NEW DESIGN FOR A CENTRAL REGION OF THE K500 SUPERCONDUCTING CYCLOTRON

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ABSTRACT

A direct and compact approach is described for decoupling the dees electrically in the central region of the K500 superconducting cyclotron. Two shields between deel and dee2,and between deel and dee3 are to be inserted instead of the introduction of neutralizing links located on the dee stems. After some rearrangement of the configuration in the central region, a new design was completed which is encouraging on the basis of the computation for a 3-dimension electrical field and ion trajectories.

1. Introduction

In the K500 superconducting cyclotron, three spiral dees are used for accelerating ions to the final energy. Since the dees are coupled capacitively to each other in the central region, neutralizing links are necessary for operating each dee independently. Nevertheless,those links, which are located on the dee stems,results in undesiable reduction of the high frequency range,according to experience with the MSU K500 cyclotron. In an earlier unsuccessful attempt to shield the K500 dee-to-dee capacitive coupling a computer analysis was made where shields were placed between the dee tips of the original central-region design[1]. Since that time shields have been used successfully in the new central region design for axial injection into MSU K500 [2]. This design incorporated new dee-tip configurations, so it was decided to use these as a starting point for a new design which incorporated the PIG source instead of an inflector.

The modification of central region configuration pursued the following principles. First of all,the shields should be put between deesl and 2 and between deesl and 3 for electrical independence. The ion source itself provides the shields between dees 2 and 3. Secondly, an effort was made to make the central region configuration for the internal ion source as compatible as possible with one for the axial injection. The new design as described below is for initial operation of the K500 and should require only the replacement of the PIG source by an inflector to accept axially injected beams. The design proceeded as follows:

(1) After the shield was inserted between dees 1 and 2 the equipotential lines was distored locally. This lowered the ion energy gain between dees 1 and 2 so that the possibility of hitting the ion source and dees 3 post existed. It was necessary to change the dee 2 tip and posts in order to obtain sufficient energy gain.

(2) A shield was introduced between dees 1 and 3,which followed the local equipotiential line thus minimizing the disturbance for the field between the ion source and the puller. This shape simplifies the design computation for the central region.

(3) In order to prevent sparking between dee 3 and the shield,the dee 3 tip was smoother on the side nearest the shield, and the post in the dee 3 tip was shortened to conform with the dee tip change.

After several revisions,the final design was confirmed by the computation of the electric field and the particle orbits.The layout of the new central region is shown in Fig.1.

2. Electrical Field Calculation

The electric field produced by the dees and by the ion source which cross the median plane was computed for each central region configuration by the code RELAX-3D[3]. This code is a useful tool which solves the 3-dimensional POISSON or LAPLACE equation numberically with a regular mesh.

The electric field calculations for the central region can be divided into two steps to satisfy the requirements of the orbit program. First,a region of 111x111x 11 with a mesh step of 0.05" (1.27mm) in the x,y direction and a mesh step of 0.0535"(1.36mm)in the z direction was computed with a convergence tolerance of less than 1x10^{-7}. This large field region ranges from 2.75" (-69.85mm) to 2.75" (69.85mm) in the x direction,and from -2.75" (-69.85 mm) to 2.75" (69.85mm) in y direction in machine coordinates. The computation region and corresponding equipotential lines are shown in Fig.2. Secondly, the ion source-puller region with a smaller mesh step of 0.0125" (0.3175mm) in the x, y direction was calculated again. This calculation is most critical due to the low ion energy and closeness to the electrodes. This small field region ranges from -0.25" (-6.35mm) to 1.25" (31.75mm) in the x direction, and from -0.75" (-19.05mm) to 0.75" (19.05mm) in the y direction in machine coordinates. The potential values on the boundary of the small field region were set fron the results of the large field region computation by the interpolation procedure. This means that the boundary condition becomes a DIRICHLET one instead of the NEUMANN condition of $\partial v/\partial n=0$ for the large field region calculations. The map of the small field region is shown in Fig.3.

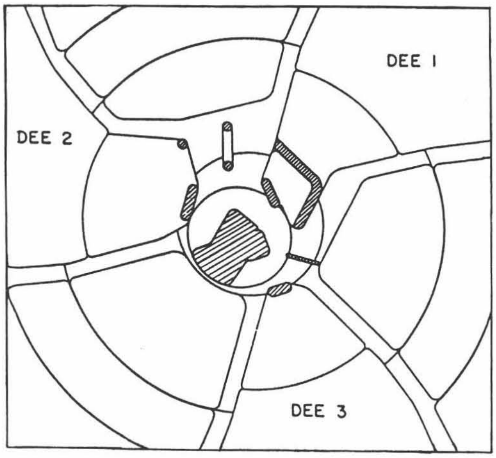

Fig.1: Layout of a K500 central region with shields between Dees.

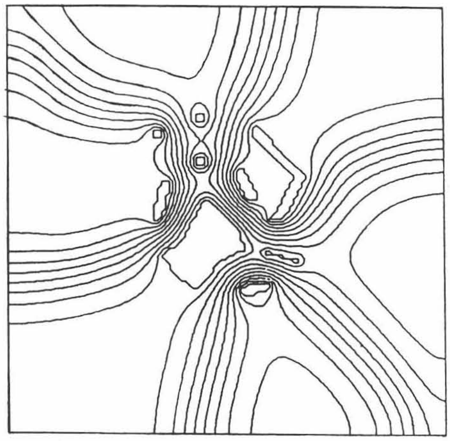

Fig.2: Electrical field map on the median plane for the large field region with a mesh step of 0.05" in the x, y direction.

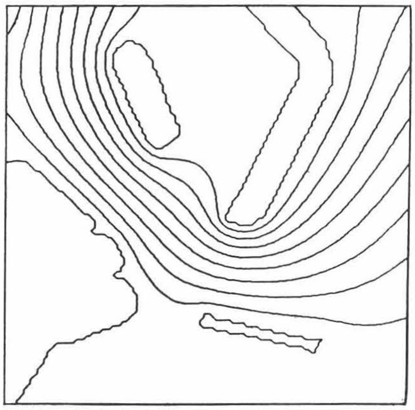

Fig.3: Electrical field map on the median plane for the small field region with a mesh step of 0.0125" in the x, y direction.

3. Orbit Computation in Central Region

The code 3D-ZCYCLONE[4] was used for the orbit calculations. This program consists of three parts. In part 1, the ion moves from the ion source to the entrance of the puller under the influence of the small electric field. Part 2 tracks the ion path for a few turns as far as the boundary of the large electric field is reached. Part 3 follows the orbit until any desired place before the ion is extracted. The magnetic field is the same for the three parts and is achieved by using the isochronous field fitting routine TCFIT incorporating the trim-coil form factors and base field maps. Dee voltage is appropriately chosen to obtain a constant orbit for the several ions and final energies. The electric field is superposed by the potential maps of the three dees at the appropriate phase. A typical ion of

Q/A=0.5, E=66MeV/n was selected for the orbit calculation with B_0=33.15kG, V_{dee}= 84kv. The central trajectory which clears all posts,has a sufficient energy gain,and appropriate starting RF phase is shown in Fig.4.

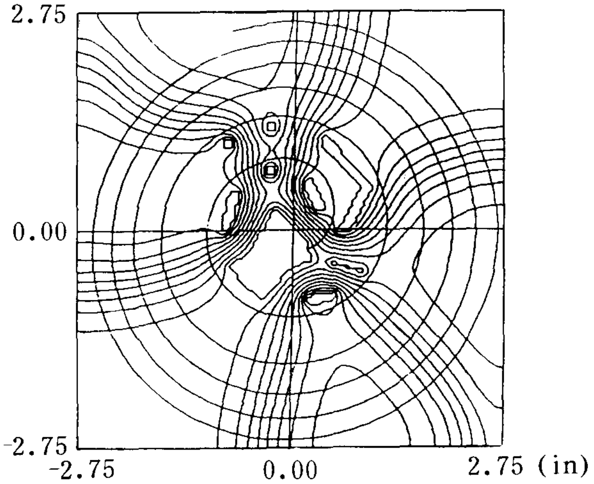

Fig.4: Central trajectory of the ion with Q/A=0.5, E=66MeV/n and Φ=240°.

Considering the slit of an ion source with a median plane aperture of 0.375 mm and a length of 3.18 mm,initial positions of ions emerging from the slit edge are ±0.188 mm and angular divergence of ions become ±36 degree. Fig.5 shows the trajectories of the ions which define the beam with an emittance of 471 mm-mrad in the x,p_x space at the ion source exit. A group of ions with different starting times of 235, 240 and 245 degrees are plotted in Fig.6. These illustrate that the new central region configuration has a sufficient acceptance to accelerate ions either transversely or longitudinally.

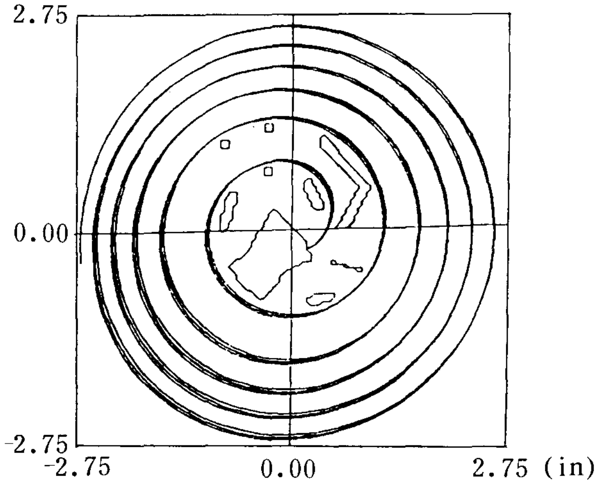

Fig.5: Group of ions with the emittance of 471 mm.mrad in x, p_x space.

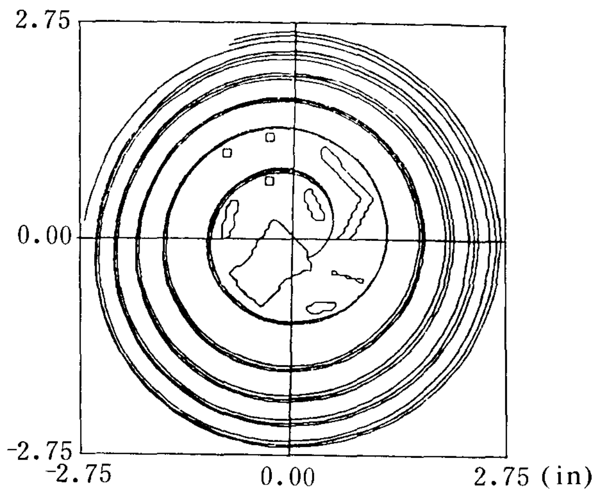

Fig.6: Bunch of ions with different starting times 235°, 240°, 245° in RF phase.

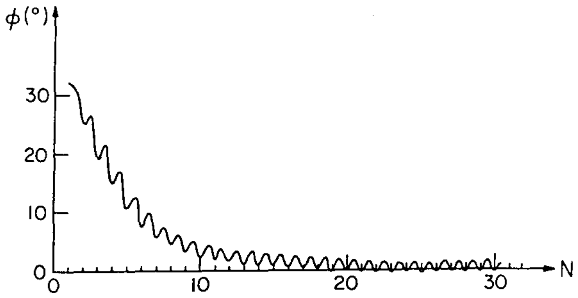

Fig.7: Phase history of the central-trajectory ions of Fig.4 as a function of turn number.

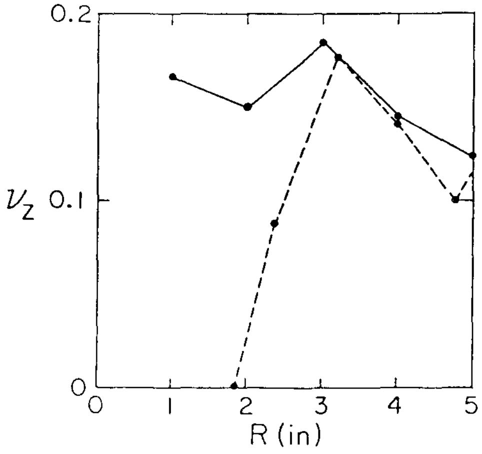

Fig.8: Vertical focusing frequency as function of radius for ion with Q/A=0.5,E=66MeV/n. The dashed line is an estimate of the magnetic focusing. The solid line represents ν_z under the influence of the combination of electrical and magnetic focusing.

The starting time expressed in RF phase angle was so determined that the phase of ions will approach zero degree after about 25 revolutions. A phase history of an ion with Q/A=0.5 and E=66 MeV/n is shown in Fig.7. A large positive phase in the beginning stage of the acceleration is due to the magnetic field bump in the central region. This magnetic field bump is essential for the axial focusing keeping ν_z larger than 0.1 during the first revolutions where the magnetic field flutter is low in the region. Fig.8 shows the vertical focusing by the magnetic field only,or the conbination of the electric field and magnetic field. It clearly shows the substantial contribution made by the electric focusing at the beginning of acceleration.

After a series of the computations a conclusion can be drawn that the new design of the central region essentially meets the requirements on centering,axial focusing,clearances and proper phase history under the constant orbit mode.

References

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