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MECHANICAL DESIGN OF ISABELLE MAGNET CRYOSTATS*

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SUMMARY

It has been proposed to construct an intersecting storage ring accelerator, ISABELLE, at BNL, consisting of two concentric rings of magnets containing counter-rotating beams of charged particles. Each ring contains 216 dipole magnets and 138 quadrupoles. All magnets are superconducting and operate at a temperature of 4.3 K. A description of the design of the cryostats, including the internal supports, heat shield superinsulation system and the vacuum vessel is given. Details of fabrication techniques are also included.

INTRODUCTION

As an integral part of the ongoing ISABELLE magnet program, considerable effort has been directed to the design and development of the cryostats. Included is the magnet support system within the vacuum vessel, the heat shield superinsulation system, internal plumbing and the vacuum containment vessel. Obviously, a major goal of this program has been to develop a system that would minimize heat flow into the helium coolant. Also, because the accelerator represents a large and complex cryogenic system, reliability of operation was a prime consideration. Finally, particular attention was directed toward reduction in the overall cost of the system.

Although the magnet structure is not a subject of this report, but because it is an integral part of the cryostat, a brief description is presented to help clarify the overall cryostat concept. A unique feature of the ISABELLE design is that the magnet core support structure is also the helium containment vessel of the cryostat. The magnet iron core consists of washer type laminations and are contained within a closely fitted, one inch thick, stainless steel core support tube. The laminations are compressed and then secured by internal retaining rings inserted in grooves machined in each end of the core support tube. After the magnet coil has been axially inserted into the core, end plates are welded to each end of the core support tube, resulting in a closed helium containment vessel. Because of the inherent longitudinal rigidity of the core support tube, support of the magnet within the vacuum vessel is greatly simplified.

The design of the quadrupole and dipole cryostats are similar in concept, differing primarily only in size. Details are directed toward the dipole design, with comments where there is a significant difference in the quadrupole design.

SUPPORT SYSTEM

It was established initially that the support system should satisfy certain criteria. Heat flow by conduction through the supports should be limited to a total of less than 5 watts. The support system should have a long-term dimensional stability. In particular, it is required that the quadrupole magnets maintain a positional accuracy of better than a few thousandths of an inch over several years duration. Deflections of the magnets, especially rotation, from external forces should also be within the same close limits. These forces could result from incompletely balanced magnetic interactions, unbalanced pressures in bellows connections, stresses due to misalignments, etc. It was assumed, very conservatively, that the total of such forces would not exceed 500 pounds in any direction, but could act anywhere on the magnet. The assembled magnet should also be able to withstand reasonable forces as a result of being transported. Finally, it was considered desirable, though not essential, that the longitudinal axis of the magnet remain fixed in space when the magnet is cooled to operating temperature. This would greatly facilitate the initial magnet survey and simplify plumbing and electrical connections to the magnet.

Figure 1 shows the support system developed to meet the above criteria. At one end, it consists of two inclined tension members, attached between the dewar support tube and the vacuum vessel. At the other end, two inclined tension members are attached between the magnet and a yoke assembly. A single tension member joins the yoke assembly to the vacuum vessel. This arrangement results in a mathematically determinate three point suspension. All connections to the dipole magnets are made at the quarter points to minimize vertical deflection of the core support tube. Because the quadrupole is much shorter, connections are made at the magnet ends. Lateral stability is provided by two cross rods located at each end of the magnet and on the lower surface of the support tube. Although nonmetallic tension members would have resulted in a lower thermal conduction, uncertainty about long-term creep stability eliminated them from consideration. For ease of assembly, the tension members for the dipole magnet are stainless steel roller chain. Since the quadrupole assembly, because of its shorter length, is easier to assemble, the tension members are 3/8" diameter Invar rods. A complete mathematical analysis[1] of the system verified its conformance to the design criteria.

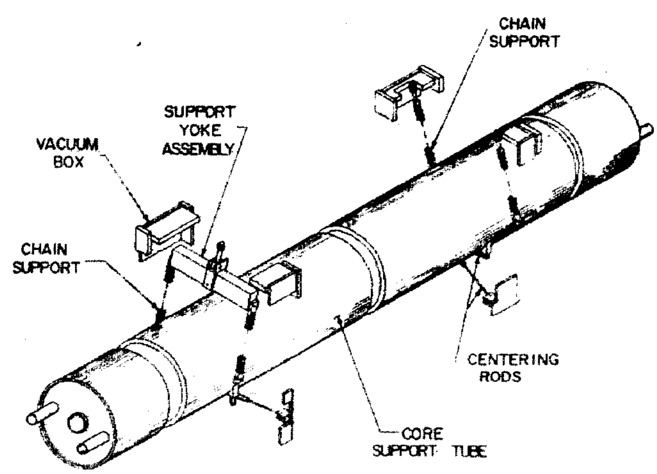

Fig. 1. Isometric of magnet support system within the vacuum vessel.

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This system results in a zero displacement of the longitudinal magnet axis during cooldown to operating temperature in the following way. With reference to Fig. 2, point A on the core support tube will move a distance Δ, to point A′ when the magnet is cooled down due to longitudinal contraction. It will also move transversely a distance Δ_2. At the same time, the tension member L will contract an amount Δ_3, resulting in a length L′. The value of various contractions will depend on the average temperature of the member. Assume the tension member is initially inclined at some angle α. By choosing a particular combination of the values of L, d, and α the contraction of the core support tube will be compensated for by the contraction of the tension member, and the longitudinal axis of the magnet will not be displaced vertically[2] when cooled to operating temperature. This same approach was applied to the lateral stabilizer rods, to prevent an increase in tensile stress during thermal cycles.

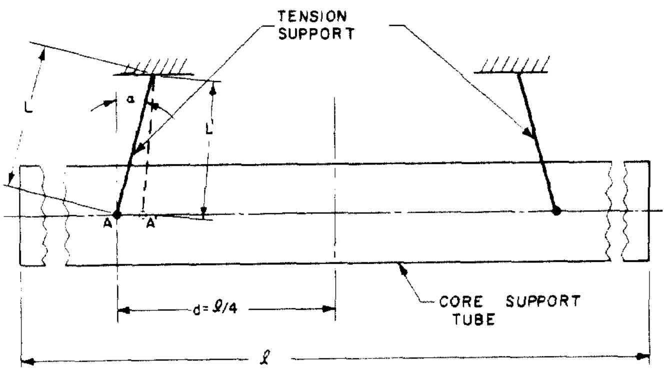

Fig. 2. Longitudinal contraction of magnet is compensated by contraction of tension supports

HEAT SHIELD - INSULATING SYSTEM

Magnet cooling is accomplished by flowing supercritical helium fluid, at a pressure of 15 atm, through all the magnets in a sextant.[3,4] At the end of a sextant, the coolant is returned back through the sextant by means of a pipe attached to a shield surrounding each magnet and contained within the vacuum vessel. Any heat flow to the magnet is intercepted by the shield. It consists of a 1/32" thick copper cylinder surrounding each magnet and spaced from the magnet by 3/8" diameter nylon balls. Twelve layers of aluminized Mylar provides radiation shielding between the copper shield and the magnet. Radiation shielding from ambient temperature is provided in the annulus between the vacuum vessel and the heat shield. According to an analysis by Shutt,[5] of primary importance for an effective radiation shield, it is essential that a pressure of 10^{-4} Torr be maintained between layers of insulation. This is accomplished by providing adequate pumping channels between layers and by selecting materials with minimum outgassing properties. The desired density of insulation is about 40 layers per inch of available space. The system used consists of 80 layers (2" available) of doubly aluminized Mylar, 0.0005" thick, interleaved with 0.005" thick polyester cloth. To further enhance pumping between layers, bumper strips, 2" wide by 0.008" thick of polyester cloth are spaced approximately 20 inches on center and wound in between insulating layers. In order to obtain the desired insulation density, the tension used to apply the insulation must be carefully controlled.

Figure 3 shows the system used to install the insulation. Temporary trunnions are attached to each end of the magnet support tube and the entire assembly supported on rollers contacting the trunnions. The various insulating components, aluminized Mylar, polyester spacer cloth, and bumper strips are mounted on a framework parallel to the longitudinal axis of the magnet. The magnet is rotated about its axis at a speed of about 5 revolutions per minute by a drive motor, and the insulation wound directly onto the heat shield. This entire insulating process is accomplished in about one hour. After the magnet has been suspended in the vacuum vessel, the trunnions are removed, and the insulation on the magnet ends installed. To further reduce outgassing effects, a pump, heat and purge cycle was established. About six such cycles were required to obtain the desired vacuum. The effectiveness of the insulating system was verified by tests on an assembled magnet (MK-IV).

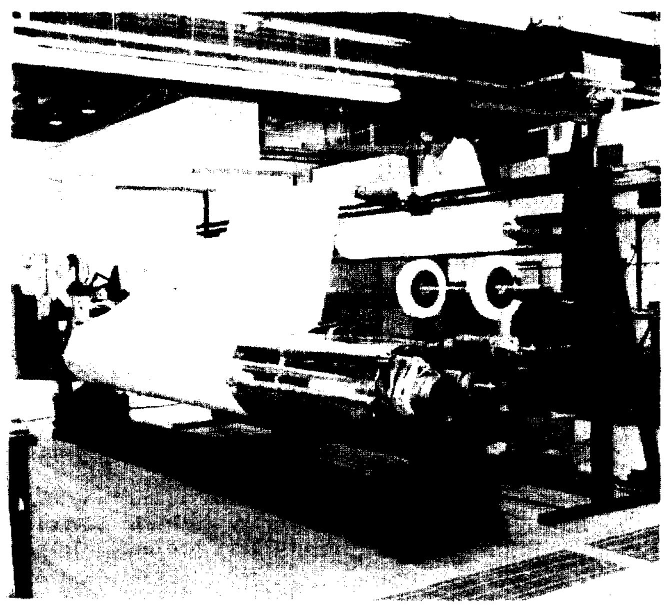

Fig. 3. Set-up for installation of superinsulation system.

In addition to the shield pipe, a distribution header is also contained within the vacuum annulus. This eliminates the need for external transfer lines and results in a considerable cost saving.

VACUUM VESSEL

The vacuum vessel is shown in Fig. 4. It consists of a center cylindrical section, 28" in diameter and ¼" thick, attached to rectangular box sections at each end. These box sections provide space for installation of the vertical supports and horizontal stabilizer rods. For the dipole vessel, end bells are attached to the rectangular box sections to complete the assembly. A flat plate completes the quadrupole vessel. The vacuum vessel is fabricated entirely from carbon steel plate. In order to reduce costs, machining of the vessel is minimized. To insure maximum reliability, all gasketed joints have been eliminated, resulting in an all welded assembly.

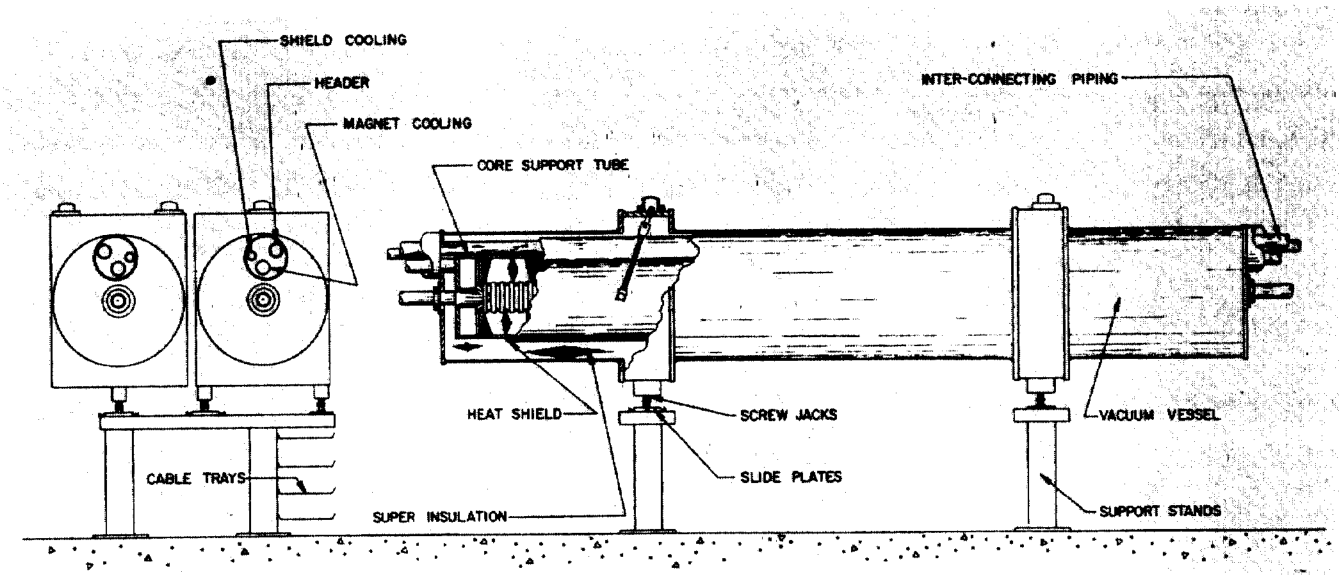

Fig. 4. Completed magnet assembly on support stands.

Radially adjacent ring magnets are supported on a common stand. Three simple screw jacks under each magnet provide vertical adjustment. The jacks in turn are supported on slide plates, providing horizontal translation alignment.

Interconnecting piping between magnets is contained in a single 10" diameter vacuum pipe. The pipes are enveloped by a common copper heat shield and aluminized Mylar radiation shield. Each line contains a bellows to accommodate longitudinal thermal contraction. The 10" vacuum line also contains a bellows to allow flexibility to facilitate the adjustment of adjacent magnets. To allow accessibility to connect the internal piping and power leads, a slide coupling is also provided in the outer vacuum tube.

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