Octupole Magnet Design for the 1/2 Integer Resonant Extraction of Electrons from the South Hall Ring(SHR)*

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Abstract

The MIT-Bates SHR, a 190m long race track shaped electron storage ring with a 9.144m bending radius, is designed for nuclear physics experiments using two modes; the STORAGE mode with internal targets or the PULSE STRETCHER mode, which uses the 1/2 integer resonance and 2 ramped quadrupole magnets and 3 octupole magnets to (smoothly) extract the stored electrons of up to 1.0 GeV energy and 80 mA intensity over a period as short as 1 millisecond into the extraction line.

I. INTRODUCTION

This report summarizes the design features and results obtained for the octupole magnets, which are characterized by poles of 24.89 cm axial length, located 3.25 cm from the electron beam axis and having variable pole-tip field strengths of up to 6.0 kG, with the pole/coil assemblies mounted in a cylindrical steel return frame.

II. MAGNETIC DESIGN

The octupole specifications call for a variable octupole field with a minimum of other multi-poles, which is achieved through the appropriate pole tip contour defined by the radius to the pole from the beam axis and by the angle (a) from the pole location angle. This radius slowly increases from the minimum Ro of 3.25 cm according to the following relationship:[1]

R(a) = Ro/[cos 4(a)]exp(.25)

A compromise must be made between the optimum pole angle and the space needed to install the water cooled copper coil and insulation. Iteration of several configurations using the POISSON program [2] resulted in the selected design where (a) varies from -12 to +12 degrees about each pole tip and which allows a physical space for installation of reasonable coils. Reasonable coil parameters of; turns/pole, current, voltage, power, cooling, and temperature rise were achieved for the selected design.

To determine the required ampere-turns per pole (a-t/p) it is assumed that the field strength varies as the third power of the radius up to the pole-tip where the design calls for Bp = 6000 Gauss. In the cgs system of units this is also Hp = 6000 Oersted. The assumed variation of H(R) is cubic and can be expressed as:

H(R) = Hp(R/Ro)exp(3)

Integration of this function over R (0 - 3.25 cm) allows determination of the MMF (gilberts) needed to excite the pole.

MMF/p = Hp(Ro)/4 = 4875 Gilberts

NI/p = MMF/0.4(pi) = 3789.4 a-t/p

The magnetic efficiency of the magnetic path is assumed to be 0.97, therefore the a-t/p = 3789.4/0.97 or 4000 a-t/p for the coil excitation requirements.

III. MECHANICAL DESIGN

The return frame is based on a thick wall pipe/tube of 1018 carbon steel with OD/ID of 11.5"/8.5" nominal size, which is "rough machined" to within 1/16" of the final dimensions, annealed at 1500-1800 degrees F for 1-6 hours and oven cooled to relieve internal strains after the auxiliary brackets and support blocks were welded on, then honed to the correct ID. A final electro-less nickel plating of 0.5 mils thickness is added, to provide corrosion protection, completing the frame fabrication.

The poles are made from bar stock of 1003 carbon steel to ensure good permeability at high magnetic field strengths. The poles were rough machined on a CNC Machining Center to within 1/16" of final dimension and then annealed, and finally machined before plating completes the pole(s) fabrication.

The octupole magnet steel parts were preassembled without coils to establish the proper alignment of each pole to the axis and to each other and then bolted up after which the pole/frame interfaces were maked and pinned (Dutchman) to the frame at each end to allow reassembly of the magnet after the coils were mounted on the poles. The magnet final assembly involved the sliding of the coil/pole assemblies non-lead ends into the frame,

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locating position by the pins and bolting up tight. Tolerances for the pole locations require the poles to be within ± 0.002" to the axis and ± 0.004" to each other. Measurements completed indicate that the required tolerances were met in the assembly of the magnetic frame and the poles.

IV. COILS

The coil design is based on a copper hollow conductor[1] of CDA 102 OFHC alloy with OD/ID dimensions of 0.162 SQ/0.090 RD. The copper is served with an wrap of double dacron/glass fiber to a thickness of 0.006" for turn to turn and layer to layer insulation requirements. Each of the coils have 12 turns per layer for a total of 24 turns per coil. The total magnet resistance is calculated to be 0.202 Ohms at 40 C. The total octupole magnet voltage and power at 167 amperes DC current is calculated to be 33.8 Volts and 5.6 kW respectively. A ground wrap of fiberglass 0.015 thick was placed on the external coil surfaces to provide additional insulation between the coils and the steel frame. The coils were vacuum impregnated with epoxy in a mold. The power supplies chosen to excite the octupole magnets have a rating of 50 Volts and 200 Amperes (10 kW).

V. AUXILIARIES

There are attached to the cylindrical steel return frame a number of brackets and blocks to interface the octupoles to the outside world such as; power terminal blocks, interlock box, manifolds for coolig water supply and return, support blocks for support and position adjusters, and fiducial bars for survey and alignment of the octupole magnetic axis on the beam line. The coil ends are arranged to have the cooling water enter and leave the coils in a combined way to reduce the number of hoses to 5 for each manifold.

VI. MEASUREMENTS

The octupoles weigh about 200 lbs. The coils resistance has been measured to be 0.024 Ohms and the total resistance measured to be 0.194 Ohms at 24 C. The flow rate at 70 psid was measured at 1.0 GPM total for the first unit delivered. The temperature rise across the manifolds was measured to be 25 C degrees at 179.9 amperes DC with a 1.0 GPM flow rate.

The pole-tip field is linear with current up to 5 kG and then departs from the airgap line by about 10% at 6.0 kG. Measurements of the strength of the octupole and the higher pole content were made on the Magnetic Analyzer at several current excitations including zero. Figure 1 shows the mutipole content for the maximum excitation current and the associated k value $\frac{B_0 Leff}{q^3}$. Figure 2 shows the k value divided by I vs. I and this curve is fairly constant indicating a linear octupole.

The design effort to produce the three octupole magnets was successful. One unit of 3 delivered has been measured. Figure 3 shows a drawing of the octupole.

VIII. ACKNOWLEDGEMENTS

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IX. REFERENCES

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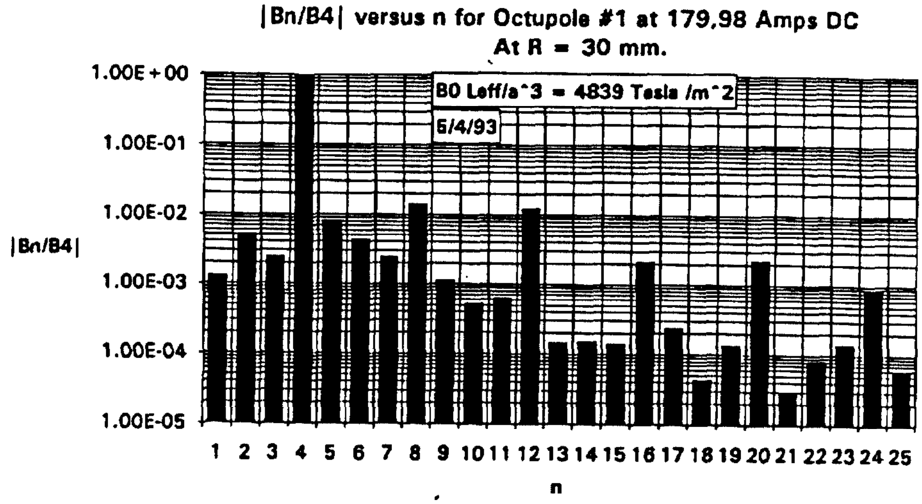

Figure 1. Octupole field harmonic ratios to the octupole field n = 4.

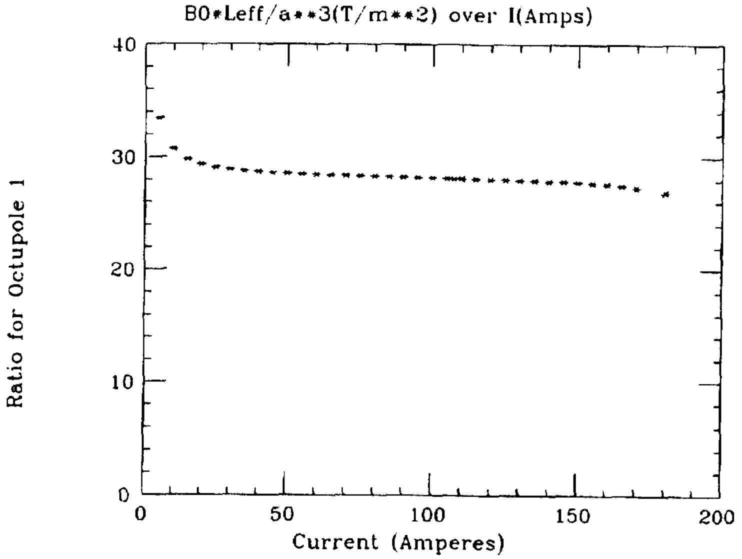

Figure 2. k/I versus I. k = Bo*Leff/a*exp(3).

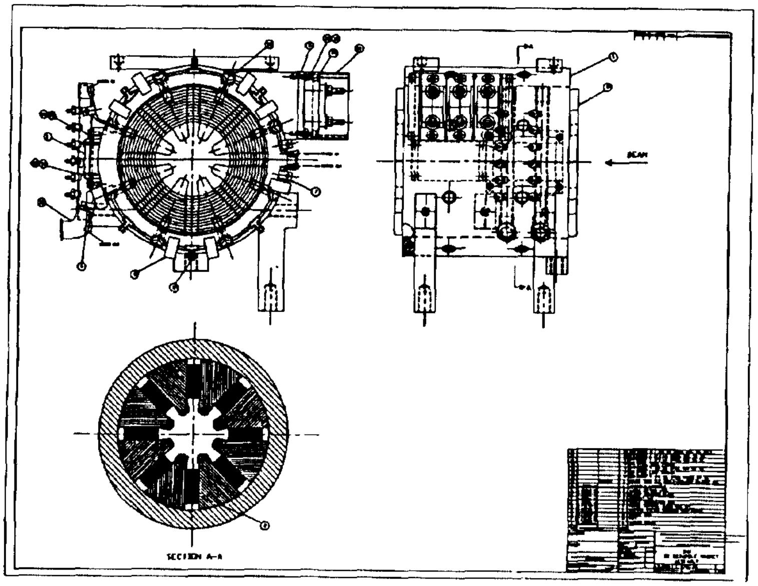

Figure 3. Drawing of the octupole showing 2-views and a section.