I. 15 Central-Region Studies of Heavy Ion Extraction for the CYRIC Cyclotron

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The pertinent characteristics of a cyclotron beam-time structure, radial and axial emittance, particle intensity and energy spread are to large degree determined by conditions in the central region. For a compact cyclotron like the CYRIC cyclotron particularly, a beam extraction region to the puller from the exit slit of an ion source is significant for the emittance requirement and particle intensity. That is, the initial orbits in a cyclotron are crucial in determining the properties of the final beam, due to a complicated tripartite force (the magnetic field, the electric field of the puller, and space charge force), the behaviour of these orbits poses the most difficult analysis problem in the cyclotron. Studies of the central-region problem typically involve rather crude approximations, particularly as regards axial motion. For the heavy ion source, the space charge force should be more considerable but this effect is not considered in the present work.

Initial aim of this study is a design of the exit slit of the heavy ion source and initial survey of the relative position for the puller and the heavy ion source.

The computer program "CALTRA" is developed in which the accelerating gap is represented as sin-wave field depending on a time within the gap and magnetic field is uniform. The field is calculated by solving a quasi-poissonian equation through use of a relaxation method. Fig. 1 shows a cross section view of the source-puller geometry in the median plane of the CYRIC cyclotron. For design of the exit slit of the heavy ion source, a gradient of the slit surface "g" and a thickness of slit aperture "t" were taken as parameters shown in Fig. 1. Beam trajectories obtained by a calculation are shown in Fig. 2, where unified magnetic field \( H = 13 \) K Gauss, amplitude of r.f. electric field 35.46 kV and this frequency 23.9889 MHz were assumed for present calculations. These are the values for \( E = 84 \) MeV \(^{14}\)N\(^{5+}\) ion acceleration. Fig. 2 (a), (b), and (c) shown the beam trajectories in case of \( \theta = 0, 15.26^\circ, \) and \( 28.61^\circ \) as a function of the thickness of the exit slit aperture \( t = 0.0, 0.25, \) and \( 0.5 \) mm. It is suggested in Fig. 2 that the thickness of exit slit aperture should be thin in the design of an exit slit if a parallel-beam situation is required as a good initial condition of optimum beam acceleration. The strong beam divergence caused by a thickness of the slit aperture rather than a feature of an exit slit surface. Fig. 3 shows the beam trajectory as a function of a starting phase \( \delta \) that indicates the start time of the ions on a plasma surface. The definition of \( \delta \) in the r.f-wave is illustrated in Fig. 4. An extracted region in Fig. 4 (b) indicates the time region that the ions emitted from a plasma surface are possible to reach to the puller. Emitted ions in a stable region in Fig. 4 (b) have
nearly equal trajectory and a starting phase gained the maximum energy of ions is denoted with $E_{\text{max}}$. The ions leave the source at different points with an initial energy of 20 eV. Fig. 5 shows the charge state dependence of $^{14}$N ions for beam trajectory. In this calculations, defocusing due to space-charge forces was neglected. Taking into account this effect, the optimum geometry of puller-source will be discussed.

![Diagram of source-puller geometry](image_url)

Fig. 1. Median plane cross section view of the source-puller geometry.
Fig. 2. Equipotential lines and $^{14}\text{N}^{5+}$ trajectories in the case of a flat ion-source structure. The parameter of recessed slit in Fig. 1 (a) $\theta=0$, (b) $\theta=15.26^\circ$, (c) $\theta=28.61^\circ$. The letter $t$ denote a thickness of exit slit aperture of the ion source.
Fig. 3. $^{14}_N\,^5+$ ions trajectories depending on starting phase $\delta$. 
Fig. 4. An illustration of accelerating field in a sin-wave
Fig. 5. Beam trajectories of $^{14}_N^{3+}, 4^+, 5^+$ ions.