Initial Equipment Commissioning of the Northeast Proton Therapy Center

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The equipment for the Northeast Proton Therapy Center (NPTC) is currently being installed and commissioned in Boston. Aspects of the facility goals, design, and status will be presented.

1. INTRODUCTION

Massachusetts General Hospital, in collaboration with the Massachusetts Eye and Ear Infirmary, has been treating patients with high energy proton beams for cancer and other diseases. This work, based at the Harvard Cyclotron Laboratory (HCL), has been ongoing for more than 30 years. The Northeast Proton Therapy Center (NPTC) will continue this work with higher proton energy, isocentric rotating Gantries, and with the capability for higher patient treatment capacity. Details of the facility and the clinical requirements can be found in references 1and 2. The beam production and beam delivery equipment is an integrated system, developed by Ion Beam Applications s.a. (IBA) to meet the clinical specifications. The system includes a compact 230 MeV isochronous cyclotron, and an energy selection system which can be used to modify the energy delivered to the treatment rooms. The beam is directed into a isocentric rotating Gantry on which a Nozzle containing a beam spreading system is mounted. In addition, the system includes a global control system, safety system and robotic patient positioning systems.

The system is subdivided into the major subsystems as described above. To the extent possible, each major subsystem is factory tested prior to its integration on site at the Hospital. Many of the components have been tested, and the system is currently being integrated.

The clinical specifications[1], are high level system specifications. In order to test the subsystems properly, the clinical specifications are flowed down to subsystem performance requirements. In a system such as the NPTC proton therapy equipment, many components combine to affect a particular clinical specification, therefore, it is necessary to take this into account in the system tests.

II. MAJOR SUBSYSTEM COMMISSIONING

2.1 Beam Production Equipment

2.1.1 Fixed Energy 235 MeV, CW Cyclotron

Some details of the Cyclotron design have been previously reported [3,4]. The Cyclotron is shown installed at the NPTC in the photo below.

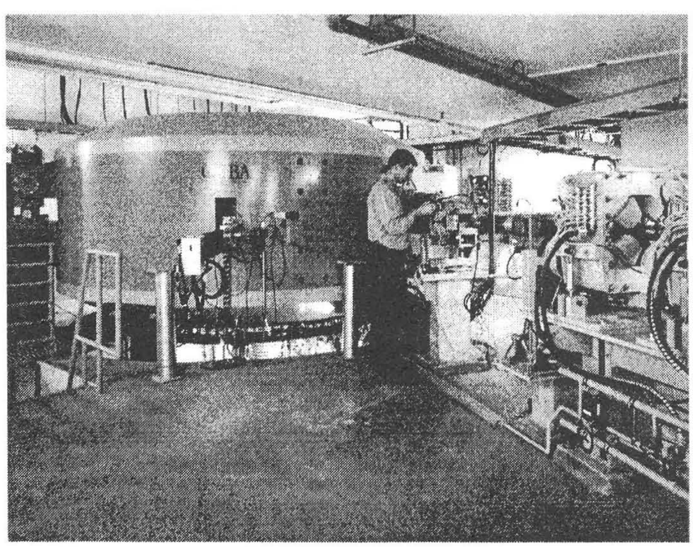

Figure 1 IBA C235 Cyclotron installed at the NPTC

In the design of the IBA C235, a primary goal is compactness and reliability. The compact size is achieved by using a high field value and a special gap shape. Accurate coil manufacturing, and machining of the magnet, ensured by tight quality control was required. The reliability arises from minimizing the adjustable parameters, and robust design.

The Cyclotron was tested in Belgium with the Energy Selection System and shipped to Boston in April, 1997. The Cyclotron was reassembled and achieved first beam on June 12, 1997. Three days later, the cyclotron and the ESS were used for the US Particle Accelerator School Laboratory course on Accelerator Instrumentation and Beam Measurements.

The process of commissioning the cyclotron involved an iterative procedure of field mapping, pole pieces shim adjustment and measurements with beam as well as fine adjustments to the ion source to puller geometry. The cyclotron optics was adjusted close to isochronous during the field mapping portion of commissioning. Using the accelerated beam, fine tuning was possible to achieve the isochronicity required by the design. Below is a Smith Garren plot showing the results of a measurement.

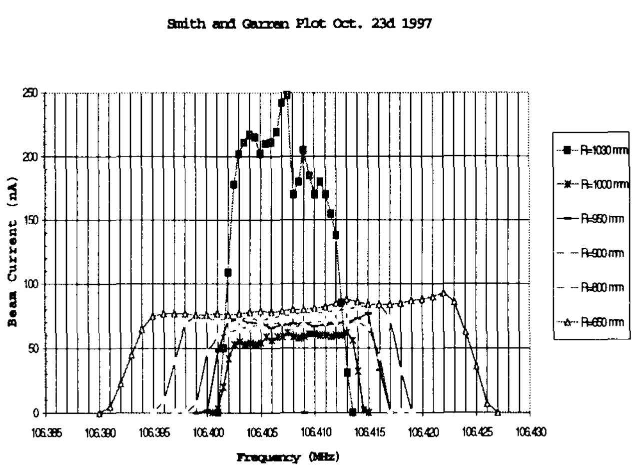

Figure 2 Smith Garren Plot

The beam phase space extracted from the cyclotron has been measured downstream of two quadrupoles which are positioned just after the beam is extracted. Using the method of varying the quadrupole excitation the beam sizes are measured as a function of focal length. An example of such a measurement is shown in figure 3, below.

The beam phase space parameters extracted from the cyclotron can be calculated from these measurements. They correspond to a horizontal emittance of 11 mm-mrad and a vertical emittance of 13 mm-mrad. The admittance of the beam transport system is determined by the degraded energy beam and is as high as 30 π mm-mrad.

Since initial operation in the NPTC facility last year, the cyclotron has been operated most evenings. The operation of the cyclotron has proven very reliable. Beam is accelerated within 0.5 hours of a cold start. With the help of a feedback system relating to the magnet yoke temperature to the magnetic field, a fixed frequency operation is possible.

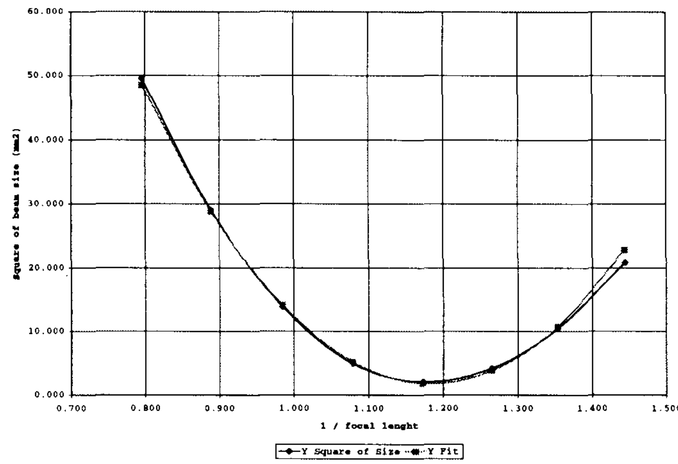

Figure 3 Vary Quad measurement of beam phase space

2.1.2 Energy Selection system (ESS)

The NPTC Beamline is shown schematically below.

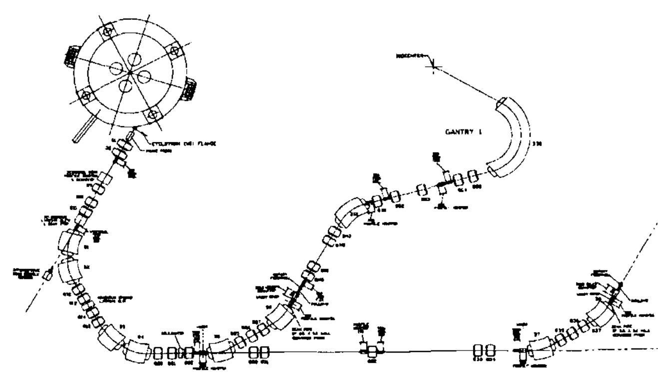

Figure 4 Schematic of the NPTC Beamline

The extracted beam from the cyclotron is focussed at the energy degrader which is the beginning of the Energy Selection System (ESS). An adjustable collimator downstream of this degrader is used to limit the emittance transmitted to the remainder of the beam line. This beam is then energy analyzed in an achromat which also includes slits to limit the proton beam momentum spread transported by the rest of the system. Once the energy analysis is complete, the beam is directed to treatment rooms.

The beam intensity exiting the ESS is a function of the energy loss and the desired admittance. This transmission has been measured and agrees well with the predictions as shown in the figure below.

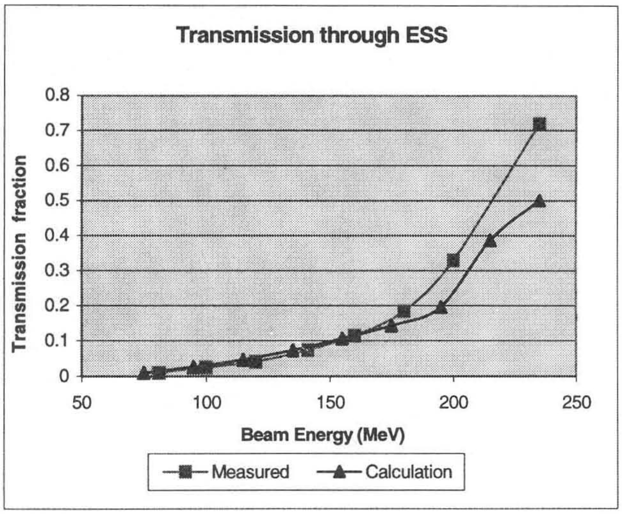

Figure 5 Beam Transmission through the ESS

The ESS acts to tailor the beam characteristics to those required for clinical treatment. For example, it is required that the intrinsic contribution of the distal edge of the Bragg peak due to the beam energy spread be no more than 1mm. Below is an example of a low energy Bragg peak measured after the ESS which demonstrates the capabilities of this system.

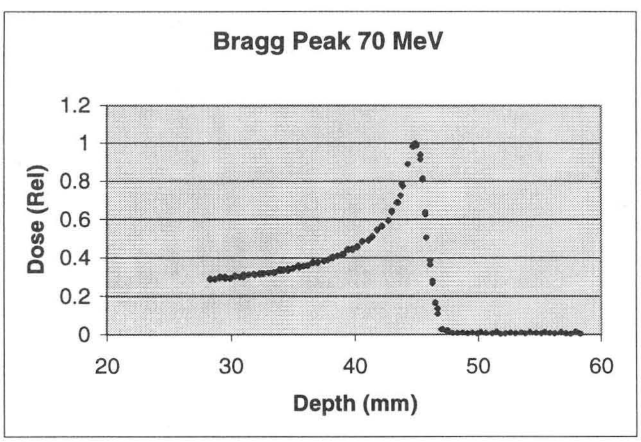

Figure 6 Bragg Peak Measured after the ESS

3.1.3 Beam Transport System (BTS)

The beam lines provide the required focussing and achromatic bends to deliver the beams to each of three treatment rooms. The beam phase space and trajectory centroid is measured with multi-wire beam ionization chambers. Measurements have been made from the ESS and the beam line through the beam line mounted on the first Gantry. The beam profiles measured compare well with the designed optics. Reproducibility on a day-to-day basis has also been extremely good. One of the advantages of an ESS system is that the beam properties are controlled by mechanical parameters and are decoupled from the accelerator.

Within the third treatment room, the beam is split further into three beamlines allowing a total of five treatment stations in the facility.

2.2 Patient Treatment Equipment

One of the clinical specifications is the requirement to be able to direct the beam to within ±1mm of the intended target. There are several factors which can contribute to this. They include:

- Gantry Isocenter Pointing Reproducibility and Accuracy
- Patient Positioning Reproducibility and Accuracy
- Beam Trajectory Correctability

Achieving this specification is one of the significant challenges of this project. To date we have measured the individual contributions of the potential error sources and conclude that the specification can be achieved.

The recent status of the installation of the treatment equipment in the NPTC treatment room is shown in the photo below. To date the first Gantry has been installed, as well as the first Nozzle and Patient Positioning System (PPS).

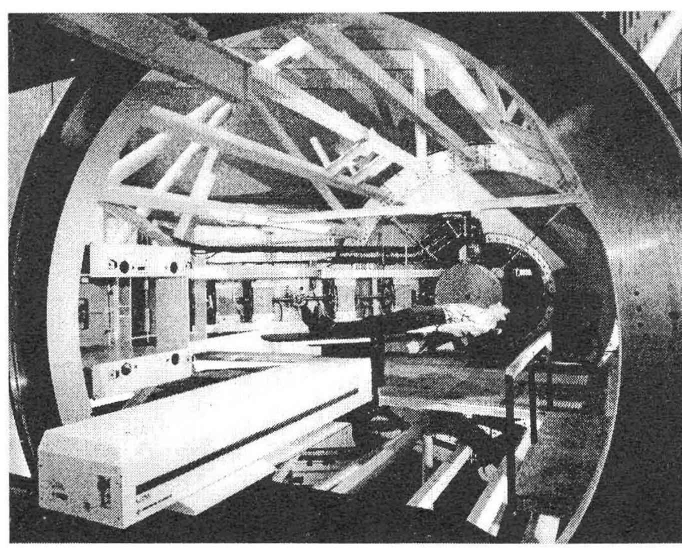

Figure 7 Recent Photo of the NPTC Treatment Room #1

2.2.1 Gantries

The Gantries are conventional gantries in the sense that all the bends are in the same plane. They are capable of over 360 degrees of rotation about an isocenter with the virtual source about 2.3 meters from the isocenter. The gantry structure supports the beamline and serves to minimize the deflections of the beamline magnets during gantry rotation as well as to provide a consistent beam direction through the beam spreading Nozzle.

Measurements of the Gantry Isocenter without the Nozzle have been made. The results indicate deviations of less than 1 mm from the ideal isocenter and with reproducibility much less than that. The plot below shows the measured coordinate deviations as a function of Gantry angle.

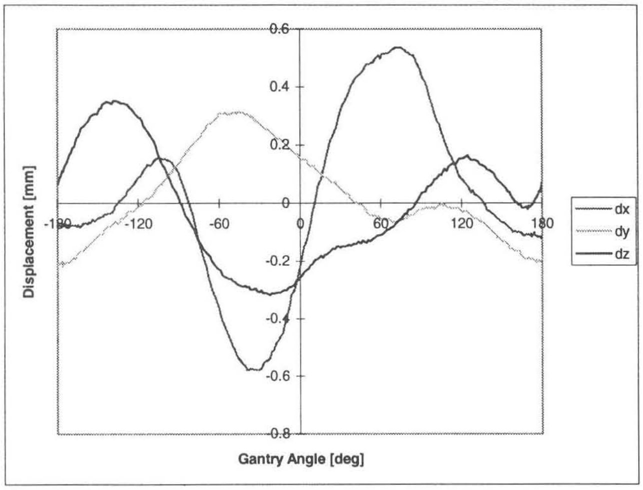

Figure 8 Measurements of Gantry Contribution to Deviation of beam to position compared to isocenter

2.2.2 Patient Positioning System

The PPS has been assembled and its performance has been measured. It has proven to be a device with a high degree of reproducibility. The figure below is a histogram representing a number of measurements representative of the reproducibility of the system for each axis.

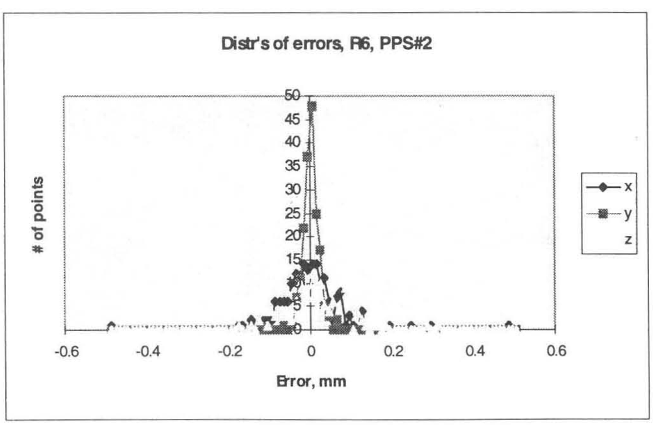

Figure 9 PPS Reproducibility measurements

In addition, measurements of the absolute accuracy of the PPS have been made. There are some configuration dependent elastic deformations that were expected. Analysis has shown that these can be predicted and the PPS can be set to an absolute position with accuracy very close to the measured reproducibility.

2.2.3 Beam Spreading/Delivery System (Nozzle)

The first Nozzle has been completed and installed in the Gantry of Treatment Room #1. Tests of the beam spreading system have already started.

2.3 Computer Control and Safety System:

The controls and safety system are under development. All the measurements made to date have been accomplished with the computer control system.

III. NPTC BUILDING

The NPTC building houses the proton therapy equipment and related program space such as clinical space and administrative space. It provides approximately 23,000 net square feet of program space including three clinical treatment rooms, accelerator equipment, and offices. The lower level contains the accelerator, treatment rooms and some equipment support space. Two of the treatment rooms contain gantries, and the third room is used for a fixed horizontal field. It also includes clinical space for patient examination and care. The ground level contains administrative, staff and miscellaneous support space as well as aspects of equipment support and clinical space. A photo of the facility shown below. Occupancy of the building began in March, 1997.

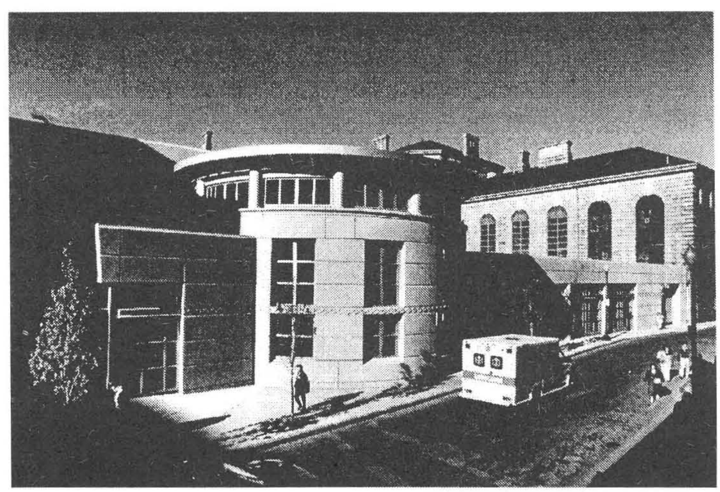

Figure 10 A view of the Completed NPTC Building

References

[1] J. Flanz, et. al. Proceedings of the 14th International Conference on Cyclotrons and their Applications. (1995),499.

[2] Y. Jongen, et. al., ibid , 606

[3] W. Beekman, et. al. ibid, 218

[4] D. Vandeplassche, et. al., ibid, 454