

DESIGN OF AN ULTRA HIGH VACUUM COMPATIBLE COPPER SEPTUM MAGNET*

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Abstract

An Ultra High Vacuum compatible thin copper septum magnet has been developed at Brookhaven National Laboratory. The solid core, single turn magnet is pulsed at 1500 amps and has a field of 0.6 KG. The 0.76 mm thick copper septum is water-cooled and is designed to run at a maximum power of 2 KW. A remote positioning system is used to optimize the septum position during various extracted beams. The cross section of the septum magnet was modeled and 2-dimensional magnetic field calculations were performed to compute the magnetic field uniformity in the main field region and in the field strength in the fringe field region. The calculated field uniformity as well as comparison of the calculated fields in the fringe field region with the measured fields in the same region will be presented. The design and construction techniques used to fabricate this magnet will also be described.

INTRODUCTION

A thin septum magnet, Figure 1, was designed, fabricated and installed as part of the beam extraction system for the NASA Space Research Laboratory (NSRL) at Brookhaven National Laboratory. The Magnet is installed in the Booster ring in the Collider-Accelerator complex. The Booster ring used to accelerate heavy ion and protons for various projects at Brookhaven.

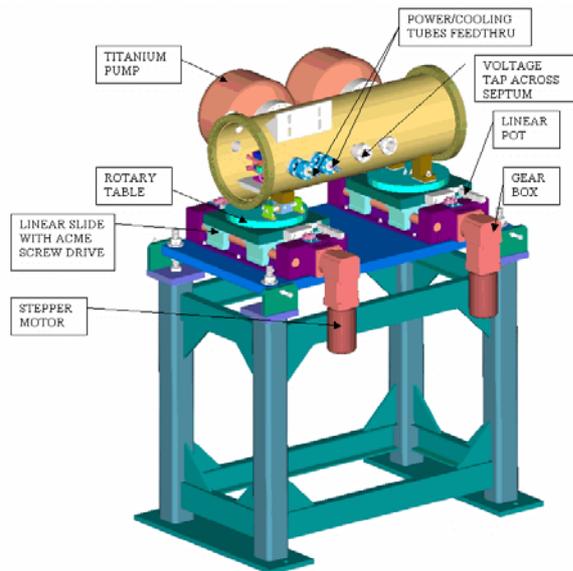


Figure 1. Isometric view of Thin Septum Magnet assembly

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The Booster ring vacuum system is required to operate at a pressure of low 10^{-11} Torr, especially for gold heavy ions in order to reduce beam loss. The vacuum requirements of the system presented a challenge to design a magnet, which meets the vacuum criteria. Similar magnets were designed and built at Brookhaven but were not bakeable and contained organic materials used for electrical insulation.

The magnet was designed to run as a pulsed magnet, which typically runs at 7.5 pulses/sec at a nominal current of 1500 amps. However in order to test the magnet and especially cooling capacity of the monel cooling tubes the magnet was run at 2000 amps DC and was subsequently pulsed at a rep rate of 1 sec at 2000 amps for 1 million pulses. The cooling of the copper septum is of particular concern since the current density can be as high as 94 amps/mm².

DESIGN

The materials used for the internals of the vacuum system must meet outgassing rates of 5×10^{-13} Torr-l/s-cm² at 25° C. The vacuum vessel is fabricated with 316L stainless steel with 316LN stainless steel Conflat flanges with a 90° knife-edge. These special Conflat flanges are typically used throughout the Booster vacuum system since the knife-edges are less prone to rollover during repeated high temperature bakeouts. In addition all Conflat flange seals are copper seals with .05% silver impregnated to prevent crystallization of the copper during bakeout cycles.

The magnet core is fabricated from 1006 low carbon steel and is a solid c-shaped core 965mm in length. The magnet coil, which is a thin copper strip 0.73 mm thick, the back leg and the buss bar/cooling tube connections are all fabricated from OFHC copper. All other supports and brackets used inside the vacuum vessel are stainless steel. The fasteners are all silver-plated stainless steel and are vented whenever they are installed in blind tapped holes.

A key to designing a UHV compatible magnet was the use of porcelain enamel¹ to electrically isolate the power connections and the magnet coil from ground. Stainless steel parts were coated with 0.02mm of porcelain to clamp the septum against the magnet core and support the buss bar/cooling tubes inside the vacuum vessel. The edge of the core where the septum banks along the length of the magnet was also coated with porcelain to insulate the coil from the core. The thickness of the porcelain can be controlled very accurate to with ± 0.025 mm of thickness with some practice.

The porcelain is applied to parts with a paint sprayer allowed to air dry and then fired in a high temperature air furnace at 850° C. The result is a very durable glazed finish, which has an outgassing rate approaching that of stainless steel. In addition porcelain is radiation resistant and can be used at elevated temperatures.

The copper septum is cooled by two rectangular Monel cooling tubes as shown in Figure 2. These tubes were brazed to the septum with BAG 8 fluxless braze in a vacuum furnace with a partial pressure of 30 mtorr of Argon. Since it is desirable for most of the current to flow through the septum the material for the cooling tubes must have a much lower conductivity than copper. For this reason Monel 400 with a very thin wall was chosen to be a good material. A fixture was fabricated to clamp the tubes to the septum, which allowed longitudinal expansion during the brazing process.

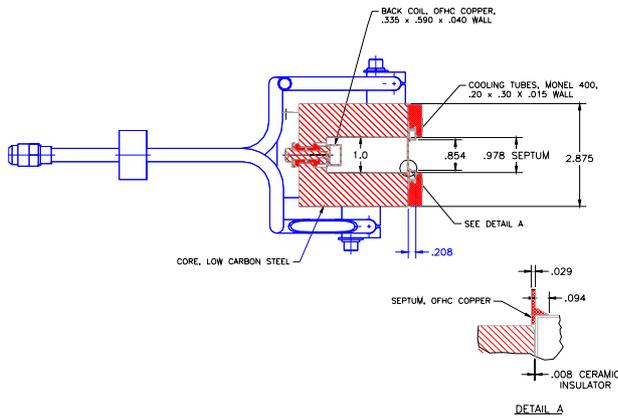


Figure 2. Cross section view of magnet core assembly

MOTION/DRIVE SYSTEM

The septum is required to move in and out of the beam in the horizontal plane as well as skew at any angle as shown in Figure 3. The upstream and downstream ends on the vacuum chamber can move independently of each other. This is accomplished by mounting each end of the vacuum chamber to a rotary table, which is mounted on a linear slide. Each linear slide is driven by an AC synchronous stepping motor coupled to a 50:1 gear reduction box. The output shaft of the gear reduction box is coupled to an ACME screw that moves the linear slide in the horizontal plane. The rotary tables allow the magnet to skew when the slides at each end are moved.

To accurately move the septum, linear potentiometers on each end of the vacuum chamber are coupled to a PC and indicate the exact position of the septum in the horizontal plane. The position system allows the septum assembly to move in and out of the beam with a repeatable accuracy of 0.025mm.

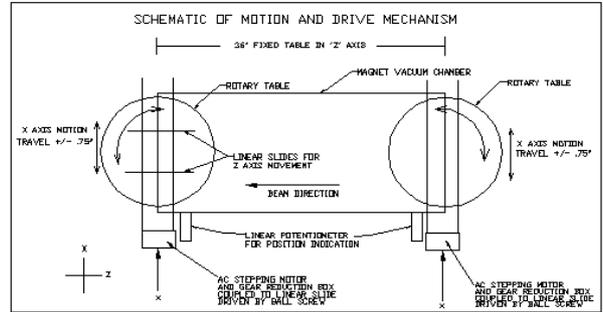


Figure 3. Schematic of motion and drive mechanism

MAGNETIC DESIGN/CALCULATIONS

The purpose of the magnetic field calculation was to twofold, first to calculate the field homogeneity of the magnet in the “Main Field Region” and second to calculate the strength of the fringe field at the “Fringe” region of the magnet where the beam is circulating.

Figure 4 shows a cross section of the magnet, with the “Magnet Iron” the “Septum” and “Return” conductors which both are made of copper, and the “Cooling Channel” which is made of material Monel 400.

In the calculations, which were performed with the 2D version of the code opera² the conductivity of both materials copper and Monel were taken into account by

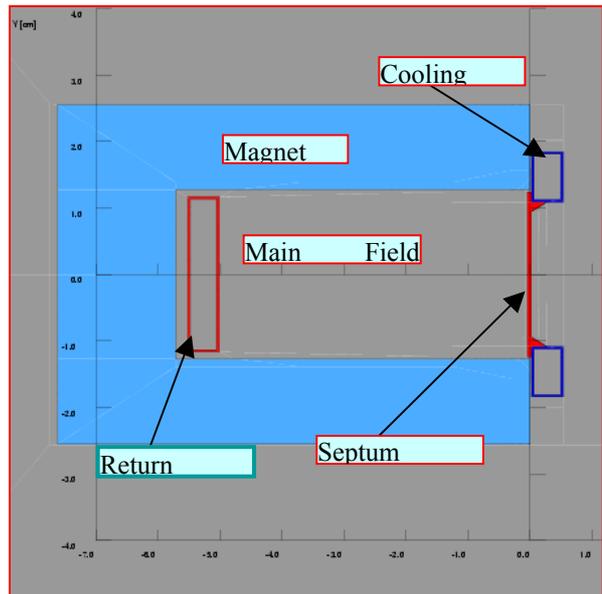


Figure 4. Cross-section of the Septum magnet showing the “Magnet Iron” the “Return” and “Septum” Conductors, the “Cooling Channel”. The “Main Field Region” corresponds to the extracted beam, and the “Fringe” region to the circulating beam.

adjusting current densities in the “Septum” ($J=5.871 \times 10^7$ A/m²) and the “Cooling Channel” ($J=1.888 \times 10^6$ A/m²).

Figure 5 is a plot of the magnetic field homogeneity in the “Main Field Region” from the edge of the “septum” to a distance 4 cm inside the magnet. The maximum magnetic field in the “Main Field Region” is 462.5 Gauss.

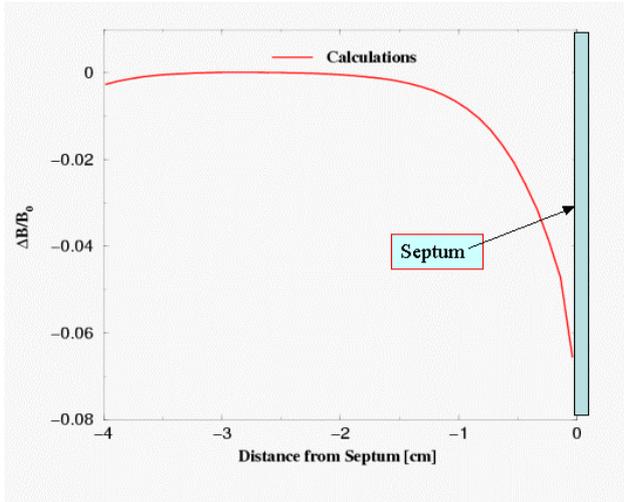


Figure 5. Field Homogeneity in the “Main Field Region” of the magnet

The magnetic field in the “Fringe” field region where the beam is circulating is plotted as function of distance from the edge of the septum. On the same plot the experimentally measured field is also plotted.

CONCLUSION

A successful UHV compatible Thin Septum Magnet has been designed, fabricated and installed in the Booster ring at Brookhaven. The magnet has been operational at a pressure of low 10^{-11} Torr and has been flawless.

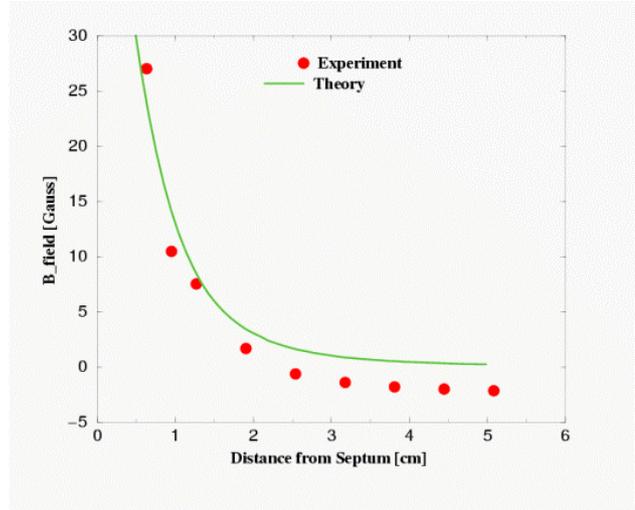


Figure 6. Experimental and Calculated values of magnetic field in the “Fringe” field region, plotted as a function of distance from the edge of the septum

REFERENCES

- [1] J.Vac.Sci. Techno.A 18(4), Jul/Aug 2000 pg 1751
- [2] Vector Fields Inc.