THE RUTHERFORD LABORATORY BENDING MAGNET

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I. INTRODUCTION

In May 1967 we decided to build a fully stabilized bending magnet to provide a field of 40 kG over a length of 140 cm with a room temperature aperture of 17 cm. Not only will this be a useful item for the new Nimrod experimental area, but we hope to learn some of the engineering difficulties encountered in constructing and operating a large magnet, and to gain experience in running it under operational conditions in the experimental area. In the design, the principle of full stabilization has been deliberately pushed to its limit, the peak nucleate boiling heat flux having been assumed. Although any magnets ultimately produced in quantity will no doubt differ substantially from this one, we are also keeping careful account of the cost and labor involved in making it.

II. BASIC DESIGN FEATURES

A drawing of the magnet (omitting some features which have not yet been finalized) is shown in Fig. 1. The uniform field is produced by intersecting current distributions of approximately elliptical shape, as suggested by Beth.[1] The conductor is a fully stabilized I.M.I. composite consisting of NbTi strands in copper, and held in position by slotted strips of nylon, loaded with 40% glass to minimize the mismatch on contraction. At the ends of the magnet the windings are bent into a circular shape, in a plane perpendicular to the axis, and held by radial slotted nylon strips. End thrusts are taken by a series of flanges mounted on the central stainless-steel spool and by longitudinal tie bolts, and lateral thrust is taken by stainless-steel clamps held with transverse bolts. Details of the winding procedure, including the correct locating of the bends and the special spacers at the corners is complicated; this has been studied with the aid of a model, but tests with dummy conductor on the final spool are now being made prior to finalizing the details.

III. TABLE OF PARAMETERS

In this section the quantitative features of the design are listed under various headings:

1. <u>Performance</u>

Angle of bend of 7 GeV beam = 12^{o}
Sagitta (including end region) = 5 cm

1. R.A. Beth, in <u>Proc. 6th Intern. Conf. High Energy Accelerators, Cambridge, 1967</u>, p. 387.

2. Dimensions

Effective length = 140 cm
Over-all length (including cryostat) = 200 cm
Central tube diameter = 22 cm
Room temperature aperture = 17 cm
Outer diameter of winding = 41 cm

3. Conductor and Winding

Material: I.M.I. copper composite, containing 32 strands of NbTi
Diameter = 0.15 in.
Length = 12 300 ft (370 m)
Number of joints = 8
Spacing between conductors = 1 mm
Number of layers = 20
Number of turns = 1036

4. Magnetic and Electrical Parameters

Magnetic field = 40 kG
Uniformity: 0.4% across the cross section at the center of magnet and $\Delta \int B\, dl < 3\%$ within 8 cm of the axis
Peak field at winding = 44 kG
Current = 1690 A
Current density = 7260 A/cm^2
Heat transfer to helium, assuming all current in copper at $4.2^{o}K$ = 0.8 W/cm^2
Inductance = 0.75 H
Stored energy = 1.1 MJ

5. Forces and Weights, etc.

Weight of conductor = 770 lb
Weight of coil assembly = 2.4 tons
Weight of cryostat = 2 tons
Weight of shielding (see Section V) = 6 tons
Total lateral force on winding = 340 tons
Maximum lateral force on conductor = 7.2 kg/cm
Helium capacity of cryostat = 350 liters
Expected helium boil-off when running (with current leads removed) = 2-4 liters/hour

6. Cost

Estimated cost, excluding internal labor costs = £45 000

IV. SPECIAL FEATURES

In order to conserve helium, detachable current leads and a persistent current switch (not shown in the figure) will be used. A flux pump, controlled by a field monitor in the magnet, will replace flux which leaks away because of the finite resistance of the joints in the winding. The details of these items are not yet worked out. Early tests on contact resistance suggested that this would be too high to permit the use of mechanical switches for the persistent current switch or the flux pump, though this is being reconsidered in the light of measurements by Zar.[2] The alternatives are a thermal switch, which might tend to be unstable, and a flux pump of the type developed by van Suchtelen et al.[3] in which a normal region is made to move across a superconducting niobium sheet. Present plans are for such a pump, which is kindly being supplied by Dr. Volger. A disadvantage of this device is that good shielding is required; a NbSn cylinder designed to provide such shielding has been ordered from the Fulmer Research Institute.

V. CRYOSTAT

In the design of the cryostat every effort has been made to reduce the heat flow into the magnet vessel. To this end, in addition to the detachable current leads, a helium vapor-cooled shield is to be interposed between the helium vessel and the annular nitrogen vessel and around the down tube assembly. The concentric vessels are supported by rods attached to thick rings at the ends and located axially by rods relative to the mid-length to minimize the effect of the differential contraction on cool-down. To avoid the effect of eddy currents when the magnet is shut down, the end radiation shields attached to the annular nitrogen vessel are constructed from thin stainless-steel sheets, rolled to form channels with an interspace of 0.125 in. depth. Through these channels liquid nitrogen passes into a sleeve, consisting of thin concentric cylinders, through the central bore of the magnet.

On assembly the vessels will be dimensionally centered within each other. Strain gauges mounted on the jacks supporting the cryostat within the magnetic shielding will then enable the magnet to be centered in the shielding.

VI. MAGNETIC SHIELDING

In order to reduce the external field in the beam line where the magnet will be used to tolerable proportions, an iron shield is being designed. This will be 20 cm thick in a horizontal plane, reducing to zero in a vertical direction. The inner edge of the shield will be 45 cm from the axis. Care is needed to prevent large forces arising from misalignments in a direction perpendicular to the axis.

VII. PROTECTION

Voltage taps will be taken for monitoring and protection purposes from every layer of the winding. If a normal region develops, an external 0.25 Ω protection resistor will be placed across the magnet within a few tens of milliseconds by reconnecting the current leads and opening the persistent current switch. With this value of resistance the discharge voltage will be about 200 V, the current will decay in about 2 sec, depositing some 5% of the energy in the helium. These estimates were made using a computer program[4] which calculates the rate of spread of a normal region assuming the reduced rate of heat transfer appropriate to film boiling. To minimize the danger of breakdown in the magnet the central tube and flanges have been covered with a thin tough plastic coating (PTFCE). The conductor itself will not be insulated. Despite initial hopes it has not proved possible to provide an effective insulating coating without seriously impairing the heat transfer.

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2. J.L. Zar, Avco Everett Research Laboratory Report AMP 234 (1967).
3. J. van Suchtelen, J. Volger, and D. van Houwelingen, Cryogenics 5, 256 (1965).
4. M.N. Wilson, to be published as Rutherford Laboratory Memorandum.

VIII. ACKNOWLEDGEMENTS

Many people have contributed to the design of the magnet. P.F. Smith contributed to the early formulation of the design; B. Colyer has been responsible for the cryogenic and mechanical aspects; J. Dawson and N. Cunliffe have contributed to the special winding problems, and electrical control monitoring and protection respectively; G.J. Homer and J. Brown have carried out much of the laboratory design work and testing of special items; and R.Q. Apsey has been responsible for much of the detailed mechanical design.

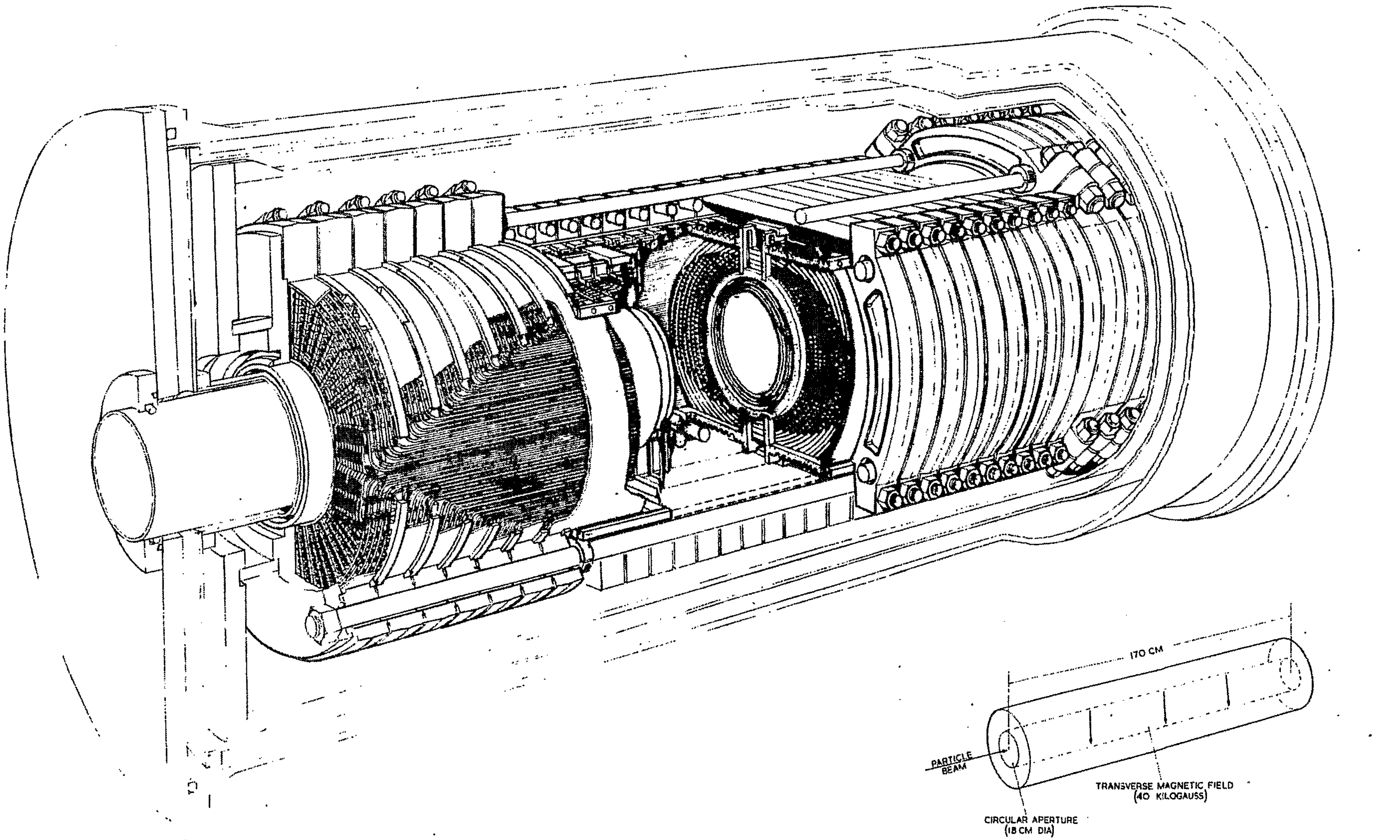

Fig. 1. Superconducting bending magnet.