Orbit Properties Relevant to Phase Selection in the MSU K500 cyclotron,*

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Abstract

In cyclotrons the traditional method of removing undesired starting phases from the beam is a pair of slits located at the same angle but at different radii. The compact nature of the K500 cyclotron and the small turn separation makes such a system unpractical so instead we are currently constructing a system which uses two thin blades located 120° apart but at the same radius. In this system the blades act as the inverse of a slit with each blade affecting the turns on both sides of it; thus with a ν_r close to 1.0 the effect on the two turns together is the same as a slit acting on a single turn. In this paper we will present the orbit conditions which will allow this system to select starting phases.

Introduction

As demonstrated in K50 cyclotron operation[1] a phase selection system is a highly effective method of producing beams with high energy resolution. It also reduces the activation of the internal components such as the deflector. The principle of operation of such a system[2] is to use the phase-dependent centering error to spatially separate different phases and then remove the unwanted beam with a physical obstruction. If this is done before the particles reach the Coulomb barrier then the activation which would have occurred from the 'phase selection' at the deflector septum, is avoided. Conceptually two movable blades located at 7.038 inches in radius and at the center of two successive hills provide the obstructions. This radius corresponds to turn number 32 in first harmonic (fixed turn number) geometry, where the turn separation is of the order of 100 mils. This small turn separation removes the possibility of using a slit as was done in the K50. One blade will be placed between turn 32 and turn 33 and another will be located on the next hill between the same turns. Given proper selection of the phase curve and beam centering using the harmonic bump coil, this method should allow the selection of a beam with a phase spread of 4 degrees which is much smaller than the 30 degrees we have currently. Our access to the median plane for such a device is restricted to two vertical, one-half inch diameter holes. One is in the upper, and the other in the lower, pole cap. As previously reported[2] in order to provide sufficient mobility each blade will be mounted off-center at the end of a forty inch water-cooled copper rod. By rotating the rod the position of the blade can be varied by ±1/4 inches in radius.

Orbit computations

To determine the ability of such a design to produce a narrow phase group and to have some idea of the correct operating mode we began a series of computer simulations of the internal orbits. For this purpose we chose the machine settings which correspond to the 30 MeV/a Carbon 4+ beam which has been frequently run and for which a large body of calculations exist. Figure 1 shows orbits for starting times of 230° to 260° in RF time (note, 270° is the time of the peak voltage), and a layout of the electrode structure in the K500 first harmonic central

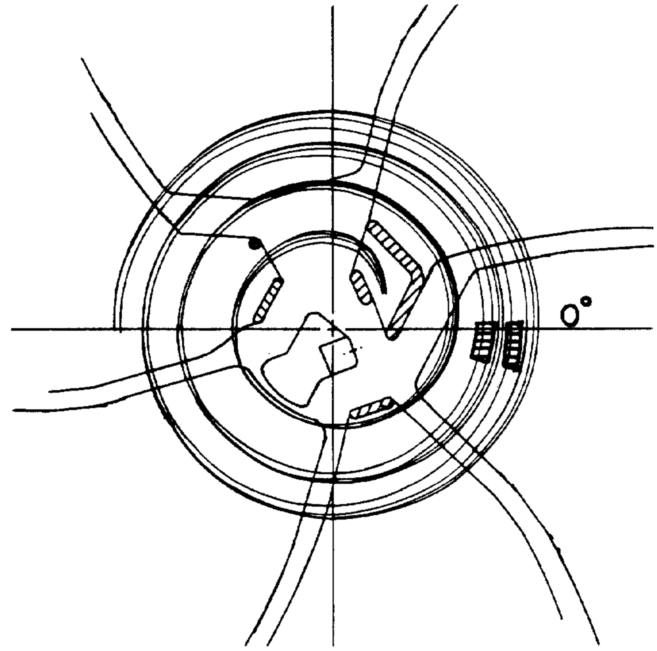

Fig 1. Electrode structure for the K500 first harmonic central region. Four orbits are shown corresponding to starting times τ_0= 230,240,250, and 260 degrees. The peak electric field between source and puller is achieved at τ_0=270. A slit is located on the 0° hill extension of the center plug allowing easy installation and removal. This slit removes all starting times which do not fall between 230 and 250 degrees.

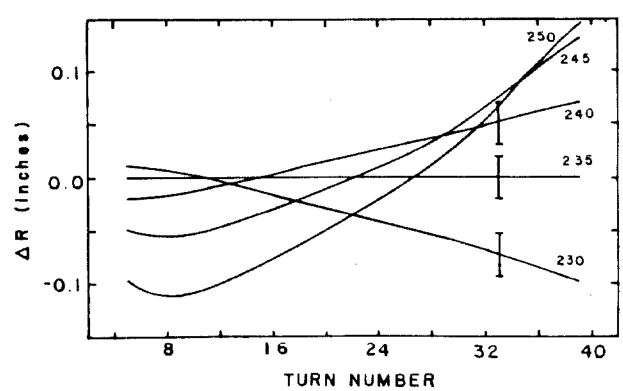

Fig 2. Radius difference $r_i - r_0$ at θ=84° vs turn number for a family of central rays. Ray 0 leaves the source at τ_0= 235°, the others at the times labeled on the plot. At Turn 33 a bar of ±.02 inches in shown to give an idea of the radius variation expected from the r,pr distribution around the central ray.

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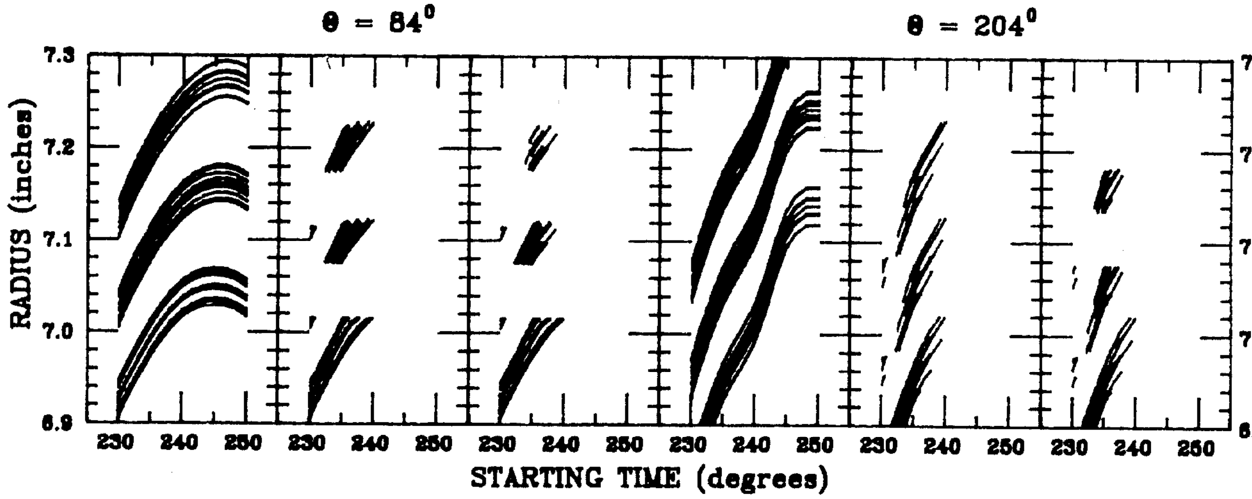

Fig 3. Radius is plotted as a function of the starting time τ_0 for turns 32,33, and 34. Associated with each central ray is set of 8 rays which populated the circumference of a .02 inch radius circle in R,Pr space. From left to right; the first one shows the situation at θ=84° before the blades are inserted,the next one shows the situation after a 60 mil blade has been inserted at 84° and the third shows the effect of inserting a second similar blade at θ=204°. The following three plots are the same except at θ=204°. Note that the final phase width is 4° and the full .02 inch phase space at τ_0=235° survives. The rays with different R,Pr values have a starting phase which gives them the same energy gain per turn as the central ray they are associated with[3] thus the horizontal label is actually an measure of the energy gain per turn.

region. As the figure shows the introduction of a slit on the 0° hill at the second turn will remove all rays whose starting times don't lie between 230° and 250°. Tracking the orbits further out gives the results shown in figure 2. Here the radius differences relative to the 235° central ray are plotted versus turn number at a machine angle of 84°. This shows turns 32 to 34 are a convenient location for additional slits as the radius separation between different starting times has become large relative to the area of the r,pr phase space and yet the turn separation is still large enough (aprox. 0.1") to allow for the introduction of a physical obstruction.

In the left most frame of figure 3 is plotted the radii of a set of rays at turns 32,33 and 34. Associated with each starting time 'central ray' is a group of 8 particles located on the perimeter of a .02" radius circle in r,pr space, thus showing the spatial extent of the beam. The next frame to the right shows the rays which remain after the introduction of a .06" rod between turns 32 and 33 at 84°. The following frame shows the result after inserting another similar rod at 204°, thus reducing the phase width to ±2°, and yet all 9 r,pr rays exist at the central starting time of 235°. The remaining three frames show the same sequence except at the second blade location 204°.

After the slit locations were determined in this manner, a set of rays which populated the starting times between 230° and 250° and an r,pr circle of .01" radius in r,pr space were tracked up to the slits and those that did not collide with the blades were run the rest of the way out to extraction. Figure 4 shows this family of rays for turns 507 and 508 (all made it to this point) at the entrance to the electrostatic deflector. Also shown is a possible location of the septum of this deflector, demonstrating that adequate turn separation exists to provide high efficiency, single turn extraction. In these runs the centering bump coil was used to center the beam in the region of turn 50 (first passage thru ν_r=1 is between turn 15 and 20), thus the lack of phase space distortion from crossing the ν_r=1 resonance near extraction, and hopefully good transmission thru the $\nu_r = 2\nu_z$ resonance in the same region. This is important because maximizing the current when a broad phase spectrum is present does not achieve these conditions. On the other hand no attempt has been made to use the extraction bump coil to enhance the turn separation at the deflector as would be done in a running situation thus the already sufficient turn separation could be enhanced by judicious choice of extraction bump coil settings.

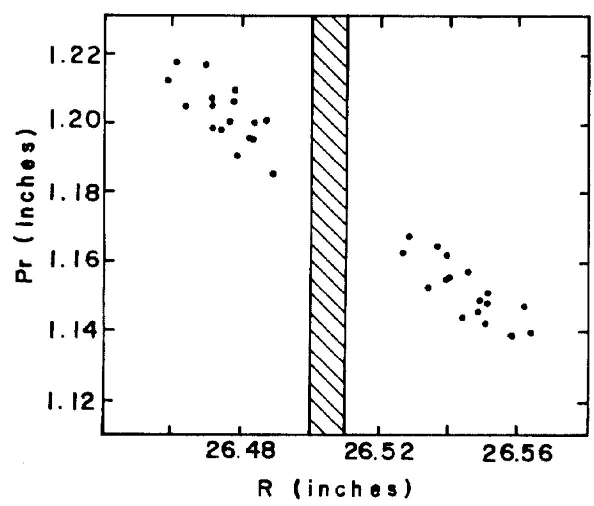

Fig 4. R is plotted versus Pr for turns 507 and 508 at θ = 336 which corresponds to the entrance to the electrostatic deflector. Pr has been divided by the momentum unit $m\omega_0$ to express it in inches. The shaded area corresponds to a possible location for the deflector septum. This plot shows that single turn extraction of resulting beam should be possible. The energy spread of this group is less than 6 parts in 10^4.

Of course the phase selection should not only allow good turn separation but also good energy resolution and this case is no exception. The energy spread of the tracked particles at the deflector entrance was ±.03 % of the final energy which will produce quite a well behaved beam at the exit of the machine.

Conclusions

It has been shown that in a realistic running situation (only the small imperfection harmonics were left out to simplify the analysis) for the 30 MeV/a 4+ carbon beam a phase width of 4 degrees could be achieved. This should also enable single turn extraction and the small energy spread of 6 parts in 10^4.

1. H.G. Blosser,1969 cyclotron conference, page 257.

2. B. Milton et al.,pg. 55,Tenth International Conference on Cclotrons and their Applications, F. Marti ed., 1984.

3. M.M. Gordon and F. Marti, Particle Accelerators 12 (1982) 13.

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