DEVELOPMENT OF VISUAL BEAM ADJUSTMENT METHOD FOR CYCLOTRON

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We have developed a computer-based visual assistance system for JAERI AVF cyclotron operation. This system provides a CRT display about the cyclotron beam trajectories, feasible setting regions (FSRs), and search traces which were designed to improve beam parameter adjustment. From the result of a test in actual operation, it was realized that simulated beam trajectories and FSRs nearly agree with actual beam conditions.

1 Introduction

A cyclotron design requires a large number of physical theories, calculation codes and analysis of the beam trajectory. These codes and analyzed results have not been used in actual operation. For a new cyclotron control technique, we have developed a computer-based visual assistance system[1,2] for the JAERI AVF cyclotron[3] by using the above codes. To examine the reliability of this system, the simulation result was compared with that of the actual operation.

2 Human Interfaces

The visual assistance system provides three functions of human interfaces for beam parameter adjustment; (a) Beam trajectory is rapidly calculated and graphically displayed whenever the operators change the cyclotron parameters, (b) Feasible setting regions (FSRs) of the parameters which satisfy beam acceptance criteria of the cyclotron's are indicated, (c) Search traces, which are historical visual maps of beam current values represented by various colored dots, are superimposed on the FSRs.

The system has been applied to three blocks of the cyclotron: the axial injection, the central region and the extraction. This system is constructed by the language of C and works on the workstation of VAX-3100 connected through Ethernet with computers controlling[4] the cyclotron.

3 Evaluation of Simulation

3.1 Axial Injection Block

The axial injection block is a region between the bottom of the cyclotron yoke and the inflector as shown in Fig. 1. There are four Glaser lenses (GL1,2,3,4) with adjustable focal lengths. The beam is led into the cyclotron by adjusting these lenses through a small gap of the inflector entrance. A typical simulated beam envelope is shown in Fig. 2. The FSRs are limited mainly by the geometry of the inflector entrance.

We have compared the human interfaces with the results of actual operation in the accelerating conditions of H^+ 45 MeV (harmonic mode 1: h=1), H^+ 10 MeV (h=2) and $^{40}Ar^{8+}$ 175 MeV (h=3). It was found that there was a discrepancy between the simulated FSRs and the search traces obtained in actual operation. To identify the main reason of the discrepancy, we have searched a condition for good agreement between the FSRs and the result of actual operation. The simulated beam trajectories deviate from the search trace just after last GL4. By correcting the estimated leakage magnetic field from the main magnet, the FSRs is made to agree with the search trace, as shown in Fig. 3. This deviation is caused by the leakage of magnetic field from the main magnet.

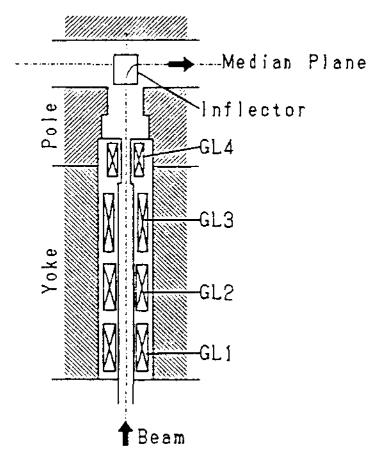

Figure 1: Cross section of the axial injection block.

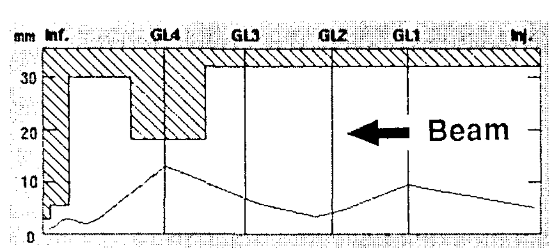

Figure 2: Typical beam envelope of the axial injection.

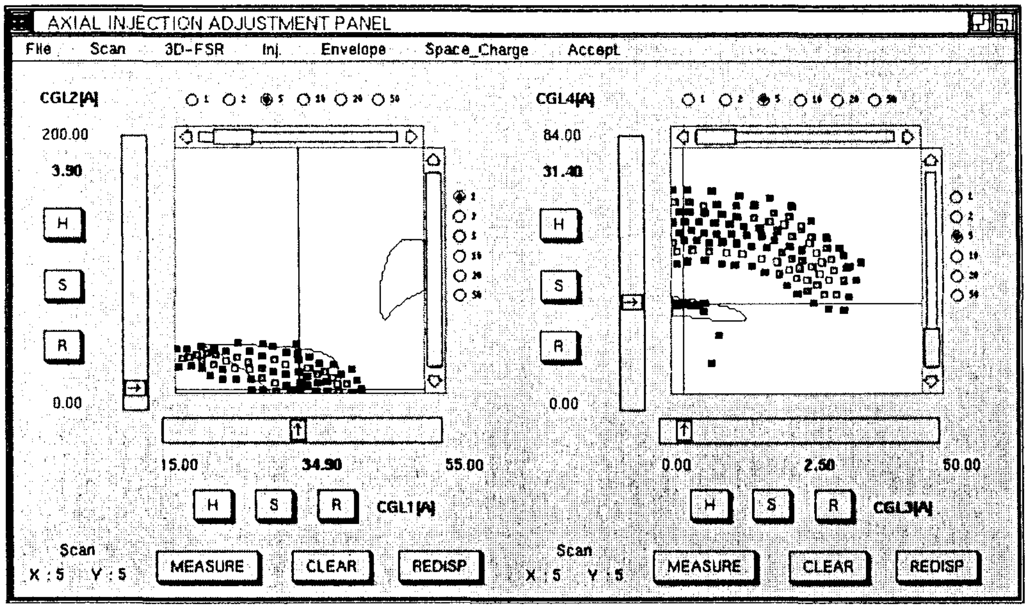

Figure 3: The Feasible setting regions (FSRs) and measuring data at the injection block.
Search trace display showing colored dots of the measured beam current values.
Ion beam of H^+ is 3.10kV, 1μA at the injection line.

3.2 Central Region Block

The central region block is followed by the axial injection block. The first turn of the beam trajectory after the inflector is determined in this block. The adjustable parameters in this region are dee voltages, trim coil currents and the phase of beam buncher voltage. These parameters are adjusted so that the beam passes through two sets of phase slits. The beam trajectory and FSRs are calculated as functions of these parameters and magnetic and electric field data. The FSRs are limited mainly by the geometrical condition of the phase slits.

At the first place, we have compared the position of actual beam trajectory with the simulated beam one to evaluate the simulation model of beam trajectory. The actual beam positions were measured by the following methods: (a) Searching a beam position of the maximum beam current monitored at the main cyclotron beam probe by moving the phase slit, (b) Searching a beam position by measuring turn patterns using the main probe. Figure 4 shows the top view of a cross section of this block and a simulated trajectory in a solid line and actual slit positions. The trajectory passes through the actual slit positions. The simulations are in good agreement with the actual condition.

We have tested the system for different values of the magnetic field of the central region and the phase of beam buncher voltage. The intensities of the magnetic bump fields produced by circular trimming coils little influence the position of actual beam trajectory. The beam phase dependency on the beam position could not be measured because the beam intensities were decreased drastically in changing phase of the beam buncher.

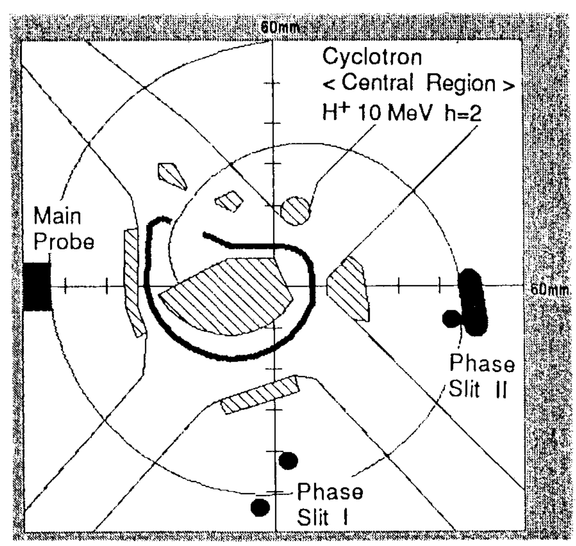

Figure 4: Simulated beam trajectory for H^+ 10MeV in 2nd harmonic mode at the central region block.

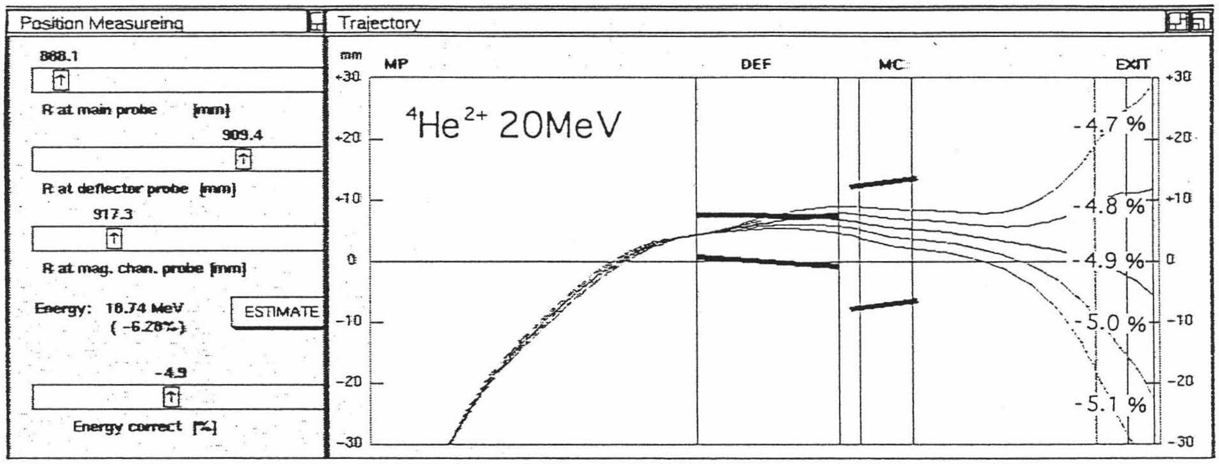

Figure 5: Beam trajectory simulation at the extraction block.
The spiral beam trajectory is shown as a stretched line in this diagram.

3.3 Extraction Block

The beam in the final turn is led into the deflector and the magnetic channel, deflected from the circular orbit, and finally extracted from the cyclotron. In this block, the system simulates the deflected beam trajectory. At the first step, the beam trajectory entering the deflector is calculated on the basis of the magnetic field data and two beam positions detected by the main and the deflector probes. At the second step, the beam trajectory in the deflector and the magnetic channel is simulated on the basis of the deflector position, the deflecting field and the magnetic channel field. The FSRs were calculated as functions of the above parameters, and the clearance of the deflector and the magnetic channel.

An example of simulated beam trajectories for nominally 20 MeV $^4He^{+2}$ ions is shown in Fig. 5. We have executed simulations to obtain the beam trajectories, passing through the exit of the cyclotron, for several beam energies. The most suitable energy for the trajectory in actual operation condition is in a range from 18.98 to 19.06 MeV. On the other hand, the beam energy is evaluated at 19.10 MeV (-4.5%) from the magnetic field of the analyzing magnet after the cyclotron. The simulated beam energy is in agreement with the beam energy measured by using analyzing magnet.

To evaluate the trajectory model of the beam extraction from the cyclotron, we have discussed how to estimate the beam energy in the final turn. Inside the cyclotron, three radial probes were installed to measure the beam intensity distribution as shown in Fig. 6. A main radial probe covers all the acceleration range of the radius from 40 mm to 1190 mm. A deflector probe provides the beam intensity before the deflector. A magnetic channel probe provides the beam intensity after the passing through the deflector. We have tried to estimate the beam energy by following techniques.

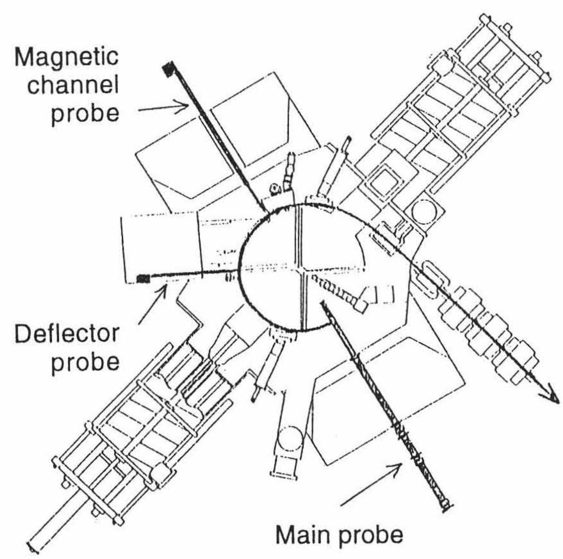

Figure 6: Location of three beam probes.

1) Orbit radius method; The beam position is measured by the main radial probe. The energy (E) is evaluated from the simulated trajectories passing through the exit of the cyclotron. As shown in Fig. 7, the beam energies depend on the beam positions of the final turn trajectory.

2) Three point method; The beam positions in the three points were measured by the main probe, the deflector probe and the magnetic channel probe, respectively. The beam energy (E') is estimated from simulated beam trajectory passing through the above three points. Figure 8 shows the

relation between the energy E and the estimated energy E'. The solid line shows the energy estimated experimentally and the dotted line shows the ideal one.

The result of estimations for beam energy, data has an uncertainty within ±2% from linear approximation formula.

4 Upgrade of the System

Application of the system has been limited to several accelerating conditions of ion beams. In the early stage of development, it is not required to execute simulations for all the available particles and energies. At present, this system has been upgraded to simulate the beam trajectories and FSRs in all accelerating beam conditions for the JAERI AVF cyclotron. We can obtain the operating parameters for new ion acceleration by using the new system.

5 Future Activity

Precise comparison of the simulated beam trajectory and the actual beam trajectory is planned for the extraction block in new accelerating conditions. The extracted beam energy will be measured accurately by other methods, such as kinematics and TOF method. It is expected that the result will be fed back to improve the system. We will expand this technique to the beam transport system.

References

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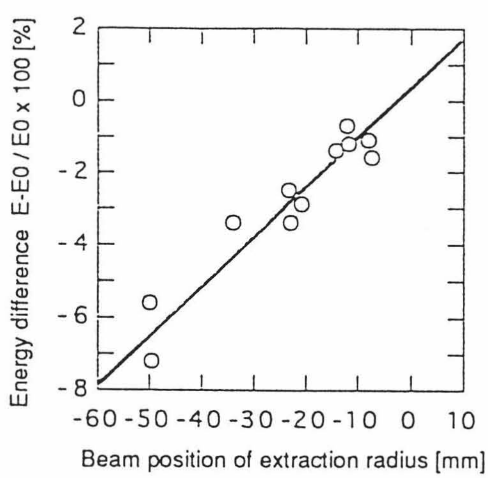

Figure 7: Energy evaluation by orbit radius method.
E : energy evaluated from the simulated trajectories passing through the exit of the cyclotron.
E0: nominal energy.

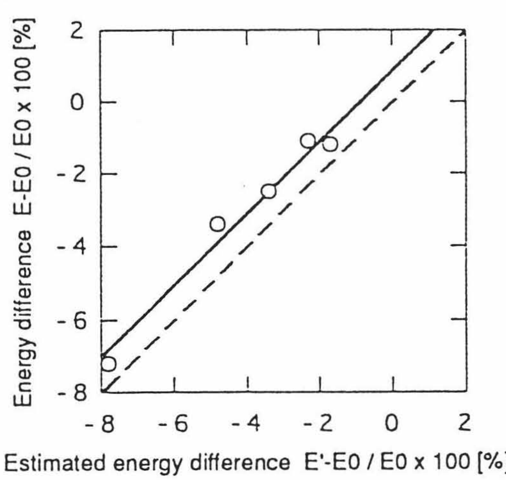

Figure 8: Energy estimation by three point method.
E': energy estimated from three point method.
E0: nominal energy.