

# DEVELOPMENT OF VISUAL BEAM ADJUSTMENT METHOD FOR THE BEAM TRANSPORT

T. AGEMATSU, K. ARAKAWA

*Takasaki Radiation Chemistry Research Establishment, Japan Atomic Energy Research Institute  
1233, Watanuki-machi, Takasaki, Gunma 370-1292, JAPAN*

T. OKAMURA

*R&D Center, Sumitomo Heavy Industries, Ltd.  
63-30, Yuuhigaoka, Hiratsuka, Kanagawa 254-0806, JAPAN*

We have developed a computer-based visual beam adjustment method for the beam transport system. The beam adjustment interface calculates the beam trajectories / envelopes using actual parameters and displays them on a CRT in real-time. This system which assists inexperienced operators has been implemented for the beam transport system at the JAERI AVF cyclotron. As a result of the test on actual operation, it turned out that the simulation approximated actual beam trajectories and beam envelopes were helpful to the operation in the beam transport system.

## 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 beam adjustment system[1]-[3] for JAERI AVF cyclotron operation by using the above codes. This system provides CRT display of the cyclotron beam trajectories, feasible setting regions, and search traces which were designed to improve beam parameter adjustment.

A new computer-based operation system which assists inexperienced operators has been implemented for the beam transport system at the JAERI AVF cyclotron. To examine the reliability of this system, the simulation results were compared with that of the actual operations.

## 2 Visual Interfaces

Ion beams extracted from the cyclotron are transported to a target point without any beam loss in the beam ducts. The beam transport system consists of bending and focusing magnets, beam monitors, beam shutters, etc. There are 9 bending magnets, 85 quadrupole magnets and 10 beam steering magnets in 10 horizontal and 4 vertical beam courses which transport the ion beam to 17 target ports on the ways or at the ends of the beam courses located in 8 target rooms as shown in Fig. 1. An achromatic and telescopic beam transport system was designed for high transmission efficiency of ion beams and good adjustability of the magnet parameters using the beam optics calculation program TRANSPORT[4].

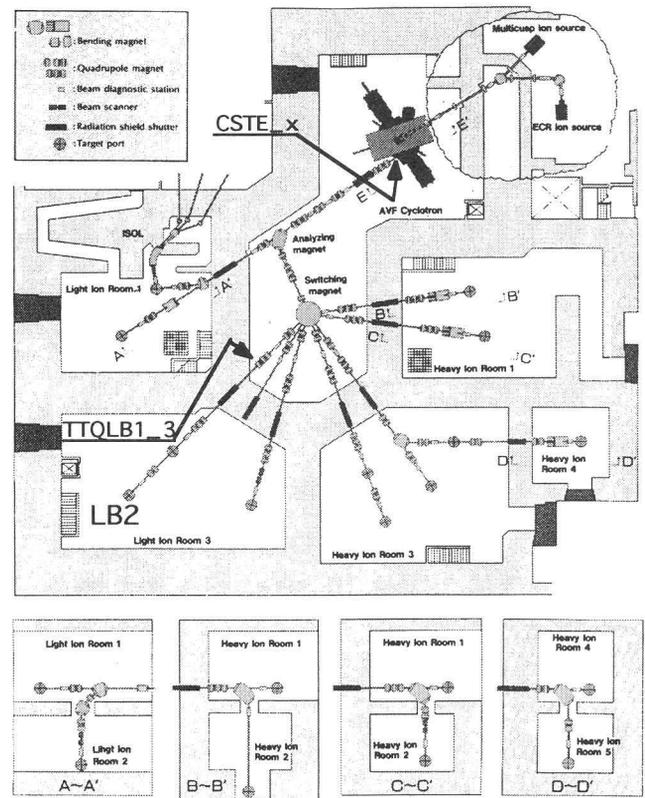


Fig. 1 : Layout of the transport system for the JAERI AVF cyclotron.

The ion beams extracted from an AVF cyclotron have large emittance and energy distribution. A beam transport system start-up operations require dozens of adjustable parameters to be finely tuned in order to maximize beam transmission efficiency. Generally, the transportation of accelerated ion beam is efficiently realized by setting quadrupole magnets as parameter for a magnetic

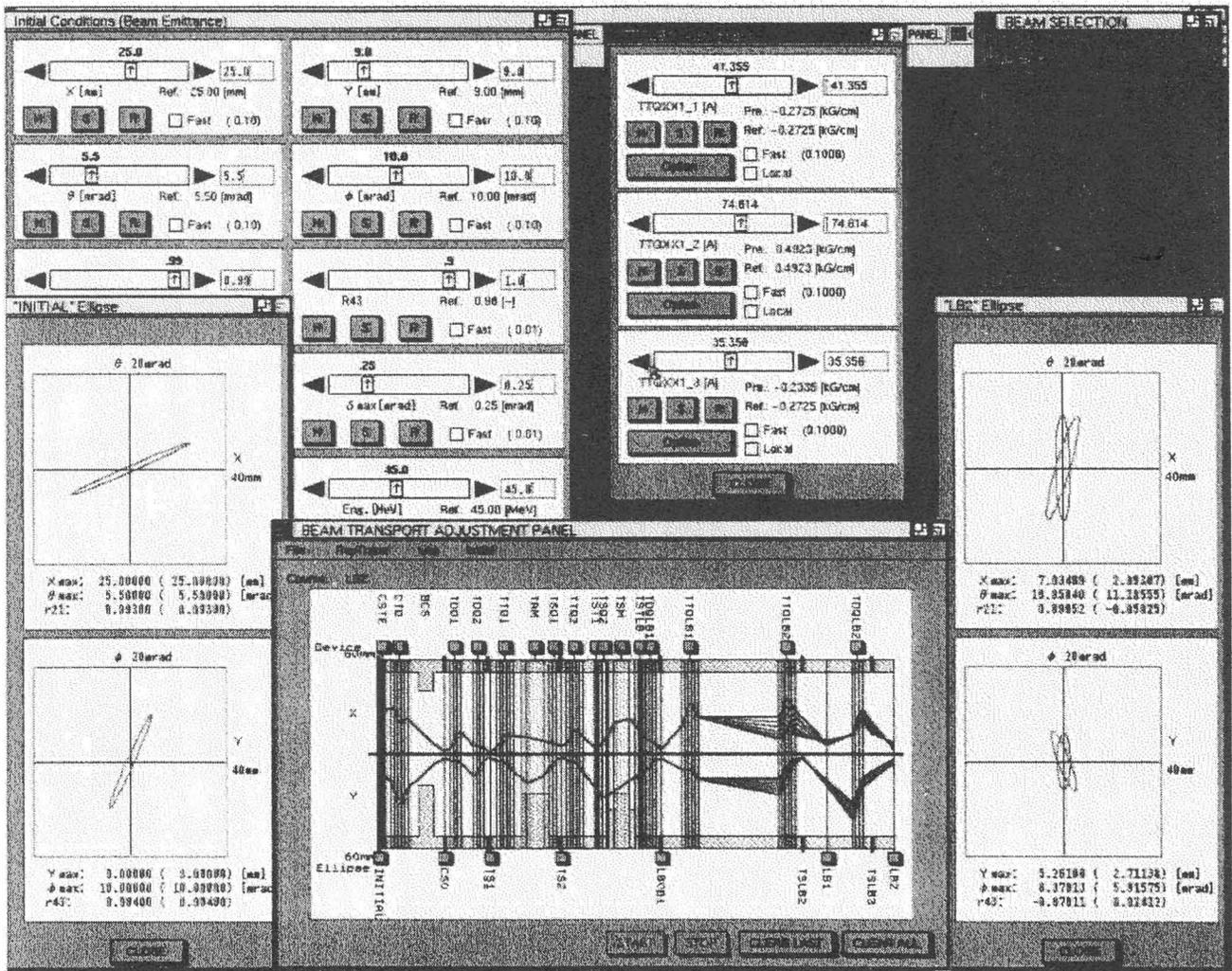


Fig. 2 : The visual human interface for the beam envelope.

field gradient designed by TRANSPORT-code. However inexperienced operators have a difficult time because operator consoles displaying measured beam parameters, alarm information, component status, etc. do not provide enough information to guide these new operators. There are two ways of describing the ion transfer properties. One is the ray tracing that is used to study the behavior of individual ion trajectories. The other is the phase space ellipsoid method that treats the beam envelopes characterized by the boundaries of the phase space volume.

The new computer-based operation system provides two kinds of visual human interfaces to support the beam adjustment of the beam transport system as follow: i) beam envelope and trajectory are rapidly simulated and graphically displayed on a CRT whenever the operators change the excitation current of the magnet, ii) historical display of the simulation of the beam envelope and trajectory are superimposed on the CRT. For the simulation of the beam envelope/trajectory, these interfaces have four special

functions as follow; i) the magnetic field of each magnets is calculated from the exciting current, which is an operator-adjustable parameter considering the effect of the field saturation, ii) the initial parameters (energy, ellipse, etc.) for calculating the beam envelope/trajectory can be changed at will, iii) the narrow channels which are obstacles to pass through the beam in the beam transport line are displayed, iv) the beam ellipses can be displayed whenever the operator changes the exciting current of the magnets.

The visual interface for a simulation of the beam envelope is shown in Fig. 2. All parameters of the bending and focusing magnets for the beam transport can be changed by using the mouse on the CRT display. Also, the beam envelope can be displayed in real-time by the actual parameters of magnets using a computer on-line. As shown in Fig. 2, historical display of the simulated beam envelopes and the elliptical phase space are superimposed on the CRT by changing excitation current of the third magnet in the triplet quadrupole one (TTQLB1\_3). Fig. 3 shows

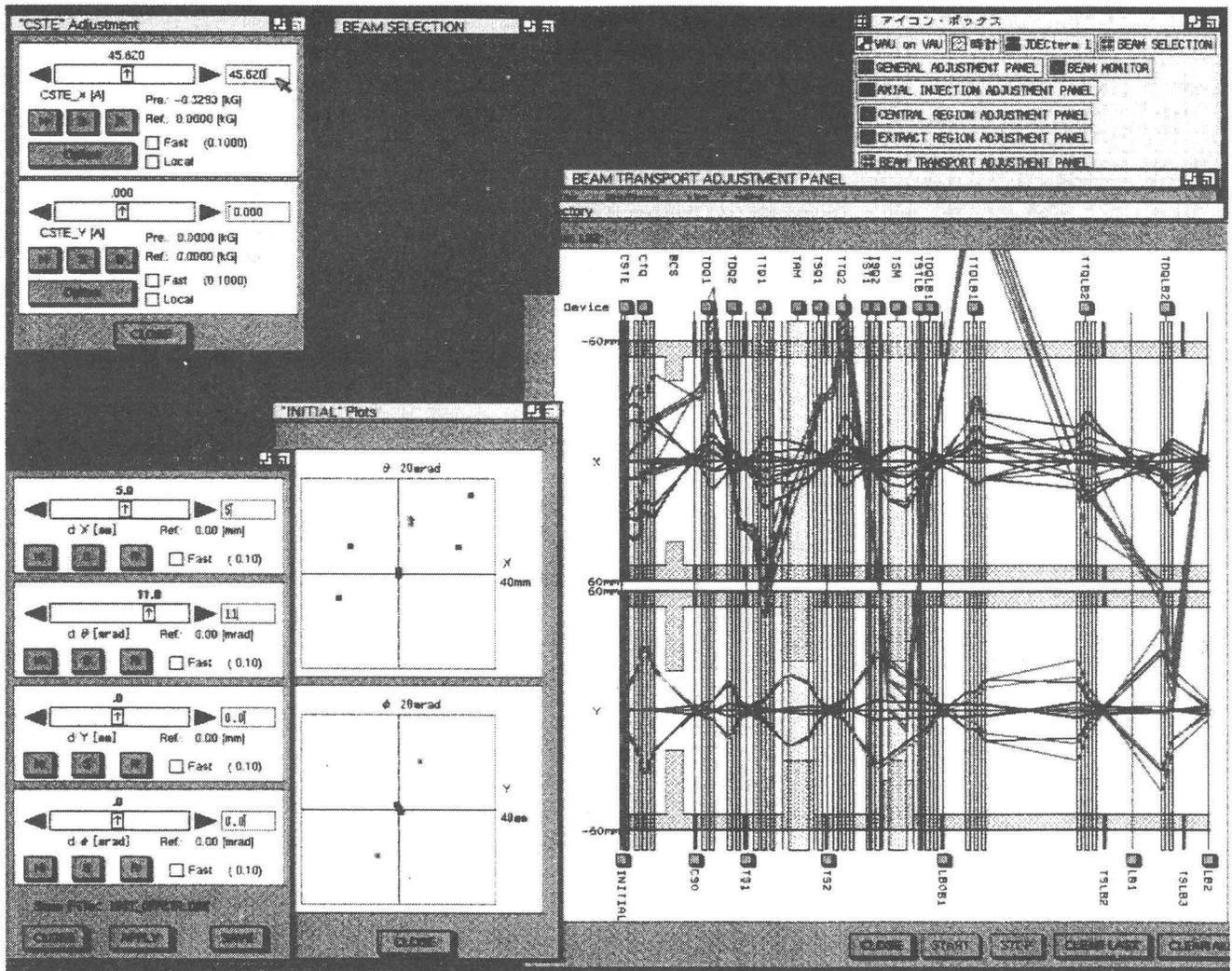


Fig. 3 : The visual interface for the beam trajectory.

the visual interface for the beam trajectory. When simulating the trajectories of a off-centered beam from the optical axis, the beam position is pulled away from the optical axis by a CSTE\_x located at the cyclotron exit. When the deviated distance ( $dx$ ) is +5mm horizontally, then the beam angle ( $\theta_x$ ) corresponds to +11mrad.

The simulation of the beam envelope is simplified by using a transfer matrix method based on the phase space ellipse. The beam trajectories are calculated at five positions on the ellipse including a center point as shown in Fig. 4. In order to reflect the operators' action on the simulation immediately, each element of the transfer matrix is linked directly to a parameter database and the calculation is renewed whenever one of them is modified. For reducing simulation and display time, the historical displays of the envelope and trajectory are saved as bitmap data. Since the data which are necessary for simulation and display, (e.g. layout data, initial beam conditions, magnet characteristics,

data base entry, etc.) are described in editable definition files, it is easy to modify these data for accurate simulation.

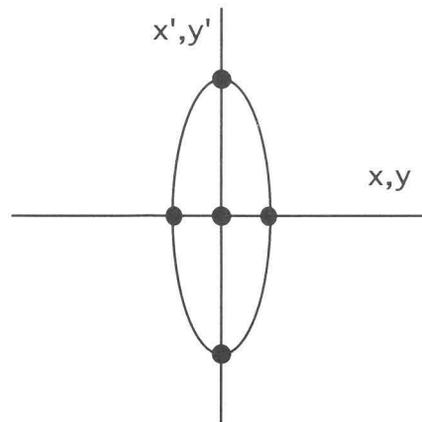


Fig. 4 : The elliptical phase space and the representative five ion particles at the first waist point of the cyclotron exit.

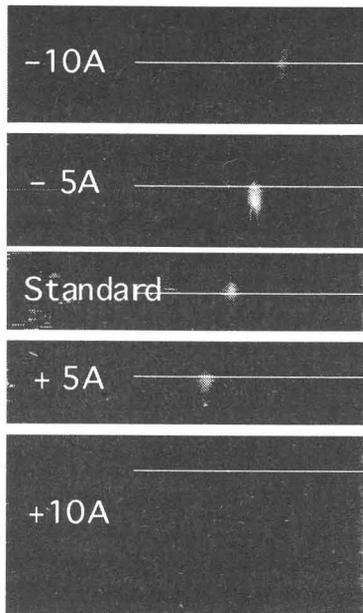


Fig. 5: The change of beam profile on the almina monitor at the target point.

In actual operation, by changing excitation current of the horizontal steering magnet located at the cyclotron exit, the change of profiles is measured with 45MeV H<sup>+</sup>.

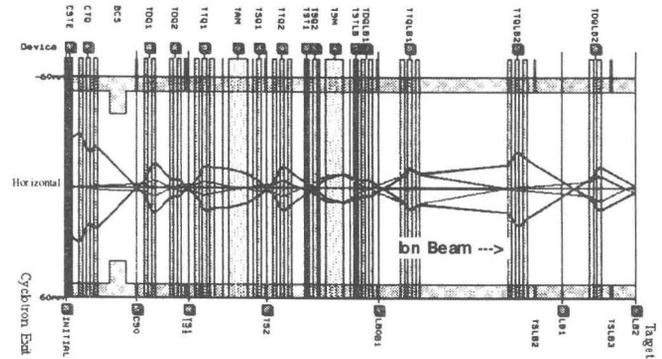
### 3 Examination of the System

In case of the ion which does not move close to the beam axis, i.e. when the ion beam is not paraxial, the beam trajectories were simulated. We examined the beam trajectories using the beam of 45MeV H<sup>+</sup>. In this real beam operation, the beam axis was changed by changing the field of steering magnet which is located at the cyclotron exit. The beam changes both the position and the profile on the target as shown in Fig. 5. The typical simulated beam trajectories for 45MeV H<sup>+</sup> are shown in Fig. 6. Fig. 6 (a) shows the simulated beam trajectories in case of the ion moves close to the beam axis. Fig. 6 (b) shows the simulated beam trajectories when the excitation current of the horizontal steering magnet, (CSTE\_x) located at the cyclotron exit, is set to +10A.

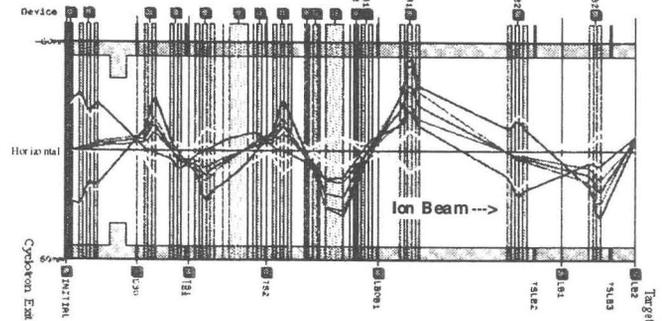
### 4 Conclusion

The beam adjustment interface calculates the beam trajectories/envelopes using actual parameters and displays them on a CRT. This display shows a historic summary of the simulated beam's trajectories/envelopes after any parameter has been adjusted by an operator. Operators can refer to either display, correct the differences between them,

and search for the optimum set point which provides desirable beam envelope/trajectories. Therefore, operators are able to quickly gain valuable operation experience which ultimately leads to a reduction of the time necessary to reach the planned beam transport condition.



(a) Beam trajectories by standard condition, namely the ion beam move close to the beam axis.



(b) Beam trajectories by setting excitation current to +10A of the horizontal steering magnet located at the cyclotron exit (the ion beam is not paraxial).

Fig. 6: Beam trajectory simulation for 45MeV H<sup>+</sup> in the beam transport system of the cyclotron.

### References

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