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THE ACCELERATION AND EXTRACTION SIMULATION FOR PULSED BEAM WITH DIFFERENT PHASE WIDTH FOR CYCIAE-100

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Abstract

A 100 MeV H- compact cyclotron (CYCIAE-100) has started operation from 2016 at China Institute of Atomic Energy (CIAE). The continuous proton beams of 75 MeV - 100 MeV has been extracted in dual opposite directions by charge exchange stripping devices. In order to analyze the extracted proton beam characteristics and control the beam loss for extracting 200 µA proton beam, the acceleration and stripping extraction process for the pulsed beam for CYCIAE-100 are simulated with the code of COMA in detail in this paper. The simulations are mainly done for the different RF acceptance or acceleration phase width. Due to the simulation results, the extraction turns are more for the large phase width and it will be reduced effectively with small phase width. The transverse beam distribution and the extracted beam profile are not affected by the initial phase width due to the simulation, that's the characters of the cyclotron with the stripping extraction mode.

INTRODUCTION

The project of Beijing Radioactivity Ion-beam Facility (BRIF) has been constructed at China Institute of Atomic Energy (CIAE) for fundamental and applied research [1] [2]. As a major part of the BRIF project, the 100MeV compact cyclotron (CYCIAE-100) will provide proton beam with an intensity of 200µA～500µA [3]. The extracted proton energy range is 75MeV～100MeV with dual direction foil stripping system [4]. The first beam of CYCIAE-100 was extracted on July 4, 2014 [5], the operation stability have been improved and beam current have been increased gradually. The main parameters for CYCIAE-100 are presented in Ref. [2]. For CYCIAE-100, the diameter of main magnet is 6160mm, corresponding to 4000mm for the magnet pole with the sector angle of 47o. The magnet is 2820mm high with a total weight of 435 tons. Two identical 100 kW RF amplifiers have been adopted to drive two cavities with the Dee angle of 38 o independently.

The CYCIAE-100 extraction system use two sets of stripping probes, can extract the beam from the symmetry direction to the various terminals. Two stripping probes with carbon foil are inserted radially in the opposite directions from the hill gap region and the two proton beams after stripping are transported into the crossing point in a combination magnet center separately under the fixed main magnetic field. The combination magnet is fixed between the adjacent yokes of main magnet in the direction of valley region at (R=2.75 m, θ=100°).

The basic optic trajectories of extracted proton beams with various energies have been studied with the code CYCTR [6] and the transport matrix from the stripping foil to the crossing point is got from the code GOBLIN [7] including the dispersion effects. With the multi particle tracking code COMA [8], the beam dynamics are studied and the acceleration and stripping extraction process for the pulsed beam are simulated. The accelerate phase for the pulsed beam are selected after the simulation and the exatracted proton beam turns are studied in detail for the pulsed beam with different initial phase width. The simulation results will give the references for the designing the beam pulsing system for CYCIAE-100. In order to analyze the extracted proton beam parameters for the pulsed beam, the simulation is mainly done for the different RF acceptance or acceleration phase width with the fixed initial transverse emittances.

THE BASIC CONSIDERATION FOR THE SIMULATION

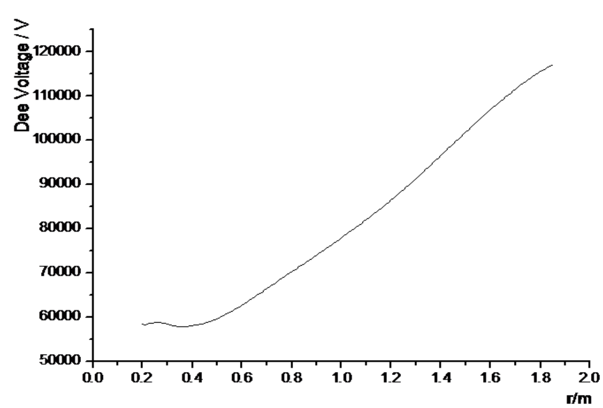

Figure 1: The voltage distribution versus along the radius of accelerating gap.

For CYCIAE-100, the outer radius of magnet yoke is 3.08 m and the combination magnet is located inside the yoke (R=2.75 m, θ=100º). The stripping foil is at the radial position of (1.609 m, 57.8 º) for extraction energy of 70MeV and (1.875m, 59.6 º) for extraction energy of 100MeV. The Dee Voltage is changed continuously from 60kV to 120kV along the radius of accelerating gap. Figure 1 shows the voltage distribution versus along the radius of accelerating gap.

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The initial matched beam condition with the fixed energy and fixed emittance can be obtained from the beam dynamic calculation at any position in the cyclotron. The chosen initial H- beam for the simulation is at the symmetry center of valley with azimuth θ=0 o, and the beam will be tracked along the inserting direction of stripping probe with azimuth θ =57.8 o. The initial beam parameters: E0=1.49MeV, R=23.1Cm, phase extension in RF with ΔΦ=±20o, normalized transverse emittance is 0.01Cm2 or 4pi-mm-mrad. The input phase distributions are random in both transverse and longitudinal directions with the initial zero energy spread and 20000 macro particles are used. Figure 2 shows the initial normalized distribution with the normalized emittance of 4.0π-mm-mrad.

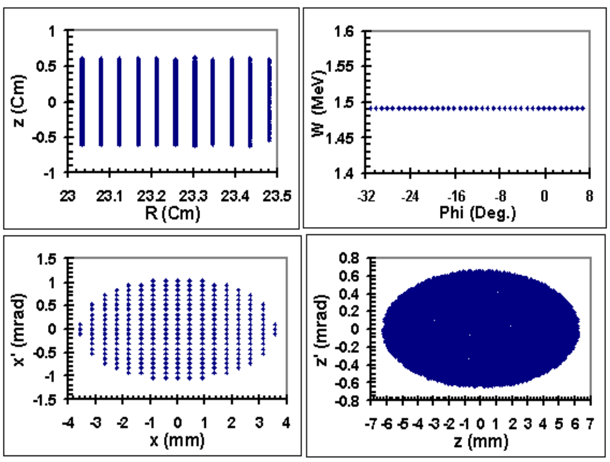

Figure 2: Initial normalized distribution with the normalized emittance of 4.0π-mm-mrad.

The extraction orbits and the extracted beam parameters are compared in detail between the measured fields and the theoretic fields [9]. Both the results are almost the same between the measured fields and the theoretic fields. So, all of the calculation results for CYCIAE-100 extraction orbits based on the theoretic fields can be used under the measured fields.

THE ACCELERATING PROCESS FOR THE BUNCH

The RF acceptance is 40º for CYCIAE-100. In order to get the accelerating phase for the pulsed beam, four initial phases with the bunch length of 40º are simulated. Figure 3 shows the simulated results for the extracted 100 MeV beam with the different initial phase. Due to the simulation results, the central accelerating phase of the bunch with the bunch length of 40º should be -5º with the initial phase of -25º for the bunch. From the simulation, the particles will be extracted in the 302th turn and they will be extracted completely after 320th turn. The total extracted turns is about 18 for the whole bunch.

The accelerating process is simulated with COMA for the bunch with the initial phase of -25º. Figure 4 shows changes of the energy and RMS phase with the turns during the acceleration. The average extraction radius is 1.6m for the energy of 70MeV and 1.85m for the energy of 100MeV. This keeps the agreement with the calculation results which got from the code CYCTR. The RMS phase is constant during the acceleration, which means the bunch length is almost un changed during the acceleration.

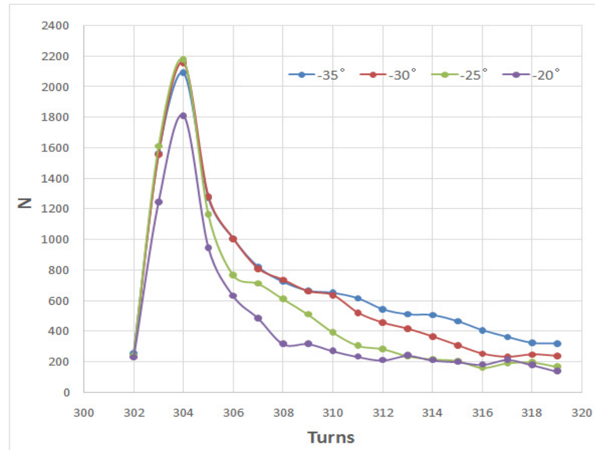

Figure 3: The simulated results for the extracted 100 MeV particles with the different initial phase of the 40º bunch.

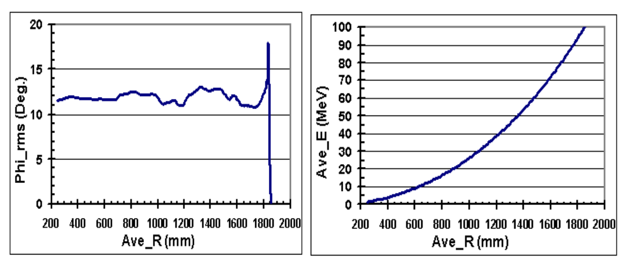

Figure 4: The changes of the energy and RMS phase with the turns during the acceleration.

STRIPPING EXTRACTION SIMULATION WITH DIFFERENT PHASE WIDTH

In order to study the extracted pulsed beam characters and time structure, the stripping extraction simulations for 100MeV beam with different phase width are done with the multi-particle tracking code COMA too. The maximum of the initial phase width is chosen as Δφ=±20° and the minimum of the initial phase width is chosen as Δφ=±5°. Other initial input simulation conditions are the same as the case for the different bunch simulation. From the simulation results, the transverse distributions are almost the same for all kinds of case. Just the extracted longitudinal distributions and the extracted turns are different. Figure 5 shows the distributions with the initial phase width of ±20°, ±10°, ±5°. It is clear, the extracted phase width is larger with the long bunch and it is smaller with the smaller bunch. The average extracted energy and

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the phase for the extracted bunch are almost the same for all of the case. The energy spread is about +-0.6% and the phase extension is about 55° for the extracted beam distribution with the initial phase width of ±20°. The energy spreads are almost the same for the different initial phase width.

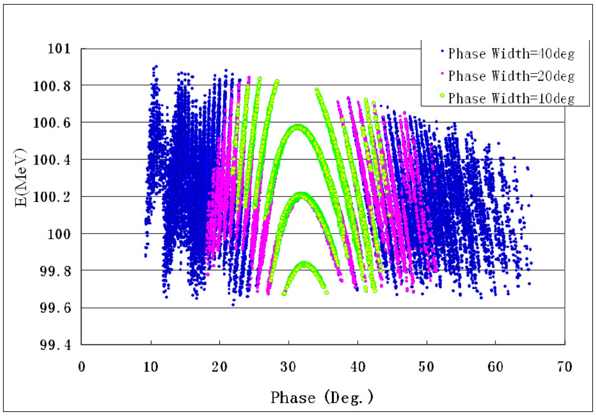

Figure 5: The extracted particle distributions on the stripping foil with different initial phase width.

Figure 6 shows the extracted beam particles with the turns for the different initial phase width. From the simulation results, it is less than 5 turns to extracted the whole bunch with the initial phase width of 10° and 5°. More than 95% particles will be extracted after 8 turns for the long bunch with 40° phase width. So it is possible to get the pulsed beam for CYCIAY-100. Of course, the phase slit is needed in order to get the very good time structure for the cyclotron with the stripping extraction system.

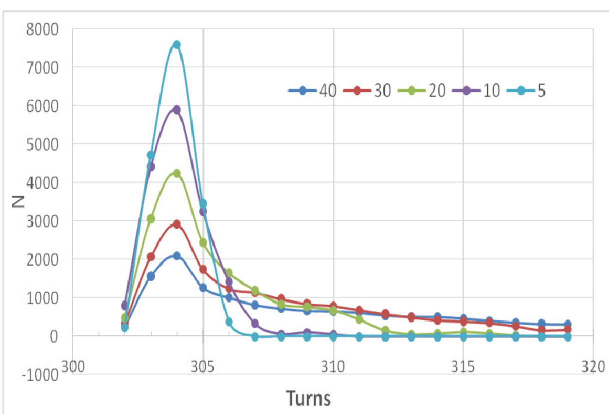

Figure 6: The extracted particle numbers at 100MeV with different initial phase widths.

SUMMARY

For CYCIAE-100, the first beam had been got in 2014 and about 300 hours proton beam were provided last year. In order to get the pulsed beam with CYCIAE-100, the accelerating process for different initial bunch are simulated in detail. From the simulation results, RF acceptance for different bunch length is almost no effect to the transverse beam distribution. Large initial phase width will lead to more extracted turns and short initial phase width will lead to less extracted turns. It is very hard to get the single turn extraction for the compact cyclotron with the stripping extraction system even with very short bunch width if the sine waveform voltage is used for the acceleration. The transverse space distributions and the energy spread of the extracted beam are almost the same for the case of long initial phase width and short phase width. Large phase width means high beam intensity. The transverse beam distribution and the extracted beam profile are not affected by the initial phase width due to the simulation, that's the characters of the cyclotron with the stripping extraction mode. It is possible to get the pulsed beam for CYCIAY-100 because more than 95% particles can be extracted after 8 turns even with large RF acceptance. The phase slit is needed in order to get the very good time structure for the cyclotron with the stripping extraction system.

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