THIRD HARMONIC CENTRAL REGION FOR THE K500-K800 SUPERCONDUCTING CYCLOTRONS*

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Abstract

In its injector mode, the K500 cyclotron will operate in third harmonic. The off-centering of the source slit is limited by the sizes of both the center plug and the ion source hole on the same plug. This starting point for the ions together with the requirement that the orbits are centered after a few turns determines a range of possible accelerating voltages which are significantly lower than our first harmonic (stand alone) mode voltages. We describe in this paper the computer studies done to design a central region geometry that would satisfy our requirements.

Introduction

In the stand alone mode the K500 cyclotron operates in first harmonic. The cyclotron runs in a constant orbit mode with approximately 500 turns in the machine. This mode of operation allows us to have only one central region and one source. The voltage thus scales approximately as

$$V \alpha \frac{(E/A)}{(Q/A)}$$

ranging from 40 to 100 kV. Accordingly, the maximum energy per nucleon is 80 MeV/n for fully stripped ions and the minimum energy per nucleon is approximately 10 MeV/n . Within the cyclotron, the radius of the source slit is 0.315 inches. The whole source body fits in a centered tube 1.0 inches in radius.

When running as an injector, the cyclotron dominant mode will be the third harmonic. The maximum energy per nucleon required will be around 7.2 MeV/n for ions such as $^{16}O^{2+}$. For the low energy case, we will run ions such as $^{208}Pb^{9+}$ at 0.91 MeV/n. The location of the source body will be the same but the geometry of the source slit is redesigned as described later. The central region of the third harmonic is changed from that of the first harmonic. Thus, the rest of the paper will describe the process and the results of these changes.

Initially we wish to decrease the transit time in the source to puller region. To accomplish that, we reduce its gap from the first harmonic value of 10 mm to 5 mm, keeping the same peak electric field of 100 kV/cm. With this peak voltage of 50 kV the high energy ions in third harmonic will be accelerated for approximately 190 turns,which will place the starting radius for these ions at a significantly larger value than the first harmonic case. This may lead to a problem since the ion source slit radius is limited by the size of the central hole, which is 1 inch radius, and the sizes of tne cathodes and clearances necessary for the enclosing tubes within the source. To increase the maximum radius that we can have access to, we will build a new center plug with three off-centered holes instead of one on center.(1) These three holes will remove approximately the same amount of iron from the plug as the old centered hole. The new holes are designed to be placed at 120 degrees apart to keep the three-fold magnetic symmetry.

The above alteration of the source-puller region then create a new difficulty for the case of the low energy ions. The voltage scaling law says that for the low energy ions the voltage required to keep a constant orbit geometry would be approximately 18 kV. As this voltage seems too low for an efficient extraction from the ion source, we then decided to study the possibility of having two central regions for third harmonic operation.

Orbit Calculations

The orbit calculation have been performed using our code CYCLONE(2). This code consists of three different parts. Part I integrates the equations of motion between source and puller using an electric potential map given in a rectangular grid. Part II continues the integration for a few more turns (typically until r= 3.6 inches). This part applies the superposition of electric potentials given by three rectangular potential grids since ours is a three dee machine. Part III uses delta function energy gain at the gaps with a transit time correction factor.

The electric potential maps have been prepared with TRIUMF's RELAX3D4 code(3). This code has proved to be a very useful tool in the design of electrodes for the central region; so useful that we have stopped using the electrolytic tank,a standard practice in our previous designs(2). The turn around time with the relaxation code is much shorter than a comparatively accurate measurement made in the tank. Our grids are typically 145 by 145 by 9 points with a mesh size of 0.05 inches and with planes parallel to the median plane apart at 0.0625 inches.

The magnetic field is given as a polar grid of values measured in the median plane and is linearly expanded from this plane.

Orbit Properties

In designing the central region, we first want to obtain centered orbits for rays starting at the ion source with times close to τ_o^*, central ray starting time. These orbits should clear all the posts that go through the median plane and that are used to define the electric field and to support the top and bottom half of the dees together. Secondly, we want that the radial phase space should not be distorted when transversing the strong electric field regions. Finally,we also want that the vertical acceptance of the central ray should not be much smaller than the acceptance of the rest of the machine.

The central ray starting time τ_o^* = -40 degrees was picked as a compromise between maximum energy gain

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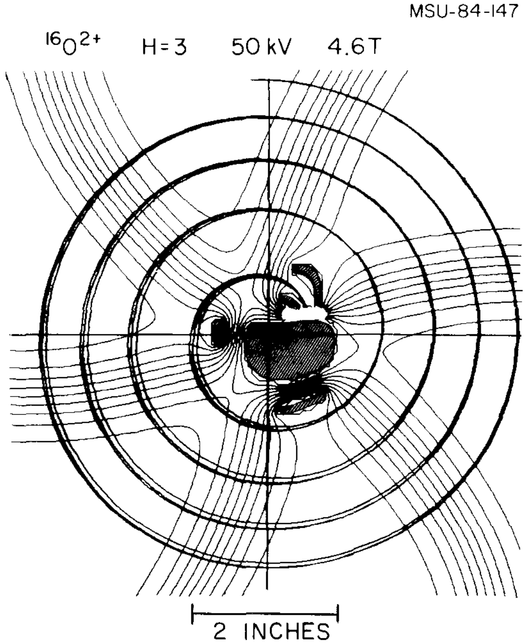

Fig 1. Central region electrodes in the median plane (hatched regions) and equipotentials for the high energy case of the third harmonic operation. Three orbits are plotted, corresponding to starting times τ_o = -50, -40, and -30 degrees. The peak electric field between source and puller is achieved at τ_o = 0 . The ions that depart from the source at τ_o = -50 degrees gain maximum energy. The centering error for the ion with τ_o = -40 degrees is below 10 mils.

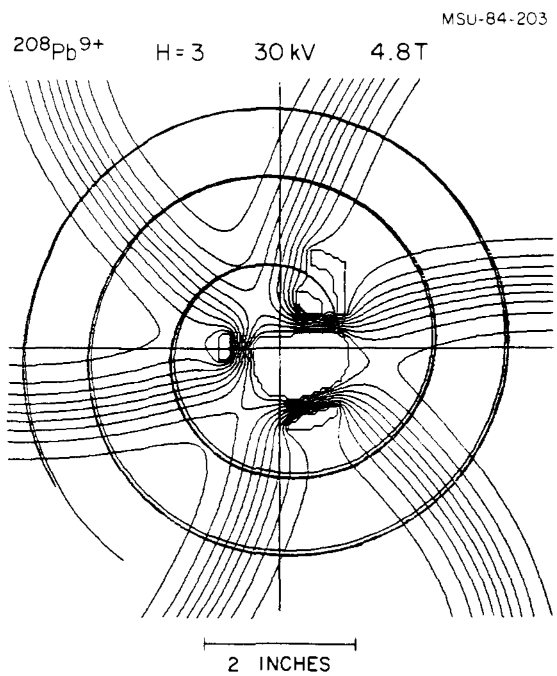

Fig 2. Similiar to Fig.1 but for the low energy case of the third harmonic operation. The tips of the second and third dees are the same as in Fig. 1, but the puller has been changed and moved further out radially.

at τ_o = -50 degrees and peak electric field at τ_o = 0 degrees. In Figure 1, we have plotted three orbits for ions starting at τ_o = -50, -40, and -30 degrees superimposed on the equipotential plot. These orbits correspond to the high energy case of tne third harmonic operation. In Figure 2, we have a similiar plot for the low energy case.

Using these low energy orbits, we found that the second region is nothing more than just moving the puller of the high energy case radially outward. We will then need only to change the puller from one case to the other while the other two dee posts remain the same. We expect to be able to change the electrodes using remote handling tools without lifting the machine cap.

The question remains : how do the orbits for the low and high energy cases behave? The following paragraphs give the comparison of the properties of the orbits in both cases. The centering error for the central ray in both cases is within 10 mils, and the clearance between the posts and the beam is good, being at least 80 mils. The radial phase space behavior is shown in Figure 3 where we plotted the low energy case. No distortion is observed in the phase space defined by eight (8) particles whose starting phases have been picked to match the energy gain of the central ray. The beam cross section was taken on a spiral line that matches the sector spiral $\theta = \theta_o - 4.407r$, where θ is in degrees and r in inches.

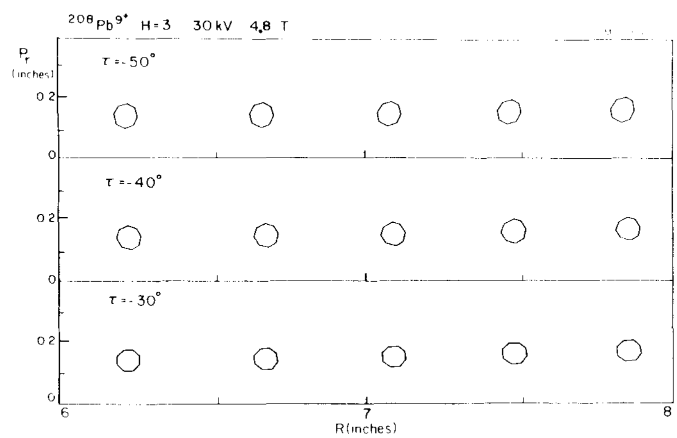

Fig.3. Radial phase space behavior. The radial phase space around the central rays plotted in Figure 2 is shown here. The plots are made on a spiral ($\theta = \theta_o - ar$) along the hill. No distortion is observed in the ±10 degrees range around τ_o = -40 degrees. Note: Pr has been divided by $m\omega_o$ to express it in inches.

The vertical motion is treated as a linear approximation in our CYCLONE code. Given two linearly independent solutions, any starting condition can be obtained as a linear combination of those two basic solutions. Figure 4 shows the vertical motion for the starting condition (z,Pz) = (0,1) at the top, and for (z,Pz) = (1,0) at the bottom. We have used arbitrary units for z in the plot. We observe from the plot the strong dependence of the vertical focusing frequency on the starting phase. Figure 5 shows the Pz curves for the three rays plotted at the bottom of Figure 4. For each of the starting phases we can generate the envelope associated with a given (z,Pz) ellipse. In top of Figure 6 we plot the ellipses obtained when we request a maximum total height of the beam of 1.0 inch. The inner ellipse will give a beam that matches

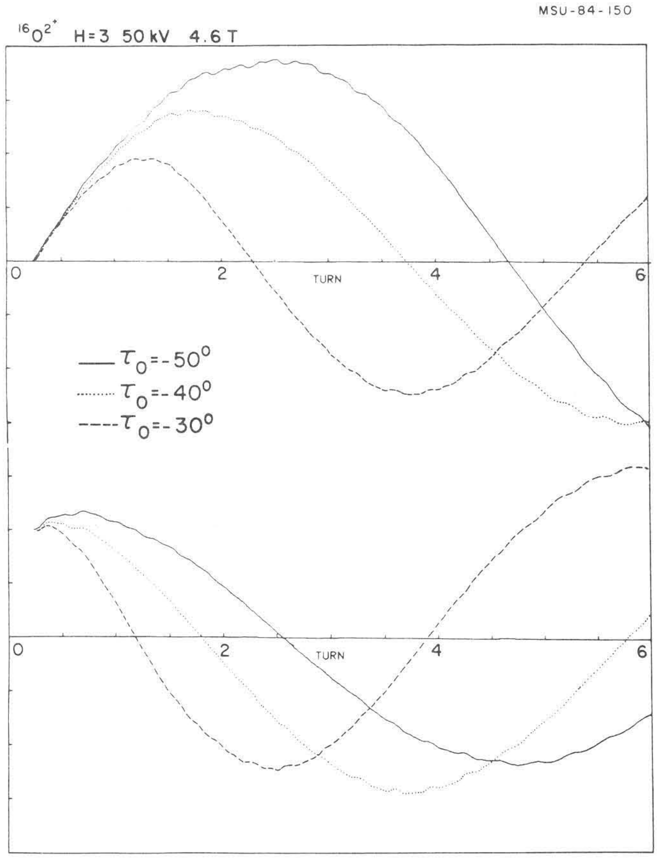

Fig.4. Vertical motion of the three rays plotted in Fig. 1. The motion is studied as a linear approximation with an arbitrary scale for z in our code. There is an indication of a strong dependence of the vertical focusing frequency on the starting time.

the eigenellipse after approximately 30 turns. The outer ellipse has maximum area for the given beam height. The bottom of Figure 6 shows the maximum area ellipses for three different starting times. The envelopes associated with the two ellipses on top of Figure 6 are shown in Figure 7. We note that the actual limitation to the beam height occurs beyond the central region. As shown above our present design of the two central regions seems to satisfy the requirements of centering, good clearance, and no phase space distortions or limitations.

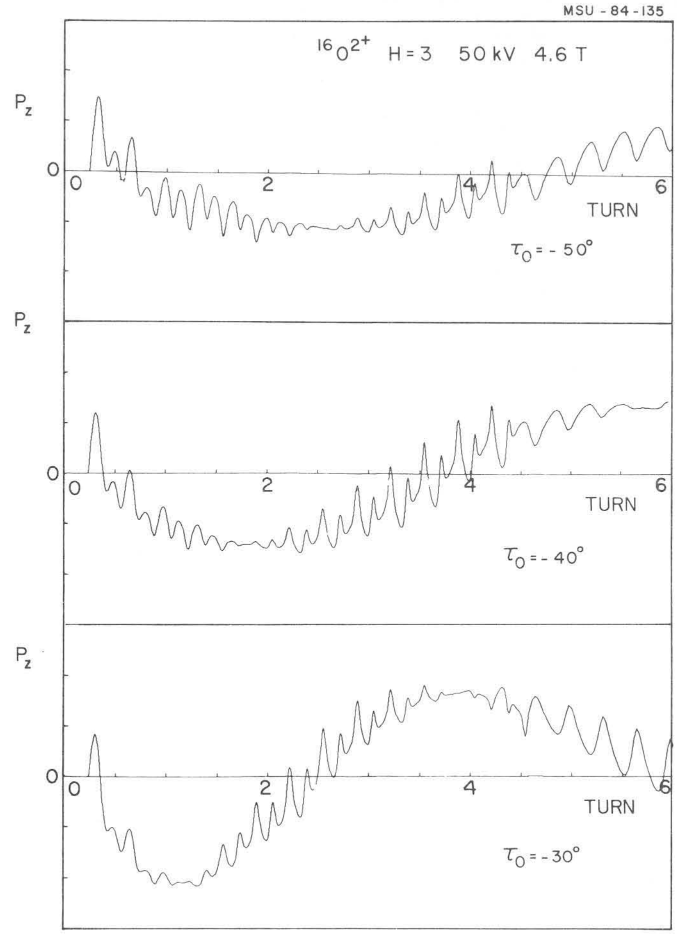

Fig.5. Plots of Pz in arbitrary units for the vertical motion shown in bottom of Fig.4.

References

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1. M. Fowler, personal communication.

2. F. Marti et al., 9th Intl. Cyclotron Conf. Caen, France 1981, p. 465.

3. C. Kost, TRIUMF, U.B.C. Canada.

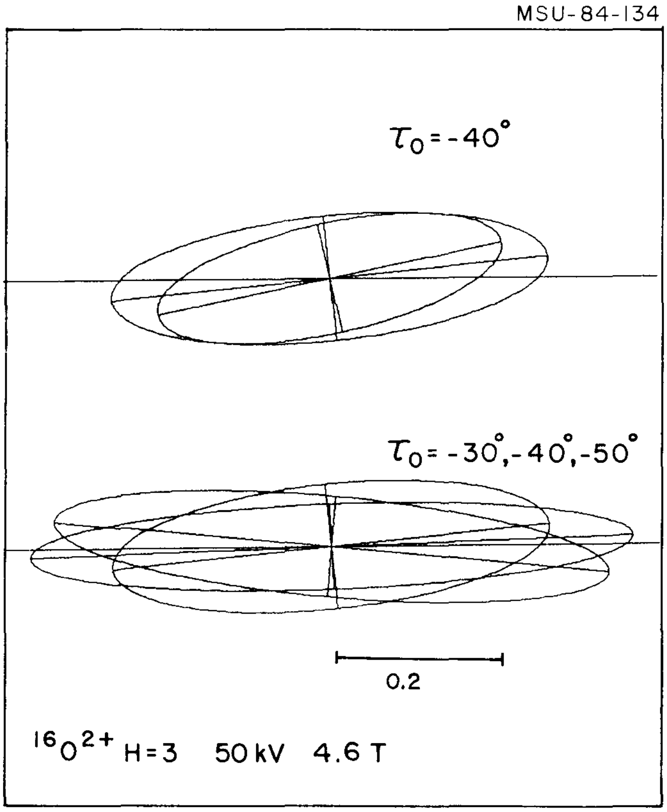

Fig.6. The (Z,Pz) ellipses that will fill the 1-inch vertical gap in the machine are shown at the top of plot. These ellipses are plotted just after the puller. The outer one has the maximum possible area, while the inner one matched the eigenellipse after approximately 30 turns. The bottom part of the plot shows the starting ellipses for maximum area transmission for three different starting times. The segment at the bottom corresponds to 0.2 inches.

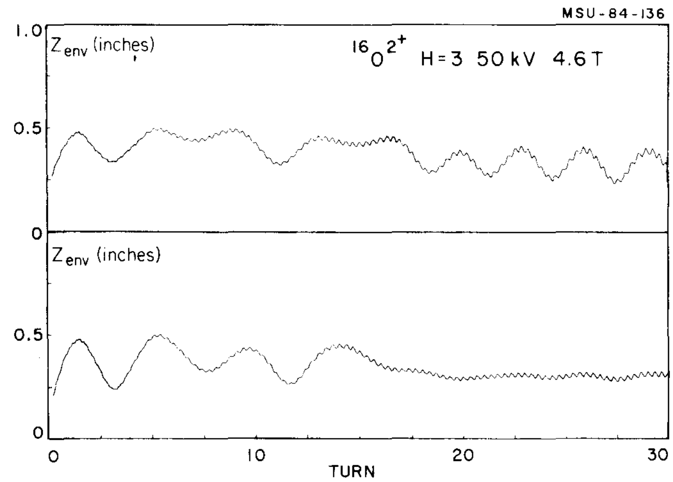

Fig.7. Plot of the vertical envelopes for the beams that occupy the ellipses in the top plot in Figure 6.