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Development of Visual Beam Adjustment Method for Cyclotron

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Abstract

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 designed to improve beam parameter adjustment. As a result of the 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 cyclotron³⁾ by using the above codes. To examine the reliability of this system, the result of the simulation 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 workstation of VAX-3100 connected through Ethernet with computers controlling⁴⁾ 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. There are four Glaser lenses (GLs) with adjustable focal lengths. The beam is led into the cyclotron by adjusting these lenses

through a small gap of the inflector entrance. 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. The simulated beam trajectories deviate from the search trace just after last GL. This deviation is caused by the leakage of magnetic field from the main magnet.

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.

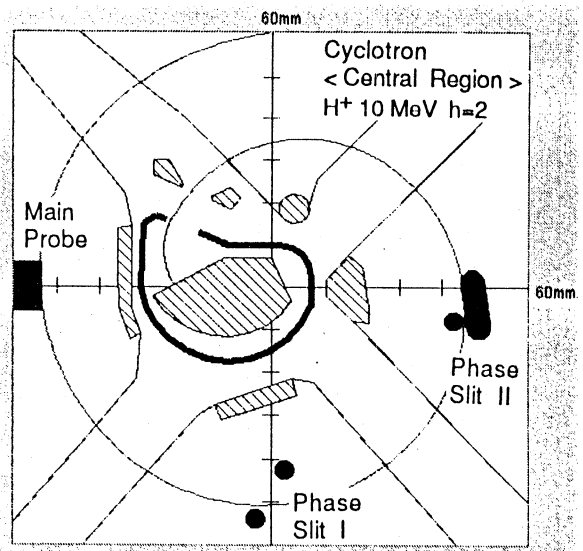


Fig. 1 Simulated beam trajectory for H^+ 10MeV in 2nd harmonic mode at the central region block.

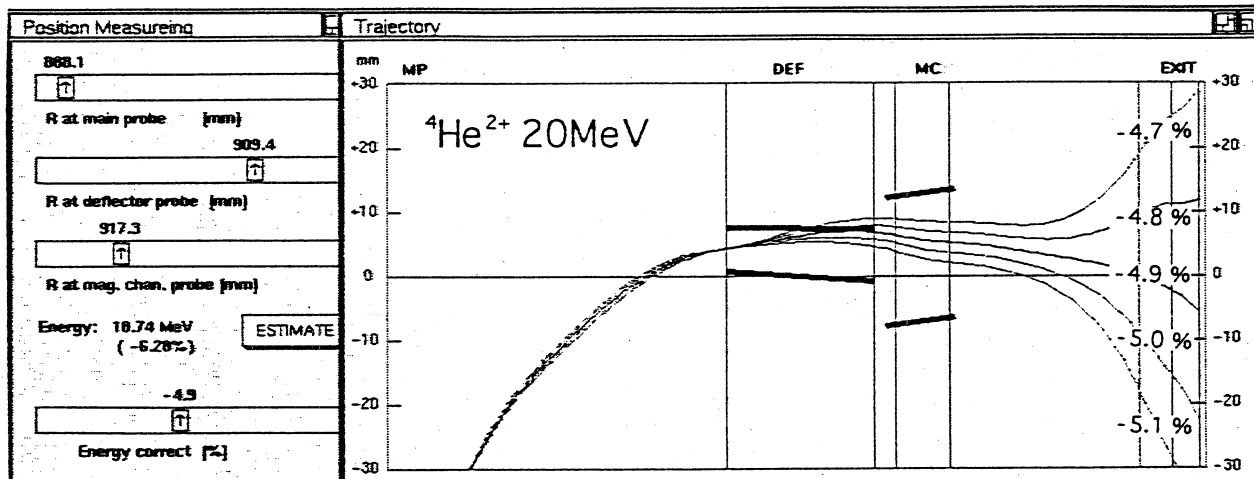


Fig. 2 Beam trajectory simulation at the extraction block.
The spiral beam trajectory is shown as a stretched line in this diagram.

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 1 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 magnetic bump field 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.

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 $^4\text{He}^{+2}$ ions is shown in Fig. 2. 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.

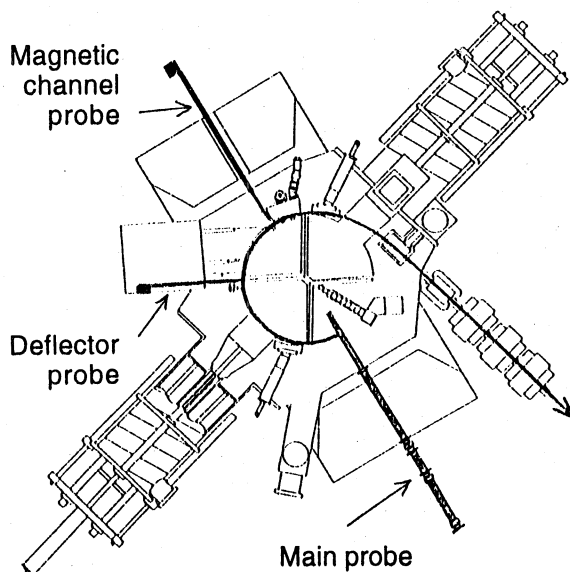


Fig. 3 Location of three beam probes.

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. 3. 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.

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. 4, 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 5 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 $\pm 2\%$ 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.

6. References

- 1) T.Okamura and T.Murakami, "An Operator Assistance System for Beam Adjustment of a Cyclotron", IEEE Trans. on Nucl. Sci., Vol.39, No.1, pp.13-20(1992).
- 2) T.Agematsu, K.Arakawa, S.Okumura, Y.Nakamura, W.Yokota, T.Nara, M.Fukuda, I.Ishibori, T.Okamura, and T.Tachikawa, "Development of Visual Beam Adjustment Method for Cyclotron", Proc. 9th Symp. Acc. Sci. Tech., Tsukuba, Japan, pp.65-67(1993).
- 3) K.Arakawa, Y.Nakamura, W.Yokota, M.Fukuda, T.Nara, T.Agematsu, S.Okumura, I.Ishibori, T.Karasawa and R.Tanaka "Construction and First Year's Operation of the JAERI AVF Cyclotron", Proc. 13th Int. Conf. on Cyclotron and their Applications, Vancouver, Canada, pp.119-122(1992).
- 4) S.Okumura, T.Agematsu, W.Yokota, T.Kamiya, M.Fukuda, Y.Nakamura, T.Nara, I.Ishibori, K.Arakawa, M.Maruyama, K.Iso, K.Hoshika and M.Tachibana, "Control System for JAERI AVF Cyclotron", Proc. 13th Int. Conf. on Cyclotron and their Applications, Vancouver, Canada, pp.648-651(1992).

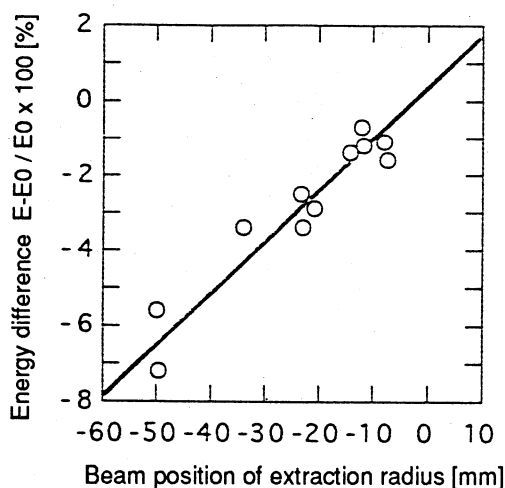


Fig. 4 Energy evaluation by orbit radius method.

E : energy evaluated from the simulated trajectories passing through the exit of the cyclotron and the analyzing magnet.

E_0 : nominal energy.

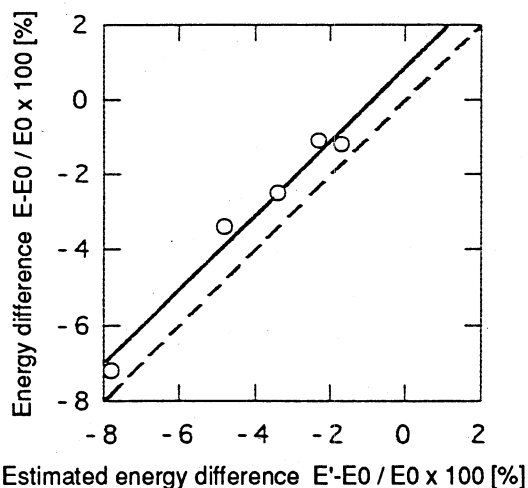


Fig. 5 Energy estimation by three point method.

E' : energy estimated from three point method.

E_0 : nominal energy.