiffener strip to provide turn-to-turn electrical insulation. A schematic of the proposed magnet coil configuration is shown in Fig. 1. A hollow copper-multifilament superconductor composite of the type shown in the schematic, 0.75 in. square with an 0.375 in. diameter hole, may be designed to carry 8500 A in a magnetic field of 65 kG. Sufficient reinforcement is also wound in with the conductor to limit the stress in the copper to 15 000 psi.

The 25-ft bubble chamber magnet is a split-pair of coils, each coil-half consisting of a number of single layer pancakes as shown in Fig. 2. The pancakes are insulated from each other by thin sheets of fiberglass epoxy. Each pancake is made selfsupporting against radial forces by clamping the external free end of the conductor at the periphery of the coil. The pancakes are connected electrically in series with stabilized superconducting connectors soldered and clamped at the inner and outer diameters of the magnet coils. The pancakes are connected in parallel to the helium supply manifold at the inner diameter of the magnet and to the helium return manifold at the outer diameter of the magnet coil.

The single layer pancakes are stacked vertically for each of the two magnet-half coils. Each magnet-half coil is 4 ft 6 in. high and has an inner diameter of 23 ft 6 in. and an outer diameter of 29 ft 2 in. The two half-coil assemblies are separated by 5 ft to allow for particle beam entry to the bubble chamber. This large coil separation permits the winding of magnet coils of a smaller diameter, reduces the axial forces on the coils, and improves the uniformity of the magnetic field over the bubble chamber volume. It also permits the large curved beam window section of the bubble chamber to extend 2 ft into the gap between the coils, as shown in Fig. 3, for easy entry of particle beams with a large range of momentum. The magnetic field intensity transverse to the beam axis has an average value of about 22 kG in the volume in the beam window between the coils. An elevation view of the magnetic field intensity plot is shown in Figs. 4 and 5. With a total of 3×10^7 ampere-turns in the magnet and an average field over the chamber volume of 40 kG, the two coil-half assemblies are attracted to one another with a force of the order of 30 000 tons. This force between the coils is supported by a coil spacer which is reinforced around the chamber beam window so that a large aperture is available in the spacer for beam entry.

The pancakes of each magnet-half coil assembly are tied together by vertical rods at the inside and outside diameters of the magnet which are threaded into or bolted to stainless-steel washers at the top and bottom of each coil-half. These rods serve to align the coils. The bottom washer of the top coil and the top washer of the bottom coil are bolted to the coil spacer, while the bottom washer of the bottom coil is bolted to the three support legs. These legs support the magnet and bridge assembly in the bubble chamber vacuum tank and are designed to carry the total weight of approximately 400 tons. Thermal insulating pads are placed between the coil-halves and the coil bridge, and between the bottom coil and the support legs to minimize the heat leak from these structures to the coil. The magnet is thermally insulated from the bubble chamber and the vacuum tank by multilayer insulation.

The final figure, Fig. 6, shows an isometric view of the main assembly of the bubble chamber.

This brief description represents a summary of some of the preliminary general design concepts being developed by the Bubble Chamber Group at Brookhaven National Laboratory for the superconducting magnet for the 25-ft cryogenic bubble chamber.







Fig. 2. 25-ft bubble chamber main assembly - front elevation sectioned view.



Fig. 3. 25-ft bubble chamber main assembly - side elevation sectioned view.

01662 286662 578.664 884 667 121671 156677 196583 240690 29069.7 347702 410,701 470689 516659 534606 505536 44.9457 381382 662 662 662 661 661 659 655 647: 634 610, 569 503 40.9 294 178 8.4 20 120 0,718 282719 571722 874727 120735 155744 197757 245772 303790 373810 459828 555836 643817 677756 538555 538539 430431 718 719 720 722 72.5 72.8 731 732 730 719 689 62.5 504 33.5 161: 32 -38 01773 26977.5 54577.9 835786 115.796 150.811 190829 23.9854 299886 379.927 488,978 642103.6 825106.3 913.995 8368 3 64164 773 774 777 781 78.8 797 807 82 0 834 846 81.3 671 396 104 80.0 46<u>5</u>483 -13.2 0825 247827 500,832 765,841 105,854 137,872 173,897 21,7930 273,976 <u>35,01041 464,1134 655,0283 111,151,4</u> 128,9138.0 1176 1176 694,167 449,520 5 82 6 83 0 83 7 84 7 / 1861 88 0 90,5 93 7 98 0 1035 1104 102 9 49.2! -4 34 -32 -26 3 82 5 217873 439,879 669,88.9 914904 118925 148954 183994 2251050 2821132 3641256 4901460 651,1517 73.21936 668,693 497,743 35,152.0 873 878 887 900 918 943 977 1026 1097 1202 1375 1370 584, -186 -667 -38.3 1821913 3.66,919 5.551930 749.946 951,86.8 116.999 13.81040 1621099 1871185 216.1316 24.91520 2801513 29.3694 27.8361 124,168.8 20.344 91.31 91.9 92.9 94.3 96.4 99.2 10.31 1,067 1170 129.8 149.9 148.7 62.9 ~23.0 ~64.5 ~44.4 1441946 2 881952 4 32 96,3 575.978 71,999 8 331028 9251066 9 59119 8 81,194 6 10,1308 471493 -71081478 -111,642 -8 66,227 -1 1562 1 500 94 6 95.2: 96 2 97 6 99 7 102.5: 106 2 111.4; 119.1 130 7 149 3 14/76 63.2: -20 9 62 1; -42 9 0969 1061971 210977 312987 4061001 4851020 3351044 529,1074 4161113 108164 -579,1237 -2011364 -461138 2 -592,835 -508,520 -2441535 701 5 969 971 976 986 1000 1019 1043 1073 1112 (164 1235 1349 1303 586 -111 -476 -348 1 0986 69.988 136,994 199,1003 254,1015 292,1031 300/1050 249,1071 90/1092 244,112 -101/1126 -24.9,1128 -512,1059 -64.6823 -56.0/564 -29 1/348 -11.123 986 988 994 1003 1015 1031 1050 1071 1092 111,23 112 110 927 1510 70 -191 -231 0997 34 998 . 66100 3 961012 121102 3 1351037 1291051 871064 - 221072 - 291066 - 6931033 - 14.3948 - 23.2782 - 2781540 - 24.31296 - 15.3158 997 998 100 3 101 2 102 3 103 7 1051 1054 1072 1064, 103.0 937 747 463 17.0 - 4.0 -7.2 1 0450 0 1026 0 1038 1026 1038 0//05/ /05/ 01061 0,063 0,048 0,997 01886 0-701 89.81 701 0:195 01002 01007 01015 <u>001</u> -01 0 1000 180-192 -

FRONT ELEVATION

RADIAL FIELD STRENGTH TOTAL FIELD STRENGTH

Fig. 4. Field strengths expressed in percent of field strength at intersection of vertical center line and beam center line.

43.0 43.1 538,539 63.5,65 5 67.7,75.6 64.3,817 55.6,836 45.9,828 37.3 810 30 5 790 24 5 77.2 197,757 15.6,1744 12.0,735 8 74,72.7 571,72.2 282,71.9 -3.8 3.2, 16 1, 23.5, 50.4 62.5, 68.9 71.9 73.0. 73.2 73.1 72.8, 72.5 72.2 72.0, 71.9 46 5148 3 64 646 8 5684 3 91 3 99 5 82 5106 3 64 2103 6 48 8 97 8 37 9 92 7 29 9 88 6 23 818 5 4 190 8 2 9 15 0 81 11 5 79 6 8 35 78 6 545 77 9 2 69 77 5 0 77 3 96 - 13 2 - 80 7 79 7 78 6 78 2 77 7 77 4 77 3 44 9 52 0 694 767 + -26 3 -32.81 // 84 11761176 12901380 1111514 6561285 4641134 3501041 273976 217930 173897 187872 195194 765447 500852 247827 -43 492 1029 104 104 1035 98.0 937 905 88.0 861 847 837 830 826 351,520 49/1753 66 9(693 732)936 6511517 490/460 3641256 282 1132 2295050 183,994 148954 118925 914904 6.69(88 9 4 39879 217)873 ↑ -38,3 -5677 -18.6 58.4 1370 1375 1202 1097 1026 977 94.3 918 90.0 8871 876 873 72 // 20.3,48.6/24 [I68.8¹ 278]36.1 29.3.694 280,151,3 249]1520 216 1316 187 118 5 16 2 [I09.9 13.8]1040 11.6;99.9 9 51]96.8 749.946 5.55,930 3.66(9).9 182]91.3 -44.1 64.5 1-23.0 62.9 1487 149.9 129.81 117.0 108.7 103.1 99.2 96.4 94.3 92.91 91.9 21.3 60 airi Dari 5.00 48.1 4 - 42.8 7/ 48 -866227 -111 642 -7.081478 471 49.3 (6.10 130.8 8.81 1194 9.59 11.9 9.25 106 6 8.331 028 711 99.9 5.75 1978 4.32 96.3 288 95.2 144.946 0 94 4 -20.9 6 3.2 147 6 149.3 (1307 119 1 114 106.2 102.5 997 977 96.2 95.2 94 6 94 4 -115 62 1 -7.0 35.5 244 53.5 -50 852.0 -59 2,83.5 -46.11382 -20/1564 -579 123.7 108 116.4 4 18 11.3 5 29 1074 5.35.004.4 4 85 102 0 4 06 100 1 312 98.7 2 10 1977 106 971 -64.6\82.3 51.0 -29.13 -19.1 -56.0) |0,7 1 -#3.1 1221160 -153156 -243296 -278640 -2321752 -14.3946 -6931033 -2.511066 -221072 .871064 129105.1 1351103.7 1.21102.3 .96101.2 .66100.3 .34199.8 .0199.7 1 -4 3 -4.02 17.0 46.1 74.7 93.7 103.0 1066 1072 1064 105.1 103.7 102.3 101.2 100 3 99.8 997 019.5 19.5 -1<u>-0|11.4</u>-450 01701 01888 0937 1048 0106.3 01061 01051 01038 0102.6 0101.5 01007 01002 01000 450 701 888 937 104.8 106.3 1061 1051 1051 102.6 101.5 100.7 100.2 1000 00.1 SIDE ELEVATION

RADIAL FIELD STRENGTH TOTAL FIELD STRENGTH

QUARTER SECTION

Fig. 5. Field strengths expressed in percent of field strength at intersection of vertical center line and beam center line.

- 792 -



Fig. 6. 25-ft bubble chamber main assembly - isometric view.