MODELING AND IMPLEMENTATION OF THE MECHANICAL SYSTEM AND CONTROL OF A CT WITH LOW ENERGY PROTON BEAM

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Abstract. *This work is part of the development of the prototype of a mini computerized tomograph based on protons beam. The prototype, developed in the UTFPR and UERJ, is being tested with the cyclotron CV-28 of IEN/CNEN. One of the project stages is referring the computer simulations to search for more detailed information about the performance of the collimation of aluminum, scattering of the beam and energy loss of the protons. The code simulate two aluminum collimation of with a hole of 0,4 mm diameter, and, also a comparison among the beam of entrance protons perfectly collimated from a dispersed beam and the spectrum of exit energy.*

***Keywords**: Computer Tomography; Protons beam; image reconstruction*

1. INTRODUCTION

Proton radiation therapy is a highly precise form of cancer treatment, which spares more healthy tissue and allows higher tumor doses than conventional radiation therapy (Meikle 2003). In existing proton treatment centers, dose calculations are performed based on x-ray computed tomography (CT) and the patient is positioned with x-ray radiographs. Alternatively, one could image the tumor and position the patient directly with proton CT (pCT) by measuring the energy loss of high-energy protons that traverse the patient (Hanson 1981, p.965) using the proton treatment gantry. The energy of protons produced by the synchrotron at Loma Linda University Medical Center (*Proton Treatment Center*), and, by now, in several other proton treatment centers (*The Harvard Cyclotron Laboratory*) is sufficiently high to achieve this goal (Schulte 2002). Although the idea is not new, pCT is currently not available. This is mainly because there are unanswered questions such as whether the image quality of pCT will be sufficient for localizing tumors and whether the accuracy of proton range calculations will surpass that of x-ray CT based range calculations without significantly increasing the patient exposure. The spatial resolution of pCT is limited mainly by multiple Coulomb scattering, while the contrast resolution is affected principally by the statistical nature of the proton energy loss mechanism (Satogata 2003). Both effects are more pronounced, and thus easier to study at the low proton energies available at CV-28 Cyclotron of IEN/CNEN (*Instituto de Engenharia Nuclear*).

2. PLANNED EXPERIMENTAL SETUP

The experimental setup, which is simulated in this work, represents a miniaturized 1^{st} generation CT scanner (Kak 2001), situated in vacuum (see Fig.1). Thin tubes filled with tissue-equivalent solutions will severe as test objects during the initial phase. By varying the solution density in small steps, the contrast resolution of the pCT method will be evaluated. In addition, the pCT data calibration problem how to relate energy loss to electron density (relative to water) will be studied. The sample will be fixed onto a tomographic turntable, which may be translated in the direction perpendicular to the proton beam axis (see Fig.2). The protons from CV-28 will be collimated to form a pencil beam of desired cross section and registered by Si(Li) detector (*L-Series Room-Temperature Lithium-Drifted Silicon Detectors)*, situated behind the turntable. A varied collimator will be installed between the turntable and the detector. All these components will be fixed onto the existing support of scattering chamber. A computer simulation of the setup performance was done to adjust the parameters of intend experimental procedure.

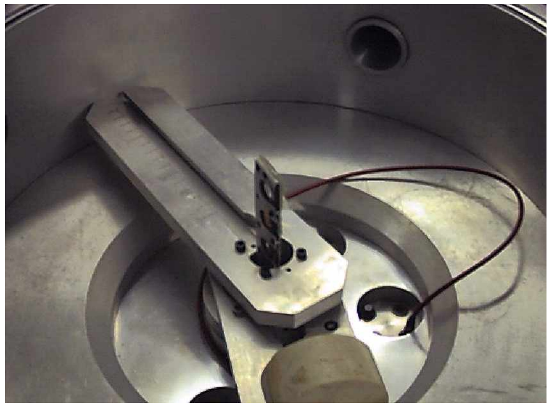

Fig. 1. The internal view of CV-28 vacuum scattering chamber, where our pCT scanner is planning to be assembled on top of the support bar.

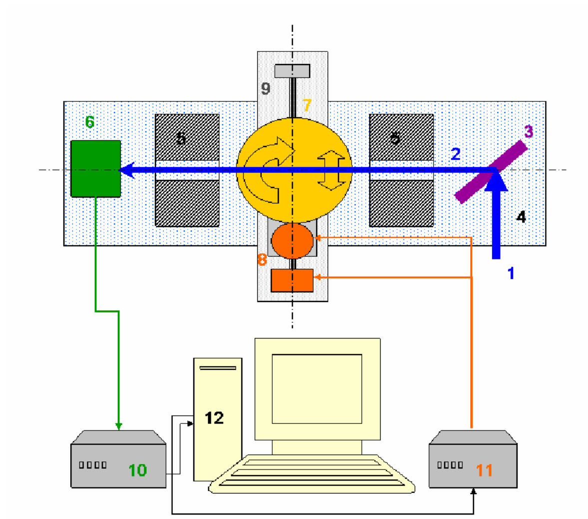

Fig. 2. The planned experimental layout: the initial proton beam from CV-28 will be reduced in intensity to an appropriate level (2) via elastic scattering on a target foil (3); the support bar (4), which appears on Fig.1, will be used to mount two collimators (5), proton detector (6) and tomographic turntable (7); two step-motors (8) will furnish the turntable with rotation and translation along the guide (9) motions; the signal from detector will be treated by readout electronics (10), and the mechanical motions will be managed by control electronics (11) under the supervision of computer code (12).

2.1 Monte Carlo Simulations

The monochromatic 25MeV proton passing through the water-filled glass tube of 5mm external and 4mm internal diameter, with a 1mm diameter polyethylene rod on the central axis, was simulated by SRIM-2003.20 computer code (Ziegler 2004). The length of parallel projection, i.e. the turntable translation interval, was assumed to be 10mm. The 10^4 proton tracks were generated for each from 25 or 100 equidistant turntable positions on the translation range. Both the energy and position of the outgoing protons were fixed in the detector plane, situated at 10cm beyond the turntable. The values of these 25 or 100 parallel projection points were taken as the mean of outgoing proton energy for a given detector collimation. Due to peculiar properties of the code, the tube was ought to be treated as a set of glass, water and polyethylene layers with the thicknesses matching a particular point geometry. The parallel projections were simulated for equidistant turntable angular positions with the angular step, determined as the smallest integer greater than or equal to Nyquist theorem prediction (Kak 2001). The tomographic images were reconstructed from these full set of projections via standard filtering back projection procedure (Kak 2001).

2.2 Simulation Results

The glass tube wall and the water fillup are clear separated on both images of the phantom cross section, reconstructed from our simulated data (see Fig.3a and Fig.4a). As far as the presence of polyethylene rod, which has only 6% less than water density, it is not well-marked. There are two reasons for this. Firstly, the mathematical features of filtering back projection procedure are responsible for some transient oscillations nearby to the density stepwise variations like glass to water boundary. This effect becomes important on the low resolution image obtained from 25 point projections (see Fig.3b). In the second place, a global image distortion due to the stopping power increasing along proton trajectory masks a smooth density variation in the center of image. The effect is similar to the beam hardening artifact in the case of conventional x-ray CT, but has an inverse manifestation: the central part of a homogeneous object comes into view on pCT image as denser, instead of rarefied in the x-ray CT case. Although both the low and the high resolution images are affected by this distortion, the last ones have a more clear demonstration of it (see Fig.4b). Finally, the statistic limitations for pCT image contrast resolution could be important, but there are no visible statistical fluctuations on both reconstructed images. Of course, the number of proton tracks was high enough, but it should be noted that, due to the multiple Coulomb scattering, a strict collimation of the detector significantly reduce the number of protons falling on detector (see Fig.5).

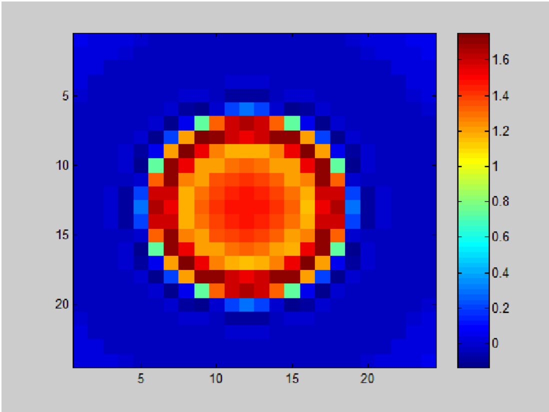

Fig.3a. The pCT image, reconstructed from 25 point projections, simulated by SRIM-2003.20. The projections were simulated at 45 equidistant angular positions with 4^o step. The initial number of protons for each projection point was 10^4.

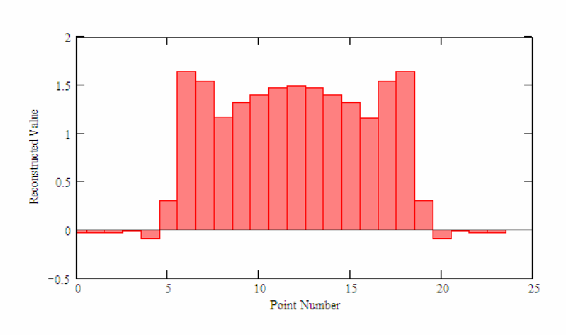

Fig.3b. The central profile of the reconstructed pCT image in the case of 25 point projections.

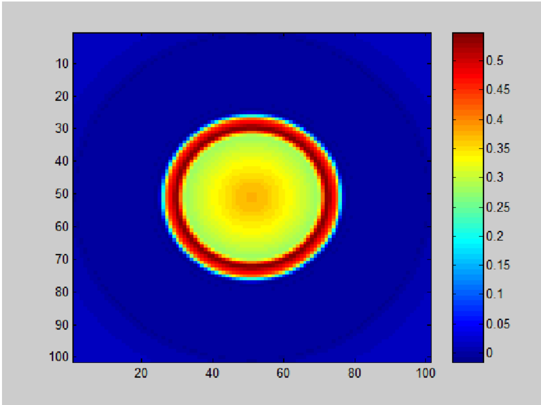

Fig.4a. The pCT image, reconstructed from 100 point projections. The projections were simulated by SRIM-2003.20 at 180 equidistant angular positions with 1^o step. The initial number of protons for each projection point was 10^4.

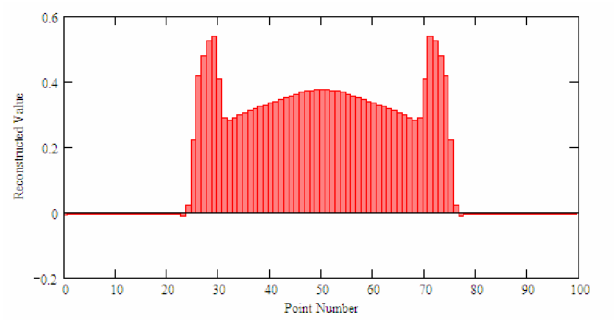

Fig.4b. The central profile of the reconstructed pCT image in the case of 100 point projections.

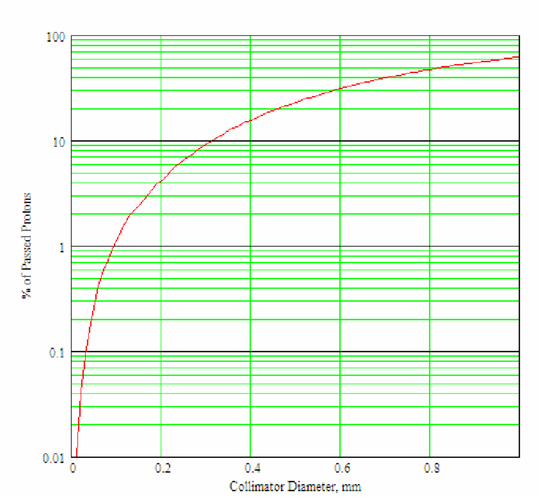

Fig.5. The percentage of protons, which could be registered, versus the diameter of collimator in front of detector, calculated for the central projection point, where the reduction due to multiple Coulomb scattering in scanned phantom has a maximum.

2.3 Discussion

It is not a fact that the real measurements will give an absolutely identical result to the simulated one. The simulation was done in the range of a very simple model, which obviously does not take into account some significant phenomena like the strong asymmetry in proton passing conditions along the sample boundaries, the degradation of energy resolution due to unparallel beam collimation, a finite precision of mechanic motion, etc. Our simulation, however, has been aimed for, and gives a quite realistic prediction for the general properties of the intend experiment. The dimensions of tomographic sample have an upper limit, determined by the mean range in matter of arbitrary low energy proton from CV-28. On the other side, the possibility to decrease the collimator hole in front of detector is restricted too: in addition to the possible degradation of energy resolution due to collimator boundary effect, an obvious trouble is connected to a huge difference in proton intensity while one will measure the projection points near and far from the sample center (Fig.5). Consequently, the main problem was to find a realistic compromise between the desire to have a reasonable high spatial resolution and the natural limitations of CV-28 facilities. It was shown that the measurements with rotation step from 1^o to 4^o, translation step from 0.1mm to 0.4mm, and the collimation from 0.2mm to 0.8mm correspondently, should reproduce the main pCT features. It defines the engineering requirements for tomographic turntable.

3. CONCLUSIONS

In spite of some significant simplifications during the simulations, the result is quite useful to design the pCT experimental setup at CV-28. This work was supported by CNPq and “Fundação Araucária”.

4. ACKNOWLEDGEMENTS

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