TUNING OF THE INR THERAPEUTIC PROTON BEAM

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Abstract

The medical proton beam channel of the INR Experimental Complex and the therapeutic beam formation system are described (see also Refs. [1,2]). Parameters of the 209 and 160 MeV proton beams were investigated and dose distributions in matter were measured.

MEDICAL PROTON BEAM CHANNEL

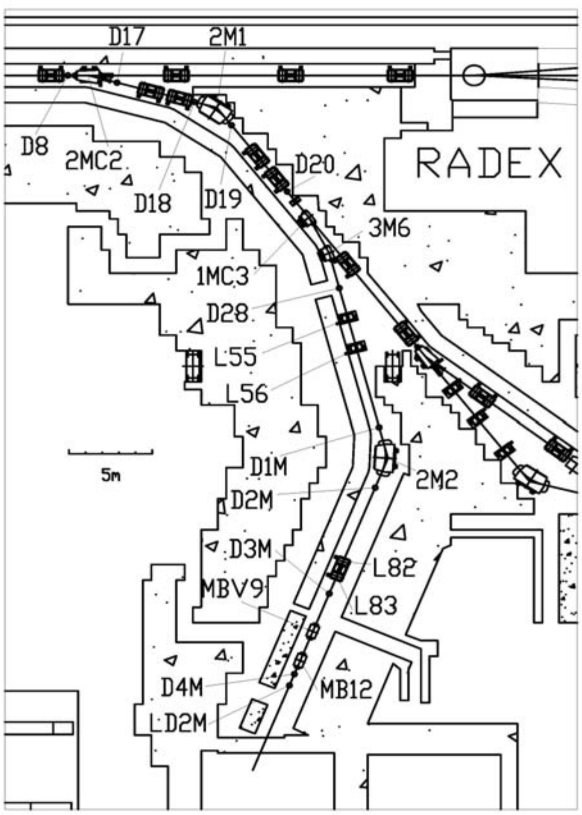

Figure 1: The layout of the proton beam channel for proton therapy. 2MC2, 2M1, 1MC3, 3M6, 2M4, MBV9, MBV12 – bending magnets; L55, L56, L82, L83 – quadrupole lenses; D8, D17, D18, D19, D20, D28, D1M, D2M, D3M, D4M, LD2M – profile detectors.

A special channel of INR Experimental Complex was built for radiotherapy needs [3]. The layout of the optical elements and profile detectors along this proton beam channel is illustrated in Fig.1. The length of this channel is about 50 metres [4].

The distinguishing feature of optics, operated during the last session in April 2010, is that only 4 quadrupole lenses have been used in the channel. Five magnets ensure beam bending on 112 degrees. The lenses L55, L56 are responsible for compensation of angular and linear dispersion of the beam after the bending magnet 2M4. The lenses L82, L83 form a beam on the scatterer with the required angular divergence of less than 2mrad and the dimensions $\sigma_x=\sigma_y=5$mm. Alignment of the beam with the axis of the treatment room is provided horizontally by magnets 3M6 and 2M4, and vertically by magnets MBB9 and MBB12. Each element in the channel is supplied by its own power source with the current fluctuations of ~ 10^{-4}. The electrical power consumption of the channel with the proton energy of 209MeV is equal to ~ 87.5kW. This amount is just a small fraction of the total energy consumption of both the accelerator and the experimental complex.

For the purposes of beam tuning there are ten 16-channel secondary-emission profile detectors, with a step of 2 and 4mm [3]. Profile detectors allow us to measure the position and the spot size of the proton beam during the tuning of a channel. A luminescent detector (item LD2M in Fig. 1) is installed at the end of the channel, just before the treatment room. This detector enables us to monitor on-line position and dimensions of the beam.

The principal aim of the tuning of the channel during the April 2010 session was the analysis of the parameters of the beam with proton energies of 160 and 209 MeV. This has been carried out with the aid of the profile detectors. As it follows from the analysis, the energy spread of protons was very small, approximately 10^{-3}. Therefore a strict achromaticity of the channel is not necessary for the required parameters of the beam. This eliminates the constraints on the regimes of the lenses L55-56 that are used for the focusing of the beam. Fig.2 shows the profiles of the beam at the entrance to the channel (distance from the accelerator is about 150 m), before the magnet 2M4 and at the end of the channel.

It is worth highlighting the details of the profile of the beam in front of the magnet 2M4. We have managed to focus the beam into dimensions σ_x=1.6mm, σ_y=1.5mm by means of the lenses L55-56.

The profile of the beam, at the end of the channel and before the scatterer, is obtained using the adjusted regime of lenses L55-56 for the beam focusing of lenses and the computed value of the regimes of the lenses L82, L83. This beam was used for forming the dose field.

One of the main properties of the medical channels is the time required to tune the channel. In the last session the tuning process took 1.5 hours. Similar time was required for the tuning of the beam during the transfer to another beam energy (without taking into account the time of re-tuning of the accelerator).

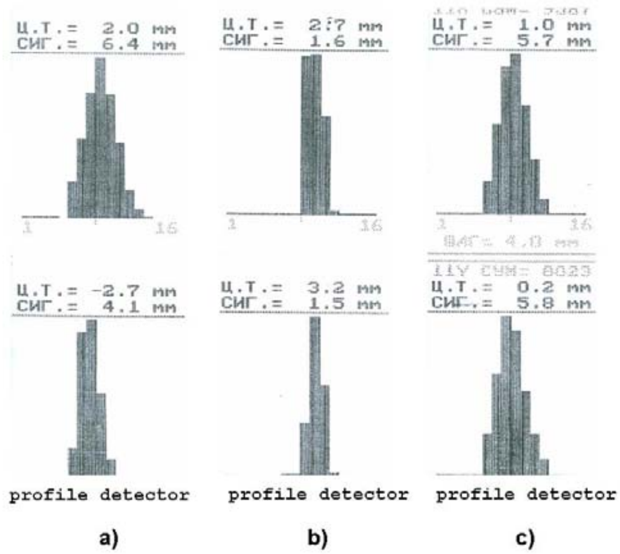

Figure 2: a) Beam profiles at the entrance of the forming proton channel (profile detector D8), b) before the magnet 2M4 (profile detector DM1) and c) at the end of the proton channel (profile detector D4M).

EXPERIMENTAL EQUIPMENT AND METHODS

The design of the end of medical channel is shown in Fig. 3. The beam is delivered to the treatment room via the vacuum transport system and passes through an output window (1.04 mm Al), a graphite collimator with the window of 10 mm and thickness 17 cm, additional 0.1 mm copper foil and a special profiled scatterer-degrader. Dose distributions in water were measured with the dose analyzer Wellhöfer WP600, including an acrylic water phantom of 60x60x30 cm, a high accuracy 3D detector positioner, two 0.14 cm^3 ionization chambers IC-10, a double channel electrometer, a control computer and electronics. A plane-parallel chamber PPC05 (Scanditronix-Wellhöfer) has been used for precise depth dose measurements.

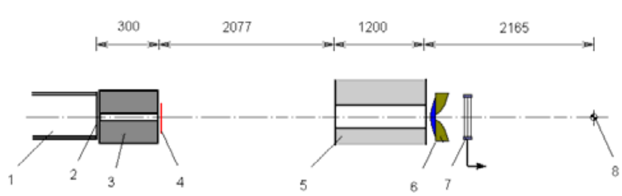

Figure 3: The individual beam formation system (160 MeV, all sizes are in mm). 1 – the end of vacuum channel; 2 – the Al window; 3 - the graphite; 4 – the primary scatterer; 5 – a 120 cm biological shield, the channel of diameter 10 cm; 6 – the secondary profiled scatterer/degrader; 7 – the monitor chamber; 8 – the isocentre of the treatment room.

Along with the ionization methods, the Bragg curve was measured inside a Plastic Water LR solid state phantom (CIRS Inc., USA) with strips of radiochromic film Gafchromic MD-55.

RESULTS AND DISCUSSION

First, the Bragg curve in water for 209 MeV protons was determined and the proton range and energy were estimated. During these measurements, the collimator and scattering system were removed from the beam line (items 3, 4, 6, 7 in Fig. 3). The curves (Fig.4) were measured using the IC-10 ionization chamber, a standard deviation over a group of 5 measurements was 1.5%.

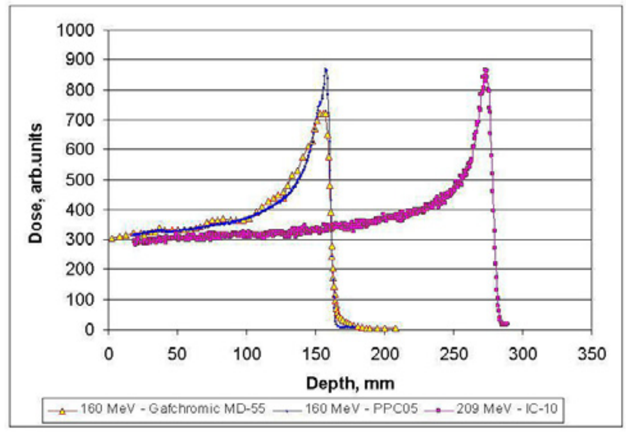

Figure 4: The Bragg curves in water.

The CSDA range in water, estimated as the depth of the Bragg curve where the dose was reduced to 80% of its maximum, was 275.6±0.2 mm. Mean proton energy was estimated as 207.5±0.1 MeV using the ICRU49 [6] range-energy relation.

On the basis of the 160 MeV proton beam earlier measured parameters, a beam spread out system was designed and manufactured. This system was simulated with the utility NEU [7] and included a flat primary scatterer (1.04 mm Al + 0.1 mm Cu) and a profiled secondary scatterer made of tin. To compensate the energy losses, a profiled PMMA energy degrader was set after the scatterer.

The beam profiles in water without using the secondary scatterer are presented in Fig.5. Both profiles are close to each other, symmetric and well aligned relative to the beam axis. The FWHMs were 101 and 99 mm respectively in horizontal and vertical directions.

The complete set of scattering system was carefully investigated: we measured vertical and horizontal profiles at depths 19, 69, 119, 157 (the Bragg peak) and 164 mm (Fig. 6 and 7), depth dose data along the beam axis (Fig. 4).

The profiles at low and medium depths demonstrated reasonable dose uniformity within a few percents. Most serious profile skewness, up to 10%, was found in the vertical profile at the Bragg peak. It can be resulted from a little energy variation across the beam and, respectively, a little Bragg peak depth variation. In this case, the skewness can be compensated in further spread-out Bragg peak formation by ridge filters.

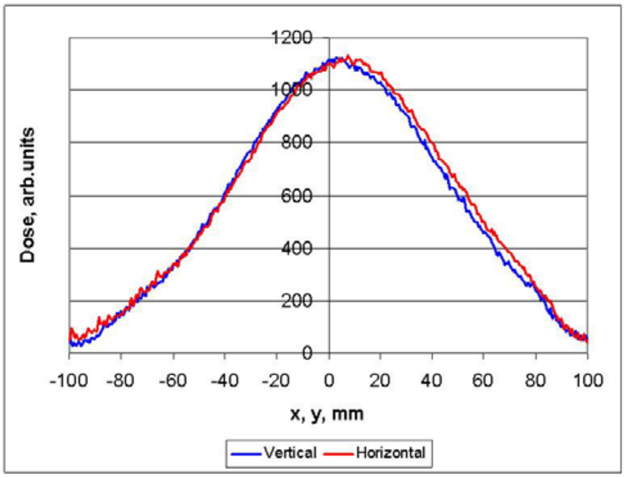

Figure 5: Horizontal and vertical dose profiles formed by the primary scatterer at a depth of 20 mm, E = 160 MeV.

The depth dose distribution measured along the beam axis with the PPC05 plane-parallel ionization chamber is shown in Fig. 5. The proton range calculated on the base of eight measurements was 159.6±0.07 mm and mean proton energy was 151.02 MeV.

It follows that the 160 MeV beam, formed by the double scattering system, meets the medical requirements under the condition of stability of main parameters.

Direct depth dose measurements in a water equivalent plastic phantom were performed using the Gafchromic MD-55 film. Two strips of the film of 127 x 15 mm were placed and aligned between the Plastic Water LR slabs. The water equivalence of the Plastic Water substitute material was verified previously [5]. The films were scanned and converted to the Bragg curve (Fig. 4). The resulting proton CSDA range was 159.2 mm, it agrees with the PPC05 data within the 0.4 mm.

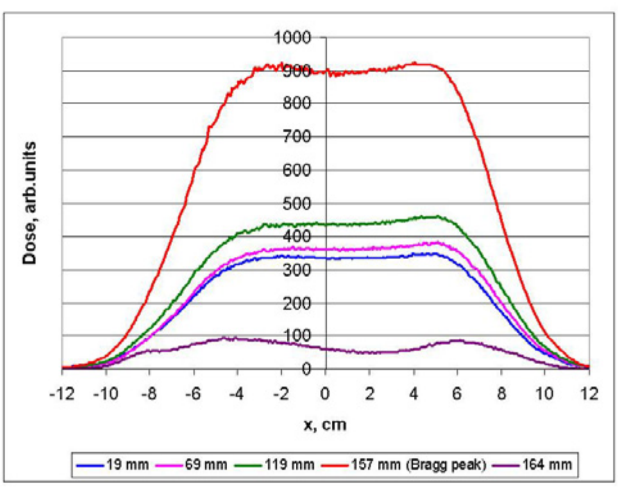

Figure 6: Horizontal dose profiles in water at depth from 19 to 164 mm, E = 160 MeV, double scattering system

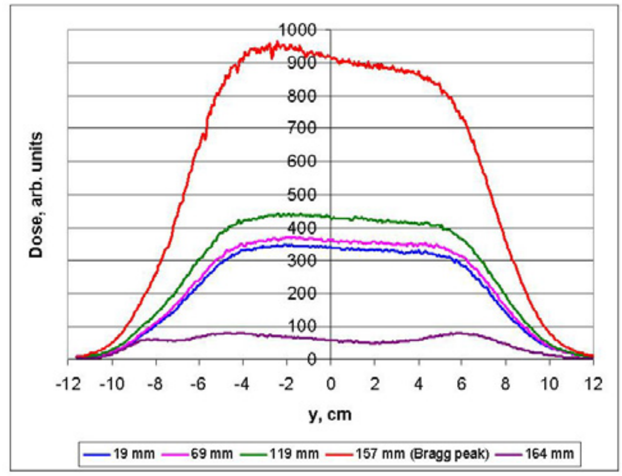

Figure 7: Vertical dose profiles in water at depth from 19 to 164 mm, E = 160 MeV, double scattering system.

CONCLUSION

The last session of the proton beam supply to the Complex of proton therapy of INR has demonstrated that medical requirements of the beam can be fulfilled with the existing beam channel and beam formation system. However, before the patient treatment will take place, further test sessions with different proton energies, as well as the installation of additional equipment in the channel and in the treatment room, should be carried out.

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