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STUDY OF THE CENTRAL-REGION ORBITS IN THE CYRIC 680 CYCLOTRON

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ABSTRACT

Orbit calculations in the CYRIC 680 cyclotron central region have been carried out in order to study a possibility of an axial injection method suitable for the cyclotron. Such studies were performed to start with the existing internal ion source and the puller configuration. The results of orbit properties in the existing central region are presented.

1.INTRODUCTION

The CYRIC model 680 cyclotron is a commercially based variable energy and 4-sector AVF machine. The acceleration system consists of two 60-deg. dees, which can be operated in push-pull or push-push mode over a frequency range of approxmately 20 to 40 MHz, allowing for acceleration of particles for harmonic number of h=2,3,4 and so on. The maximum energy is 40 MeV for proton , and $50 \times q^2/A$ MeV for other ions (with charge number q and mass number A).

Concerning the central region (shown in Fig.1) of the cyclotron, one should note that the machine had been designed to use a fixed puller, and to take a roughly the same orbit for the three harmonic acceleration modes. The ion source, which is introduced axially upto the median plane, can be adjusted independently. It has three degrees of freedom of horizontal position and rotation of the source pipe about its axis. The aim of the present work is first to study the beam behaviour in the existing central region geometory, and to design a new central region for an axially injected beam with a minimum modification of the central electrodes. Keeping the above-mentioned fact in mind, the studies were begun to calculate for a single particle orbit that converges to the presently accepted trajectories calculated previously by the manufacture of the cyclotron(CGR-meV) with the existing central region geometory and the internal ion source configuration.

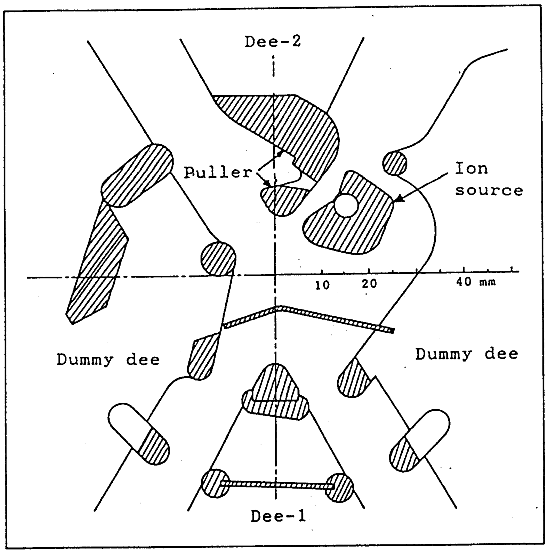

Fig.1- Schematic drawing of the central region of the CYRIC 680 cyclotron.

2. ORBIT STUDY

2.1 General outline

The orbit study has been made with a computer program[1] developed at IPCR (The Institute of Physical and Chemical Research) for numerical orbit calculation. The code used to evaluate the beam dynamics integrated the equation of motion $\vec{F} = q(\vec{E} + \vec{v} * \vec{B})$ using either a cylindrical coordinate system with time as the independent variable.

2.2 Magnetic Field

The three magnetic field components, which can be calculated by using a first-order Taylor expansion near the cyclotron median plane (z=0) and relations from rot $\vec{B}$ =0, are represented as follows :

$$B_r(r,\theta,z) = z\frac{\partial B_z}{\partial r}(r,\theta,0) \quad (1)$$

$$B_\theta(r,\theta,z) = \frac{z}{r}\frac{\partial B_z}{\partial r}(r,\theta,0) \quad (2)$$

$$B_z(r,\theta,z) = B_z(r,\theta,0) \quad (3)$$

where $B_z(r,\theta,0)$ is calculated by using the 4-points Lagrangian interpolation of the field data which was expressed in a Fourier series as

$$B_z(r,\theta,0) = \bar{B}(r)[1+\sum_{i=1}^{m} A_i(r)cosi(\theta-\psi_i(r)]. \quad (4)$$

The average field $\bar{B}(r)$, the coefficients $A_i(r)$ and the phases $\psi_i(r)$ can be obtained from the measured magnetic field.

2.3 Electric Field

The electric field components are modeled from two kinds of methods. In the first two acceleration gaps, the field was obtained by first calculating the equpotential lines of the static field solution using the two-dimensional computer code PANDIRA simulation as shown in Fig.2. These electric fields in the mesh point were put into the orbit code.

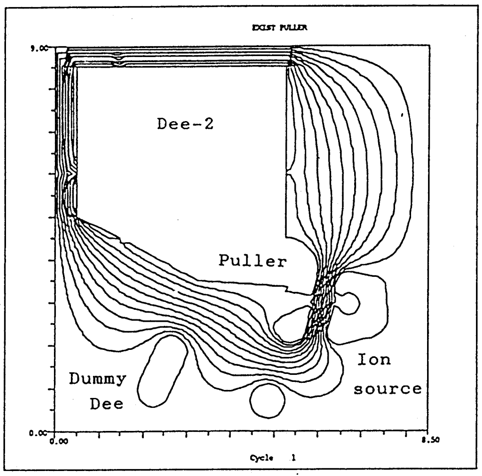

Fig.2- Equipotential contours of the first two acceleration gaps in the central region simulated by PANDIRA.

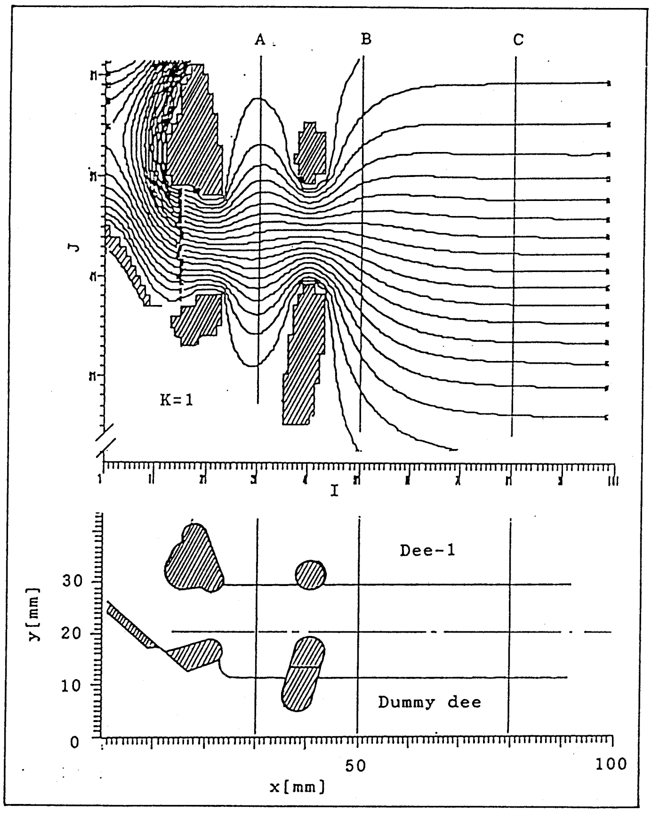

Fig.3- Equipotential map on the median plane (K=1) of the three-demensional geometory simulated by RELAX3D.

In case of other acceleration gaps were applied three types of Gaussian approximations, which were calculated by using the code RELAX3D[2] computed the potential map in the three-dimensional geometory as shown in Fig.3. The first type of Gaussian curve A shown in Fig.4 is adopted for the 3rd and the 4th acceleration gaps. For the 5th to the 8th gaps the curve B was used, and for other gaps was used the curve C, with standard deviations of σ =6.67, 10.0 and 12.1 mm, respectively, in conformity of the electric field at the median plane as:

$$E_y = \frac{1}{\sqrt{2\pi}\sigma}\exp\{-\frac{1}{2}(\frac{y-y_0}{\sigma})^2\} \qquad (5)$$

Especially, the Gaussian function C agreed with the field distibution for the standard dee gap geometory having σ =0.4W + 0.2H[3], where W and H are the gap width and the aperture of the dee and the dummy dee. In our case W and H are 18 and 26 mm, respectively. The vertical field components were calculated as

$$E_z = \frac{(y-y_0)}{\sigma^2} z E_y, \qquad (6)$$

where E_y is the longitudinal Gaussian field. The radial electric field component E_x, which exist mainly at 3rd and 4th gaps, can be found similarly as the vertical field component E_z.

2.4 Orbit Properties

In the beginning the orbit studies have been performed with the existing internal ion source and the puller configuration. Fig.5 shows the first few turns of the computer-simulated single particle trajectory in the 2nd harmonic mode. Clearly the particle orbit

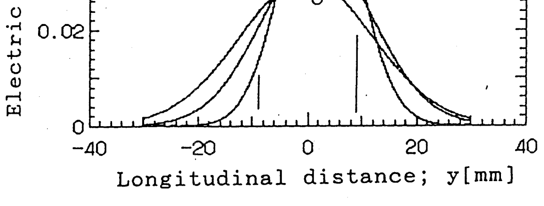

Fig.4- Three types of Gaussian fit of the longitudinal electric field. The standard deviations of each curves A,B and C are 6.67, 10.0 and 12.1 mm, respectively.

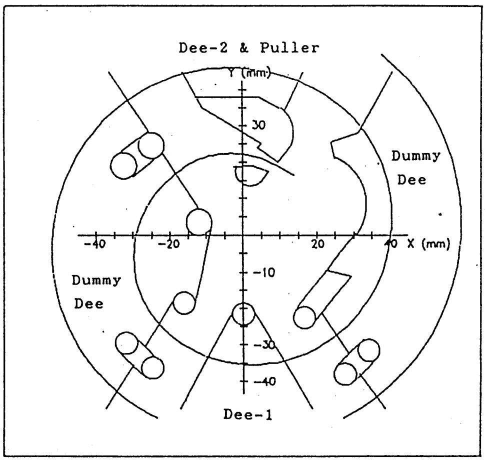

Fig.5- An example of the central trajectory of proton in the 2nd harmonic mode.

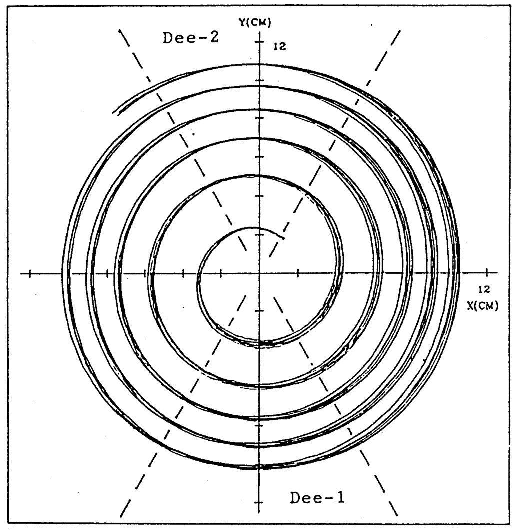

Fig.6- Radial motion of the protons in the 2nd harmonic mode is plotted corresponding to the starting RF-phases ϕ_0 = 60,70 and 80 degrees. Each of the three particles has three different initial conditions (0,0),(0,100) and (1,0) in the (x,x') space in units of mm and mrad.

is almost restricted within narrow limits, whereas the central region has many electrodes crossing the median plane. Since the central region was designed for the constant orbit mode in mind, all the ions for a given harmonic mode (h=2,3 and 4) follow the same trajectory independently of their charge to mass ratio q/m and the ion frequency ω. This condition can be satisfied from the following relations:

$$\frac{q}{m}\frac{V_0 \cos\alpha}{\omega^2} = const., \omega = 2\pi\frac{f_{RF}}{h}, \qquad (7)$$

$\alpha = \pm 30°$ for h=2 and 4, $\alpha = 0°$ for h=3

where V_0 is the peak voltage of the dee, and f_{RF} is the radio frequency. In addition to the discussion above, it is necessary to choose the initial RF-phase, i.e., the starting phase of the particle for each harmonic mode and positioning of the ion source for the particle trajectory to make a good clearance of the central region electrodes. More details of the particle motions which have different initial conditions were calculated using the orbit code. The results of simulations of the particle trajectories are presented in Fig.6 and Fig.7, where the beam is accelerated in h=2 for the case of proton of 20 MeV. The radial trajectories of three test-particles are plotted in Fig.6. They have different initial phase conditions of (0,0), (0,100) and (1,0) in units of mm and mrad with a starting RF-phase ϕ_0 = 60,70 and 80 deg. The vertical and horizontal motions of the selected two particles (0,100) and (1,0) in the space are shown in Fig.7. In these cases, the off-center error at R=30cm is about 1.8mm with the RF phase slip of ϕ =-2 deg. The central field bump and the isochronous field were adjusted carefully for correction of the phase slip.

3. OUTLOOK

As a first step for the development of our cyclotron, we have started with an investigation for the existing central region which utilizes the internal ion source for the 2nd,3rd and 4th harmonic acceleration modes. The work, however,will continue to study for axially injected beams,with a minimum modification of the central region geometroy of the cyclotron.

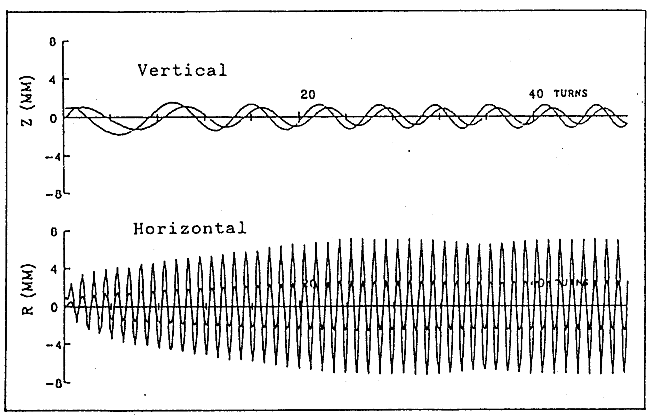

Fig.7- Motions of two particles corresponding to (0,100) and (1,0) in the phase space are plotted in the both vertical and horizontal planes upto the radius of R=30cm.

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1) A. Goto et al., Scientific Paper of Institute of Physical and Chemical Research, 74,136-145,1980.
2) C.J. Kost and F.W. Jones - RELAX3D , TRIUMF internal report TRI-CD-88-01.
3) N. Hazewindus et al., Nucl. Instr. and Meth.,118 ,125(1974).