Ramped Quadrupole Design and Performance for the MIT-Bates South Hall Ring(SHR)*

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Abstract

This report discusses the design and performance of 2 Ramped Quadrupoles (RQ). They are to be used to rapidly move the horizontal tune close to the half integer (7.5) for extraction of the up to 1.0 GeV electron beam stored in the SHR. The design chosen is an 8 conductor array symmetrically placed about the beam axis at ± 15° to the 4 axes and connected to produce a quadrupole field. The conductors are half imbedded in a ferrite shield assembly, outside a ceramic vacuum chamber, and when powered at 250 amperes produce a gradient of about 30 G/cm over the radius of 4.5 cm and along a 30 cm length. The ceramic chamber is internally conductively shielded to present a smooth bore surface for the S-band bunches, but allow the up to 20 kHz quadrupole field components to pass through the shield and influence the electron beam.

I. GENERAL

The SHR design calls for a half integer beam extraction system to smoothly extract the stored electron beam of up to 80 mA average and up to 1.0 GeV energy during periods as short as 1.0 ms during the interpulse periods of the linac (1000 pps maximum and 1.32 micro-seconds pulse length for 2 turn injection). There are 3 octupoles and 2 ramped quads which make up the resonant extraction beam line components. A review of approaches taken by others in the literature include: current sheets in air[1], current tubes in vacuum, current tubes within flat ferrite plates, and some others with very complex end connections as the number of current elements becomes large. Aircore calculations using MATHCAD determine the resulting field gradients for symmetrically placed current elements about the axis. Calculations were performed for a number of conductors (4,8,12,16,20) at various angles and radii from the beam axis. The selected design was a compromise between a simple configuration and a good field region over a fair fraction of the aperture. By placing the conductors half buried in a ferrite shield, a boost in the internal field strengths by about a factor of 2 and a significant reduction in external stray fields could be expected. This design approach, reduces the required current and power by factors of 2 and 4 respectively, while doubling the inductance.

The horizontal β-function value at the lattice location of the RQs affects the amount of tune shift obtainable. The planned location has a 20m β value where the expected tune shift per RQ at 250A and 1.0 GeV will be about 0.06, which is conservative given the operating storage nux value of 7.42, which is moved towards the 7.5 half integer value for extraction of the electron beam by the excitation of the RQs.

II. FERRITE RETURN FRAME

Several manufacturers quoted to the RQ Drawings for the ferrite shield. A contract was placed with NMGI, Bethlehem, PA for a number of ferrite rings (H Material) with 8 half round slots for the conductors to sit into on the ID of the ring. The OD/ID/t of the rings is 5.40"/3.5"/0.625" respectively. The depth of the 8 half round grooves is 0.125" at ± 15° to the principle axes to accommodate the OD/ID 0.250"/0.180" hollow hard drawn copper conductors. A prototype assembly of the RQ was constructed to verify Bo*Leff/a for the air and shielded design approaches. Because the ferrite shield rings were not available a solid steel pipe was substituted for the shield and proved the expected factor of 2 field enhancement could be approached. The achieved Bo*Leff/a at 192.5 Amperes was 0.0852 Tesla. For non-nested conductors a factor of 1.72 was achieved, while placing strips of magnetic material on either side of the conductor to simulate 1/2 buried conductors produced a factor of 1.83 enhancement of the field. The final measurements of the completed final assembly show the field enhancement factor to be about 2. Figure 1 shows a drawing of the unit.

III. ELECTRICAL DETAILS

The 8 axial conductors are end connected symmetrically as possible to produce the desired quadrupole field and are powered in series. With the ferrite shield outside the conductors the inductance is expected to be about 5.4 micro-Henrys, which is 2 times the inductance without the magnetic shield. The resistance for DC current was measured at 3.4 milli-Ohms and increases with applied frequencies due to eddy currents induced in the water cooled conductors. The maximum current is designed to be about 250 Amperes and the first order current shapes will be trapezoidal or sawtooth. Tune shift control by programming the current to the RQs is required. The period of the excitation will be 1 millisecond or greater depending on the injection-storage repetition rates of the

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injector linac. The final circuit design is not yet finalized, but it is expected that we will drive the current into and out of the ramped quadrupoles by using a linear amplifier to gain experience in the extracted beam behavior at various energies from 0.3 to 1.0 GeV.

IV. TESTING

The tests performed on the RQs were done with the ferrite shield and DC current on the Harmonic Analyzer[2] to measure the harmonics of the quadrupole fields. Figure 1 shows the relative strengths of the various harmonics as measured at various currents. Measurements of the median plane field and gradient strengths versus radius are shown in Figure 2. Harmonic field ratios for the ramped quadrupole are shown in Figure 3.

V. ALIGNMENT

The RQs will be measured to determine their magnetic axes, fiducialized and aligned using MIT-Bates standard methods[4]. The RQs can be placed in the SHR lattice to within ± 100 microns horizontally and vertically using these techniques.

VI. CONCLUSIONS

The requirements for a relatively fast quadrupole set to rapidly move the horizontal tune from 7.42 to close to the 7.5 half integer value for smooth resonant extraction from the SHR has resulted in the construction, testing and installation of the above described units. The use of ferrite rings to both boost the internal fields and to provide shielding has proved successful. The array of conductors has provided the required field strengths in a relatively simple arrangement. The excitation circuits while not finalized appear to be feasible and will be constructed in the near future. The system to produce a resonantly extracted electron beam is expected to be tried in the 2nd Quarter of this year.

VII. REFERENCES

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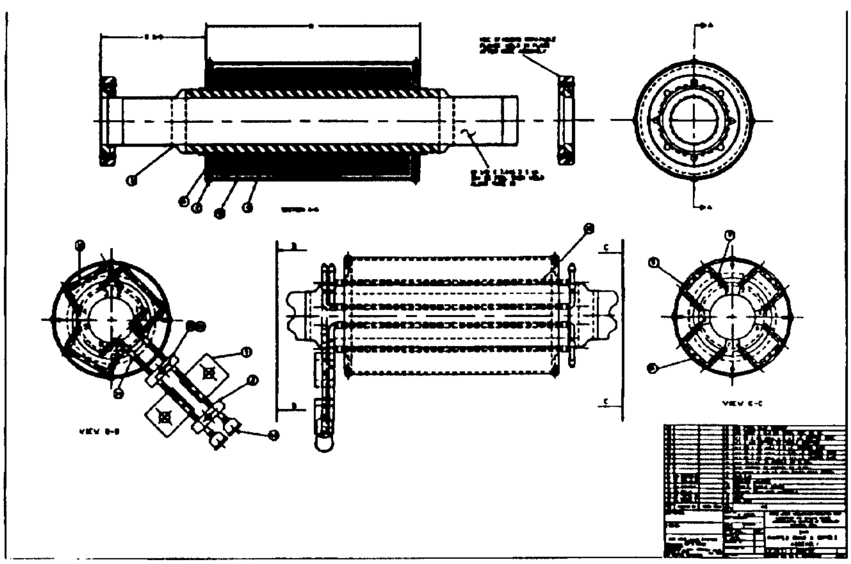

Figure 1.

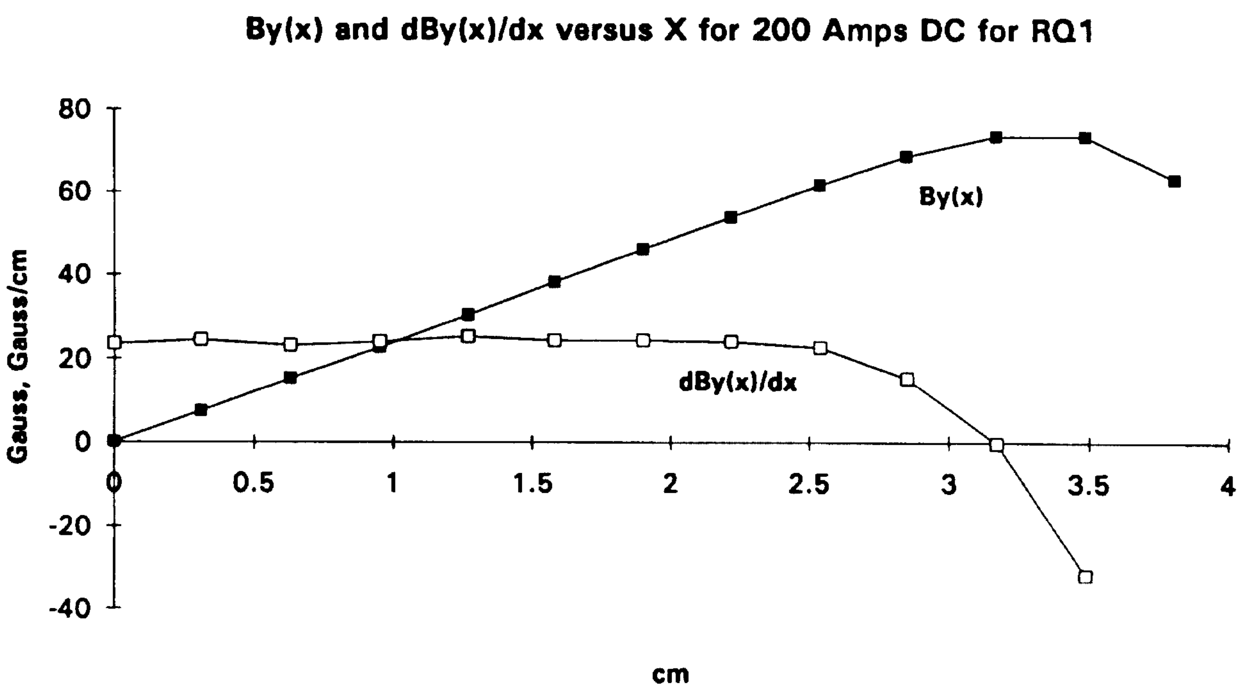

Figure 2.

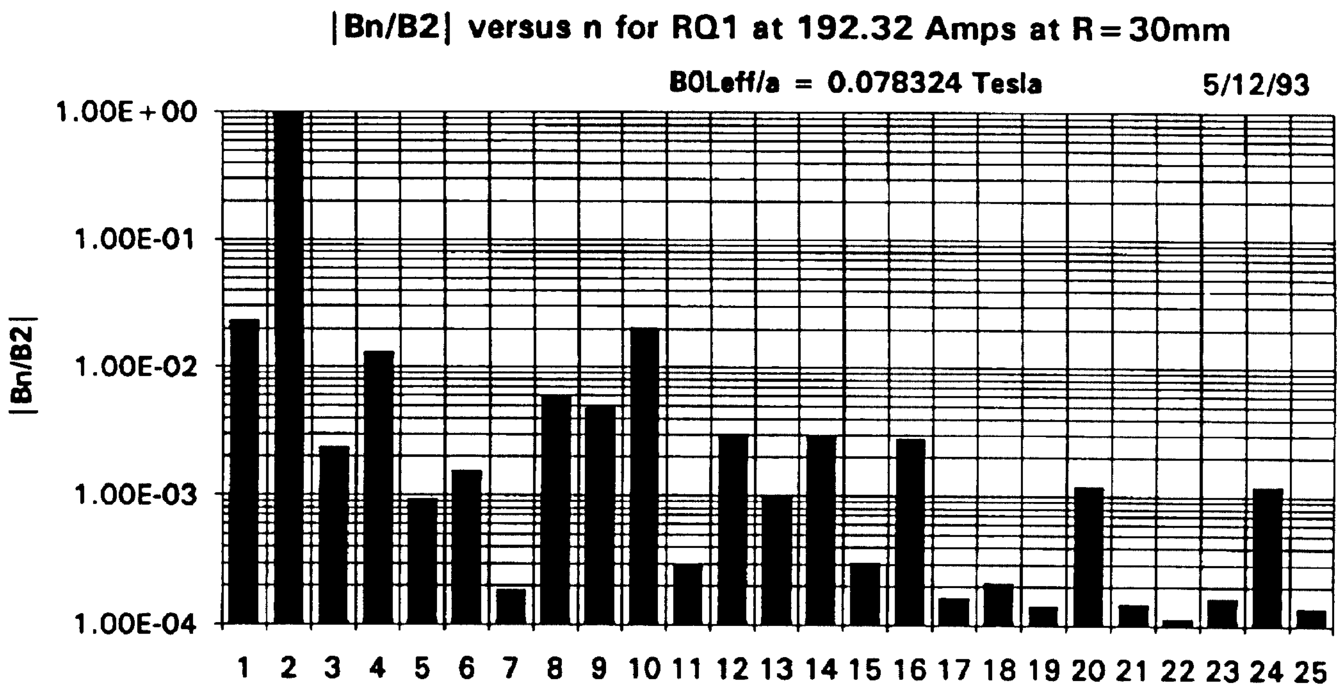

Figure 3.