CYCLOTRON BEAM TRANSPORT DEVELOPMENT USING BEAMLINE SIMULATOR

D.B. Mackay
MRC Cyclotron Unit, London, U.K.[*]

Abstract

The Scanditronix MC40 cyclotron at Hammersmith is a multi-particle, variable-energy machine. It is connected to an extensive beam transport system. Development of the facility has been made easier by the use of a beam transport modeling program. The program used is Beamline Simulator (Dehnel Consulting Ltd.). This work describes the developments that have taken place and the experience in the use of the Beamline Simulator program.

1.   INTRODUCTION

The MRC Cyclotron unit's main research interest is in PET imaging techniques. It runs 2 cyclotrons and has access to five PET scanners and supports large clinical, radiochemistry research and PET methodology groups. The unit's main accelerator is a Scanditronix MC40 cyclotron (Fig. 1). The PET research activity requires predominantly irradiations with a 19MeV proton beam to produce ^{11}C and ^{18}F. Other applications exploit the versatility of this multi-particle, variable energy machine. The cyclotron is connected to a beam transport system (Fig. 2) which allows great flexibility in the number and types of solid, liquid and gas targets that can be irradiated. The facility is available for use 114 hours per week, 48 weeks per year.

Fig. 1

2.   DEVELOPMENTS

An increasing number of requests for new radioisotopes and increased availability of enriched materials has led to a significant increase in the range of beam energies being run and development of all the available beam lines. The trend to smaller targets and expensive enriched materials has resulted in beam diameters of 10 mm being required, instead of 20 mm which used to be standard. Examples of present activities include a 30 MeV proton beam for ^{81}Rb/Kr generators, a 12.5 MeV proton beam for ^{124}I, a 52 MeV ^{3}He beam for ^{52}Fe, a 28 MeV alpha beam for ^{211}At production. Some work has been done on assessing how efficiently the beam can be shaped to impinge on apertures as small as 3 mm diameter. The beam diagnostic aperture for the 10 mm targets is shown (Fig. 3). The target aperture is framed by 4 insulated sectors made of carbon. The data is acquired and displayed in the control room via a Labview-based system.
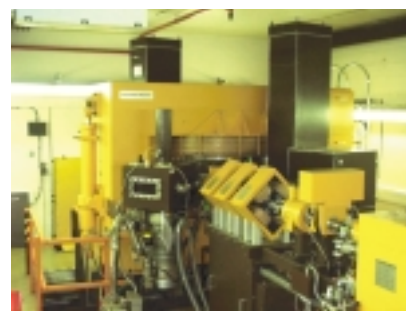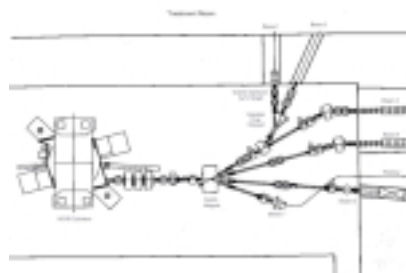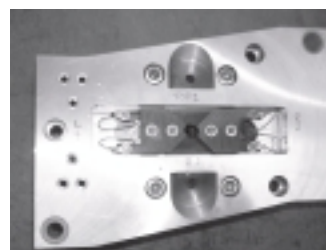

Fig. 2

Fig. 3

---

[*]   Currently being privatised as Imaging Research Solutions Limited

3.   USE OF BEAMLINE SIMULATOR

The Beamline simulator program, supplied by Dehnel Consulting Ltd, Nelson, B.C., Canada has been very useful in expediting beam development work and has also been a useful teaching aid for operator training. It is a real-time simulator for industrial beam transport systems and is available on a PC/ Windows platform. The initial impetus to develop the program followed a question from myself to Morgan Dehnel at EPAC 94. It is not the purpose of this article to provide a full tutorial in the use of this program, but to highlight ways in which it has proved useful in our situation, so what follows is a brief outline of our experience.

3.1   Data required for beamline simulator

Defining the beam source requires the particle, ionization state, energy and emittance and whether a beam envelope or multi-particle computation (up to 10,000 particles) is required. A particular difficulty in our case was that emittance data was only available for full energy beams from installation in 1985.

Beam lines are built up by adding elements such as quadrupoles, dipoles and drift tubes. A representation of the beam line is built up by assembling icons (Fig. 4). A difficulty for us was that due to lack of space for steering magnets in some of the beam lines, the quadrupoles were given a secondary function as steering magnets. This was achieved by separately varying the currents in each individual winding of the quadrupoles.
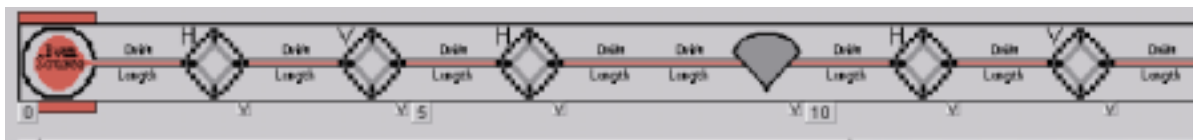

Fig. 4

The sizes and shapes of the beam line apertures for each element are tabulated separately. However, it would be more convenient if all the data for each beam line element was entered at the same time because errors can easily arise if an extra item were inserted in the beam line. The MRC beam transport system has a number of apertures where there is ample width but restricted height, e.g. in many of the bending magnet vacuum boxes. Using the beam source in envelope mode, a quick appreciation can be gained of where the beam is in danger of striking the sides of the beam line aperture. The display shows the width of the beam along the beam line (X vs Z), (Fig. 5a) or its height (Y vs Z), (Fig. 5b) along with the shape of the beam on the target aperture (Y vs X), (Fig. 5c). This particular combination of low beam energy and long beam line was a difficult challenge both to model and to tune adequately.
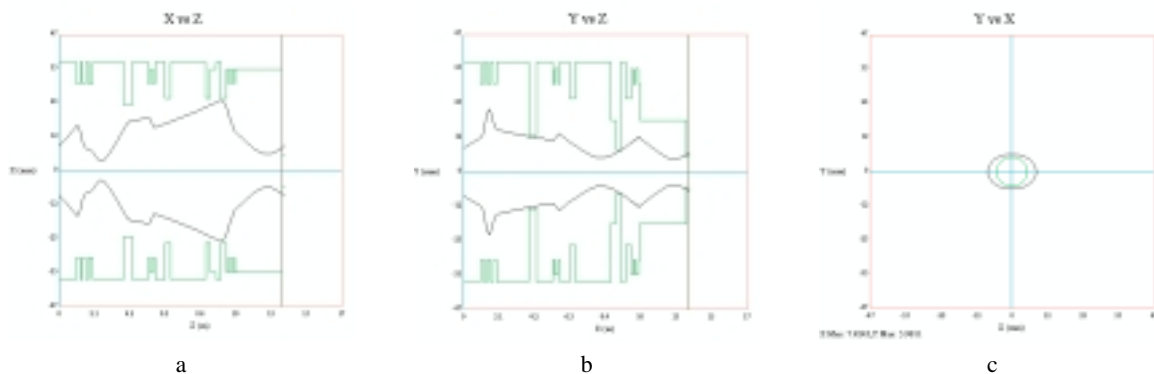

a   b   c

Fig. 5

In multi-particle mode, the beam spill on current-measuring irises can be displayed (Fig. 6). This is very similar to the way in which information is made available to the operator from the control room display (Fig. 7).
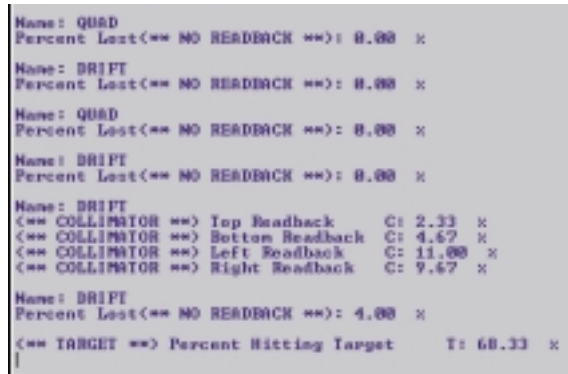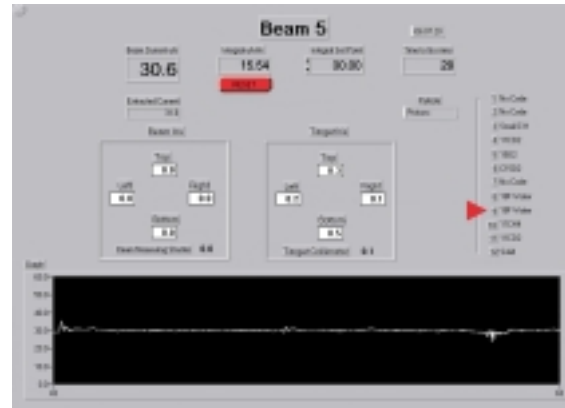

Fig. 6

Fig. 7

A very useful feature of the program is that the effects of changes to beam line conditions can be easily seen. It is as simple as clicking on the icon for that beam element, increasing or decreasing its value with the up/down arrow keys on the 'vary parameter' window, and seeing the outcome as the program instantly re-runs itself with every click. For operator training, this feature allows the operator to quickly see the effect of adjusting any of the variable elements on the beam line and results in a better understanding of the factors involved in tuning up the beam line.

3.2 Comparison of simulator with real beam line

The results shown are for beam line 4 and a 12.5 MeV proton beam. This beam line has three sets of quadrupole magnets. There are also two 30° bending magnets which can be seen to have a strong influence on the horizontal focussing. The agreement was adequate to give a starting point for real tuning to obtain beam on target in one session. The table below (Table 1) allows a comparison to be made between values as used in practice and those predicted by the simulator.

Table 1

	Quadrupole magnet pole tip strength settings (kG)						
	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Experimental	1.58	1.92	0.97	1.38	1.01	0	1.02
Simulation	1.58	2.04	1.02	1.36	1.58	0	1.10

The values shown in the table for the focussing elements correspond to the beam envelopes shown in Fig. 4 above. The actual beam spills are compared with the simulator prediction (Table 2). Quantitative predictions of beam spill are very dependent on the values chosen for the emittance and until better information than that based on 40 MeV proton measurements from 15 years ago becomes available, the correspondence is unlikely to improve. Up to this time, the majority of the development work has been done on proton beams but the simulator has also been applied to deuteron, alpha and ^{3}He beams.

Table 2

	Beam spills (%)					
	Iris				Other losses	Beam to target
	Top	Bottom	Left	Right		
Experimental	2	1	2	3	12	80
Simulation	2	5	11	10	4	68

4. CONCLUSION

Beamline simulator has been an effective tool for rapid development of new beam energy options at the MRC Cyclotron unit.

5. ACKNOWLEDGEMENTS