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0.5-METER PROTOTYPE ENERGY-DOUBLER QUADRUPOLE MAGNET

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ABSTRACT

The paper describes the construction and testing of a half meter quadrupole suitable for a pulsed accelerator application and examines the costs involved in constructing three meter magnets suitable for an accelerator proper.

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I. INTRODUCTION

The paper describes the construction of a prototype quadrupole magnet, some 50 cm in length for the suggested NAL Energy Doubler. The magnet is based on the Wilson Proposal[1,2] and contains a number of unique features. It is of the "Superferric" type with cold laminations and tight wound coils. It furthermore includes a new method for both reacting the magnetic forces and centering the coils. The magnet is constructed on a square beam tube having 2.5-cm sides.

II. DESIGN AND CONSTRUCTION

Major design parameters are summarized in Table I. The coils are wound as four flat pancakes in a special fixture which assures precise conductor placement. The fixture is also used to shape the ends after winding is complete. The finished formed coils are then placed on the beam tube "A" (Fig. 1) and lateral restraints "B" (Fig. 2) are plug welded in place. These restraints are designed to ensure correct azimuthal placement to the wire bundles and are not continuous [see "B" (Fig. 2)] to allow full helium flow over this face of the coil. The lamination washers "E" (Fig. 1) are preassembled into a 3-mm wall by 15-cm diameter outer stainless steel tube. They are then precompressed to a 99.5% packing factor and 3-mm end plates welded in place, forming the helium container. The entire beam tube assembly is then slipped into the helium container, reasonable mechanical tolerances being allowed, approximately 0.5 mm in diameter, in order to simulate the assembly of longer magnets ("G" Fig. 1). Four flattened stainless steel tubes are then placed between the windings and laminations. These tubes are connected hydraulically in parallel in order that they may be simultaneously expanded into place by pumping room temperature curing epoxy resin into the pipes. A pressure of 400 psi is used for this operation to centralize the beam pipe and lock the windings firmly in place, thus providing an irreversible hydraulic locking mechanism. The pressure is maintained on the epoxy material throughout its cure cycle, and the stainless steel tubes are capped to maintain the hydraulic integrity of the system. The superconducting wire used is manufactured by Airco and is scrap from another project. It is perhaps not the best choice for this particular magnet since the absolute value of current required is high. The overall current density, however, is a small fraction of the critical value. This magnet construction is primarily to check out some of the techniques described here and to enable a more realistic costing to be attempted. In an accelerator, however, one could obtain low values of inductance per unit length of magnet and thus reduce the required voltages in the pulse mode by use of the present wire. This is an advantage.

III. CRYOGENICS

The cryogenic design is similar to that proposed for long power transmission lines.[2] We expect that on an accelerator a forced liquid flow system will be used. Thus our cryostat looks like a bulky liquid transfer line. The design allows for phase separation as well as flow around the winding bundles. A serpentine spacer "C" (Fig. 2) on the beam tube permits flow in that region.

Since the magnet is operated well below the critical current limit of the wire, full stability design is inherent.

The support of the magnet in the outer cryostat has not been fixed at this time; however, it is proposed that a support system as shown in Fig. 3 will be adopted initially. The spider shown there is constructed by continuously welding the tube structure together over several meters in length and then cutting 1-cm slices which are slipped onto the helium container and clamped in place as the stiffness of the magnet proper dictates.

IV. TESTING

The magnet was tested by dipping it into a liquid helium bath with the beam tube in a vertical position. Cooldown in all respects was normal.

Three Hall Effect probes mounted in the bore measured field as a function of radius. This method was chosen both because of the method of cooling and the fact that the small bore made other methods of field measurement difficult. Measured values of field intensity are in agreement with the calculated values.

Current control of the prototype was extremely difficult due to the low inductance which provided little feedback voltage. This would not be a problem in later models since smaller cross-section wire would probably be used. Fast ramp tests were attempted to measure the additional boil-off due to pulsing. This was marked by the high background heat leak of the current leads which are designed for 800 A.

Examination of the magnet following cycling once between room temperature and 77°K and once between room temperature and 4.2°K revealed no mechanical or electrical defects indicating the design described to be extremely promising.

V. COSTS

The cost analysis is divided into two sections. The first, Table II, is the actual costs of the prototype and includes all charged items. The second, Table III, is the variable costs of producing a one-to-three meter long device such as one might expect to use in an energy doubler. The experiences gained with this prototype showed most of the winding time is spent on the ends. Thus the winding time for a 3-meter magnet is unlikely to differ significantly from that for a .5-meter magnet. Much of the machining required is set up time and this does not change unduly with length. Similarily the lamination charge reflects only the marginal cost of the laminations used.

It is clear that the cost indicates that a small bore magnet of this type could be constructed for a base cost not dissimiliar from the cost of today's larger bore conventional magnets. It should be borne in mind that the above costs do not contain the R & D loading and furthermore do not reflect the actual costs when profits and overhead are applied in most commercial practice. However, allowing for all these factors, it is unlikely that a magnet such as is described here could not be built within a factor of two of the costs indicated.

VI. CONCLUSIONS

The construction of this prototype necessarily involved the use of some techniques which will not be carried over into a magnet that it is intended to produce in larger quantities. A number of additional changes can be suggested to the prototype with advantage. For example, some improvement in the field may result from shaping the iron. Preliminary calculations indicate that the addition of holes as shown in Fig. 3 together with the shaped tips will result in a larger good field area while providing an adequate flow path for the helium. The serpentine spacer can be obviated by the use of a spiral ridge extrudate which when drawn into the square shape will provide the necessary helium flow paths beneath the conductors. Further helium channels can be introduced beneath the hydraulic clamps by a similar technique if required. This paper has shown that a suitable doubler magnet can be produced at a not prohibitive cost, and that further development work in this area would probably be rewarding. The problem of cryogenic accelerators may now proceed from the magnet into the areas of energy storage and extraction systems.

ACKNOWLEDGMENT

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REFERENCES

[1] Wilson, R. R., A short published description of the NAL energy doubler scheme is contained in "Physics Today", May 1971.

[2] Carrigan, R. A. Jr., FN-233 NAL Internal Report, July 1971.

[3] Long, H. M. et al, RP-78-7, "Superconducting Cable System", Final Technical Report, Union Carbide Corp., Tonawanda, New York, October 31, 1969.

Table I.

Bore	2.5 cm
Gradient	1 T/in. (40 T/M)
$\Delta G/G_0$	.02% at r=0.318 cm .40% at r=0.635 cm
Current at 1 T/M	800 A
Laminations	
Size	6.8 cm I.D. × 14.0 cm O.D. × .159 cm thick
Material	Main Ring Iron
Conductor	
Size	.075 mm square
Cu/Sc	3/1
Strands	121
Insulation	Heavy Formvar
% of Jc at B max	57%
Number of Turns	24/Pole

Table II. 0.5 Meter Energy Doubler Prototype Cost.

Superconducting wire	$ 175.00
Laminations	
Die 900	950.00
Punching 50	
Winding coils	
2 Man Weeks	300.00
Supervision	
1 Man Week	300.00
Assembly	
2 Man Weeks	300.00
Machining	
Cryostat & Misc.	2,500.00
Hardware	
TOTAL	$4,525.00

Table III. Projected Costs for 1 to 3 Meter Magnet-Energy Doubler.

Superconducting wire			$ 525/Running meter
Laminations			150/Running meter
Cryostat	$2,000	+	600/Running meter
Misc. Hardware & Materials	1,500		
Winding coils	450		Independent of Length
Assembly	300	+	150/Running meter
	$4,250		$1,425/Running meter
Cost of 3-Meter Magnet =	$8,525		

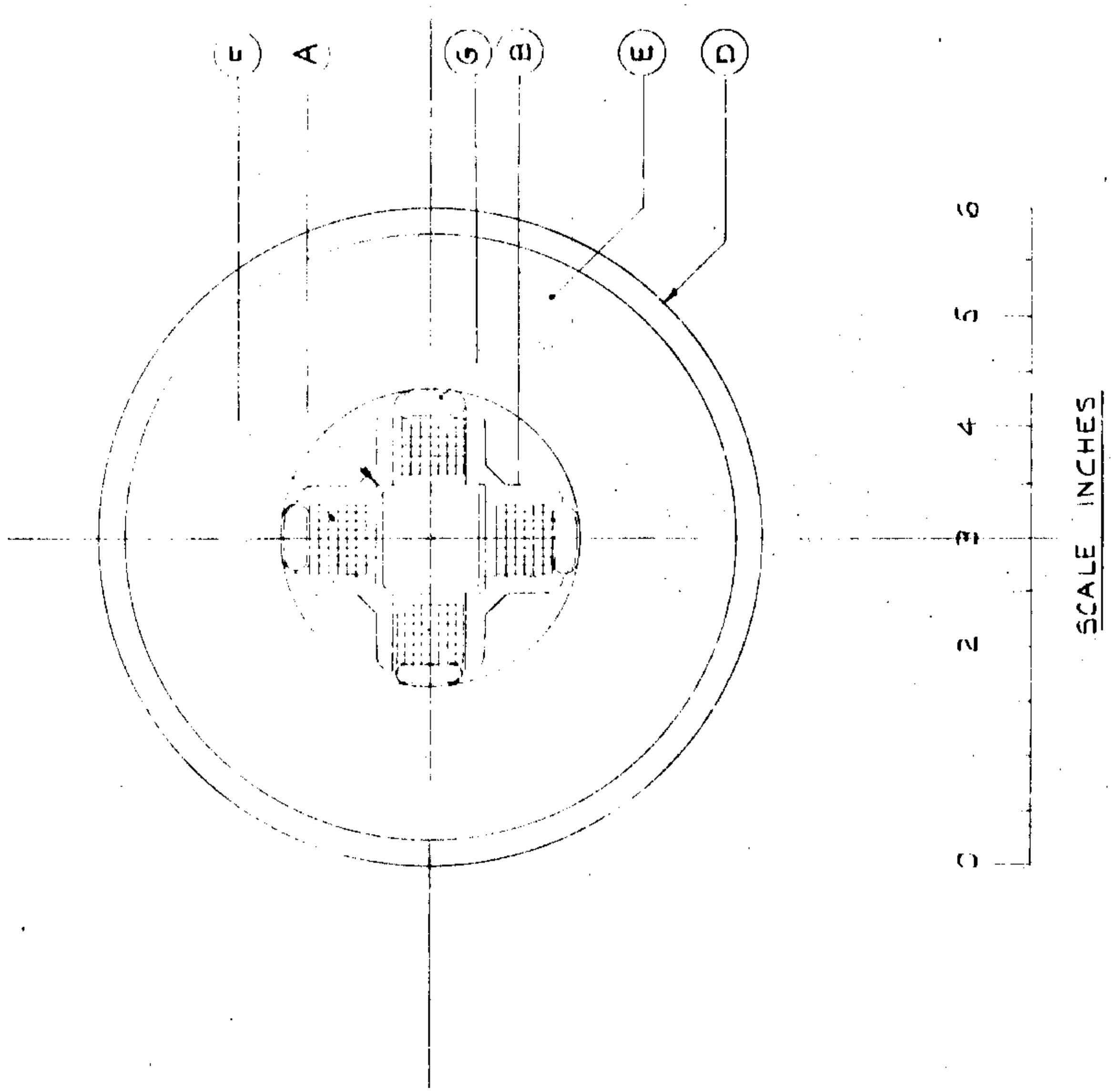

Fig. 1. Cross Section of Superconducting Quadrupole Magnet.

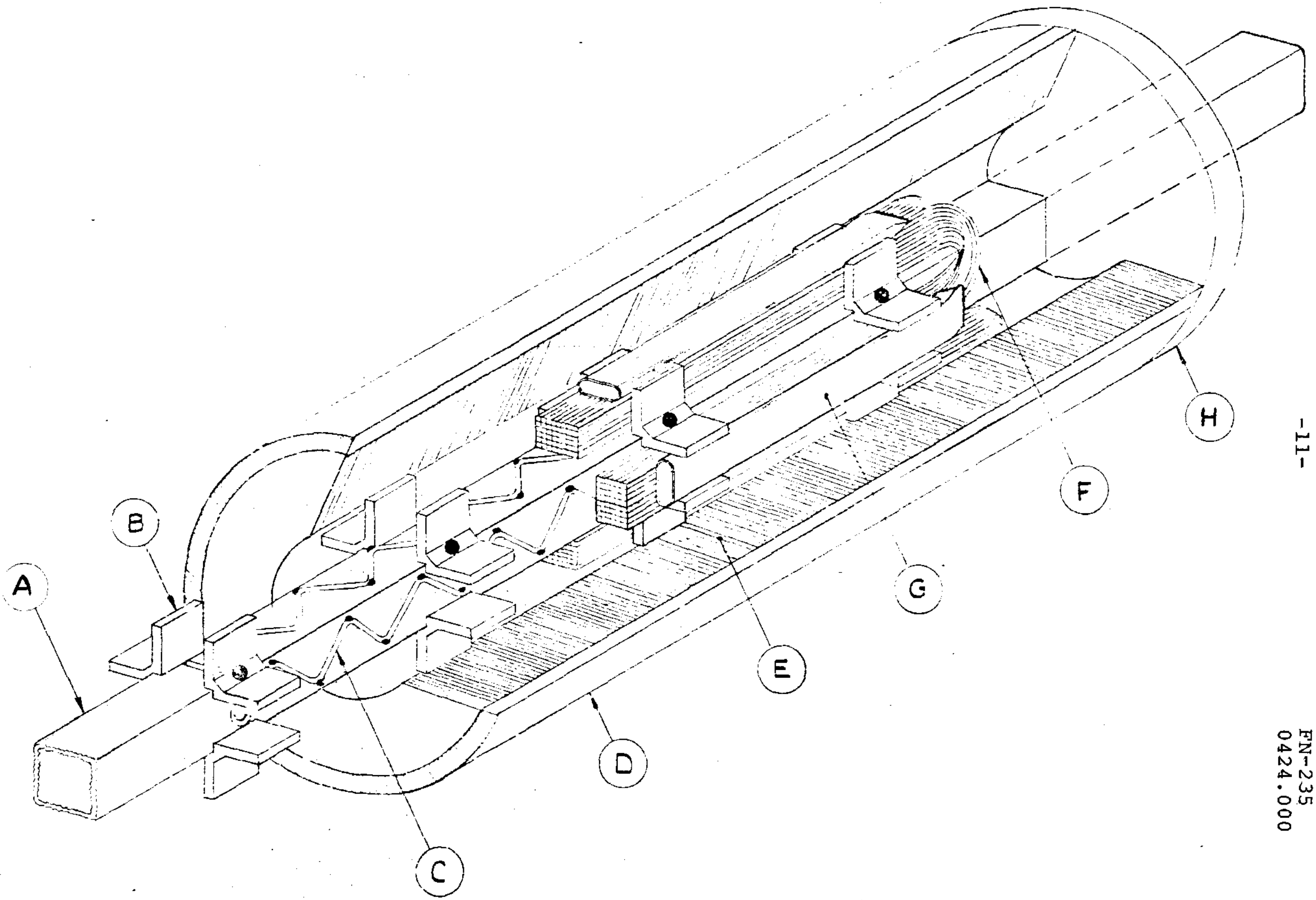

Fig. 2. Third Angle Projection of Superconducting Quadrupole Magnet.

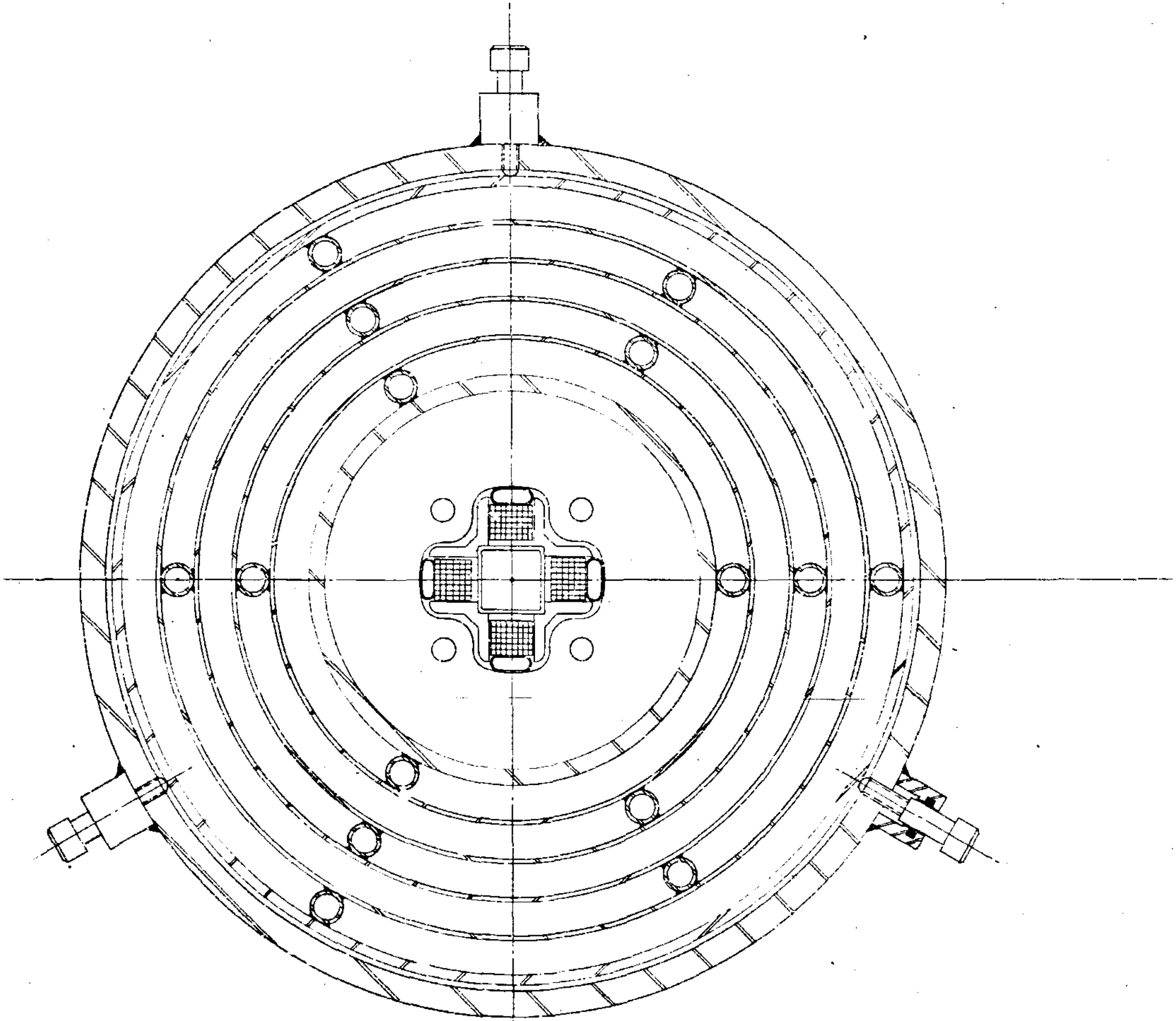

Fig. 3. Cross Section of Superconducting Quadrupole Magnet
Showing Shaped Pole Tips and Cryostat Mounting.