AN OPERATOR ASSISTANCE SYSTEM FOR BEAM ADJUSTMENT OF JAERI AVF CYCLOTRON

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Abstract

A computer-based operation system for AVF cyclotron which assists inexperienced operators has been developed. The system has been installed at JAERI (Japan Atomic Energy Research Institute) AVF cyclotron. The system provides a CRT display: the cyclotron beam trajectories, feasible setting regions, search traces and the beam envelopes designed to optimize beam parameter adjustment. The evaluation experiment for the system was carried out and the operation time to reach required beam conditions of the injection region of the cyclotron was reduced by approximately 65%. Also the system is very useful to study the problems on the beam transport such as beam trajectory, envelope, beam profile, spot size and so on.

1 INTRODUCTION

Cyclotron start-up operations require dozens of adjustable parameters to be tuned to maximize extracted beam current. Experienced operators perform this process through trial and error using their experience and intuition. However, the process is difficult for inexperienced operators because operator need to adjust parameters using little information such as measured beam data, alarm, status of components, and so on.

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 cyclotron. For a cyclotron control technique, we have developed a new computer-based visual assistance system for JAERI AVF cyclotron operation by using an applicable theoretical equations and numerical simulations.

A new computer-based operation system which assists inexperienced operators has been implemented for JAERI AVF cyclotron. The reliability of the system was evaluated by comparing the result of the simulation with actual operation [1,2,3]. The system can use to search the beam trajectory and envelope, when an operator has a difficult time in cyclotron operation.

2 VISUAL INTERFACES

The visual assistance system provides three functions of human interfaces for beam parameter adjustment:

- Beam trajectories and envelopes are rapidly calculated and graphically displayed whenever the operators change the cyclotron parameters.
- Feasible setting regions (FSRs) of the parameters which satisfy beam acceptance criteria of the cyclotron are indicated.
- Search traces, which are historical visual maps of beam current values represented by various colored dots, are superimposed on the FSRs.

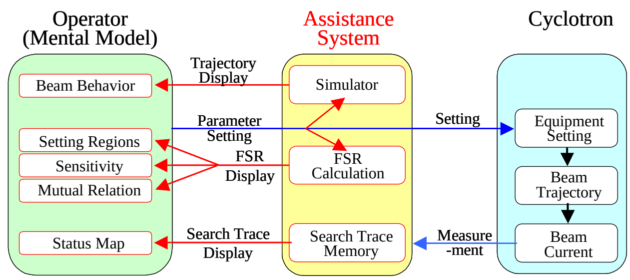

Figure 1: Block diagram of information flow in the operator assistance system.

Fig. 1 is block diagram of the information flow between the operator, assistance system and the cyclotron. 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 specific beam condition.

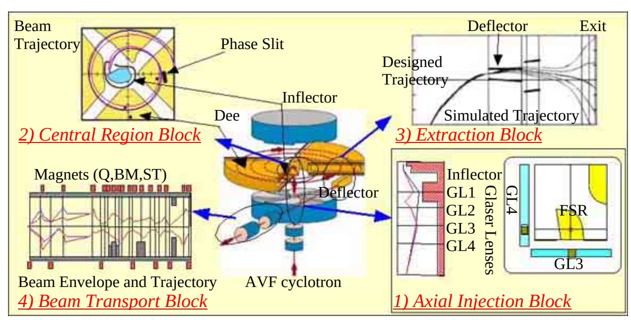

Figure 2: Schematic drawing of AVF cyclotron and example of beam trajectory display in the four blocks.

1) Axial injection block 2) Central region block
3) Extraction block 4) Beam transport block.

The system has been applied to four blocks of the cyclotron as shown in Fig. 2: the axial injection, the central region, the extraction and the beam transport. This system is constructed by the language of C and works on the workstation.

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2.1 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 (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. The resultant envelopes are calculated with in four lenses and the magnet field distribution using the transfer matrix method. The FSRs are limited mainly by the geometry of the inflector entrance.

2.2 Central Region Block

The central region block follows the axial injection block. The first turn of the beam trajectory 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 is 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.

2.3 Extraction Block

The beam in the final turn is led into the deflector and the magnetic channel, deflected from the circular orbit, and is 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 are determined as functions of the above parameters, and the clearance of the deflector and the magnetic channel.

2.4 Beam Transport Block

The extracted beam from cyclotron is led into the target port through the beam line. In this block, the system simulates the beam envelopes and the beam trajectory. The beam is led into the target port by adjusting these quadrupole, bending and steering magnets through gaps of the element's structures.

3 SYSTEM EVALUATION

The reliability of this system was evaluated [1,2,3]. In this paper, we report the system as operation tool.

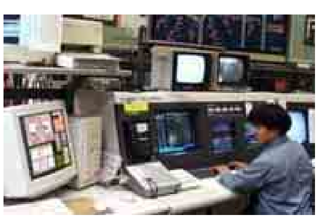

Figure 3: Typical operation display and operation at the axial injection block.

3.1 System Evaluation

To evaluate system effectiveness, the search time required to reach maximum beam current conditions was measured at the axial injection block [1]. Typical operation display and operation is shown in Fig. 3. In addition, system operability was evaluated using written questionnaires. Nine operators (1 expert, 4 trainees, and 4 novices) were asked to obtain maximum beam current by performing adjustments of the axial injection block by tuning the four lenses using three different interface modes:

- Mode 1: Using the existing console with four dials and a beam current meter.
- Mode 2: Using the assistance system without the FSR display.
- Mode 3: Using the full assistance system.

Table 1: Summary of search times using three interface modes

Operator	Level*	Mode 1	Mode 2	Mode 3
1	E	1.0	1.07	0.59
2	T	1.0	0.76	0.86
3	T	1.0	0.68	0.63
4	T	1.0	0.97	0.73
5	T	1.0	0.67	0.46
6	N	1.0	0.92	0.85
7	N	1.0	0.95	0.80
8	N	1.0	0.65	0.42
9	N	1.0	0.47	0.34
Median		1.0	0.76	0.63
* Level: E; Expert, T; Trainee, N; Novice				

Table 1 summarizes the resultant search times for the three modes and give their medians. All values were normalized by mode 1. In mode 2, the average search time was reduced by ~80% of that in mode 1. This improvement in operation is attributed to the search trace display and the ability to make beam settings using a mouse. Operational improvements were increased an additional 15% using the full assistance system (mode 3), i.e., the search time was reduced by ~65% in comparison to mode 1. The FSR display decreased the search time because an operator searches a smaller parameter area than without the display; thus more quickly reaching the desired optimal setting even though the theoretical model does not exactly represent the actual cyclotron conditions.

Table 2: Questionnaire results on the effectiveness of the operator assistance system

Function	Ave. Score	Histogram				
		5	4	3	2	1
(1) Trajectory display	4.29	2	5			
(2) FSR display	4.00	2	3	2		
(3) Search trace display	4.14	3	3			
(4) Display layout	4.71	5	2			
(5) Operation by mouse	4.14	2	4	1		

Table 2 summarizes the results of an operator questionnaire survey given to 7 operators (1 expert, 4 trainees and 2 novices) to evaluate system effectiveness.

Five system functions are considered and scored from 1 (not effective) to 5 (very effective). Since scores ranged from 4.0-4.7, the operators highly evaluated the effectiveness of system operability.

3.2 Correction of The Beam Line Level

The JAERI AVF cyclotron has dedicated to various applications as biotechnology, material science, radiation chemistry, nuclear science and radioisotope production. The ion micro beam is available to study the change of cellular structure and function by single ion hit and to develop a cell surgery technique in the field of biotechnology. A specific site of living cell is exposed to ion beam collimated around 10μm in diameter. To form the micro beam, there are three sets of the narrow collimators after the vertical bending magnet in the beam line. First collimator size is 5mm in diameter, second 0.5mm, third 10μm. It was very difficult to pass through beam into the three sets of narrow collimators because the beam is meandering through beam duct. An operator need to adjust the parameters for steering and quadrupole magnets.

To evaluate the meandering of the beam envelope, we simulate the beam trajectories using the visual assistance system as shown in Fig. 4. If we set up the operated actual parameter to simulator, the beam trajectories break down on the way. The beam, however, is transported by using the same parameter in the actual operation. When the beam trajectories simulated by changing the initial conditions from center of beam axis to +3mm on the vertical axis, it is show that the beam trajectories be able to transport with operated actual parameters. Finally, we found that the cause of beam off centering is the difference from the beam axis level between the beam line and the cyclotron. The level of beam line changed about 3mm by down flower level during thirteen years. We corrected the vertical level of magnets in the beam line [4].

4 CONCLUSION

The characteristic of the system is shown in next.

- Easy adjustment by visualized information.
- He can be understanding about the behavior of beam, when he is adjusting.
- It can effective adjustment, because the system cover physical knowledge and poor experience of him.
- Quickly training of operators.

The evaluation experiment for the system was carried out and the operation time to reach required beam conditions of the injection region of the cyclotron was reduced by approximately 65%. Also the system is very useful to study the problems on the beam transport such as beam trajectory, envelope, beam profile, spot size and so on.

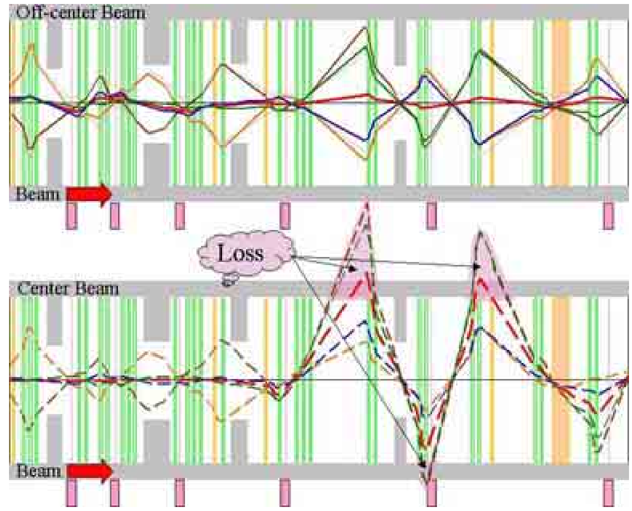

Figure 4: Examples of simulated beam trajectories with actual operating parameters.

Solid lines show the trajectories of off-centered beam by +3mm.

Dotted lines show the trajectories of centered beam. The beam trajectories are crash into the beam duct.

5 REFERENCES

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