DEVELOPMENT OF A SCANNING SYSTEM FOR PROTON THERAPY IN UPPSALA

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Abstract

A scanned proton beam yields dose distributions that in most cases are superior to other external radiation treatment modalities, and also to passively scattered proton beams. The present paper gives a description of the scanning system that has been developed at the The Svedberg Laboratory (TSL) in Uppsala. The solution with a small polegap of the magnets and a moveable second magnet gives a very compact scanning head which therefore can be incorporated in a gantry of relatively limited size. A prototype has been constructed and tested in the 180 MeV proton beam at TSL.

1. INTRODUCTION

Proton beams usually give dose distributions that are superior to conventional external radiation therapy because of the well defined range of monoenergetic protons. The energy deposition rate (stopping power) increases with depth resulting in a dose distribution with a sharp maximum at a well defined depth (the Bragg peak). The dose beyond that depth is equal to zero [1, 2]. By varying the energy of the incident protons the entire target is covered in depth. This is usually performed with a range modulator which inserts the correct amount of material (usually plastic) in the beam degrading the energy of the protons and thereby their range.

In therapy systems with passive scattering, as used at the The Svedberg Laboratory (TSL) in Uppsala and at most proton therapy systems world-wide, range modulation is often done with a rotating absorber in the beam [3]. The variation in depth of the distal end of the target with lateral position is compensated for by a filter in the beam. Since the target in most cases has a varying lateral thickness, and the depth-modulation of the beam has to cover the thickest part of the target, the normal tissue in front of the target receives an unnecessarily high dose. This will not be the case if a scanned proton beam is used because then the depth modulation can be varied over the beam. Another advantage of a scanning system is the increased flexibility, which allows inhomogeneous fluence distributions to be created. This can help in sparing normal tissue [4].

In order to take advantage of the improved dose distributions by scanned proton beams, the treatment must be given with similar ease and freedom as conventional radiation qualities. Furthermore, in order to reduce total costs, the size of the entire radiotherapy system (gantry, patient table) must not be fundamentally larger than that used for treatments with conventional rays. A functional prototype of a scanning head allowing these requirements, has now been constructed at the TSL in Uppsala.

2. THE SCANNING HEAD

In order to deflect a proton beam, much larger magnets have to be used in comparison to the deflecting magnets used in scanning systems for electrons. Especially the second magnet has to be large because its polegap has to allow the deflected proton beam from the first magnet to pass through. This would result in a very large and heavy scanning head difficult to place in a rotating gantry. By using a large SSD, source to surface distance, it is also possible to obtain a desirable field size using smaller magnets. However, the use of a large SSD results in difficulties in obtaining a small beam at the patient surface and would also require a very large gantry design.

The chosen design of the scanning head, at the TSL in Uppsala, is with a moveable second magnet which is put into a cradle with its rotational centre in the first magnet. By a proper design of the first magnet both the deflection angle and exit position of the beam from it can then correspond to a certain position of the second magnet resulting in a beam which is in the centre throughout the polegap of the second magnet [5]. Because the mechanical motion has to be synchronised with the magnetic deflection of the beam in the first magnet during the scanning procedure, the horisontal speed of the scan is limited. Therefore the first magnet, which scans parallel to the gantry axis, yields the slow part of the scan and the second magnet, which scans perpendicularly to the gantry axis, the fast one. Since the polegap of the magnets in the present design is only 1.0 cm they are small and the scanning head extremely compact. The magnetic field in the magnets are 1.8 T which for a proton beam of 200 MeV and a SSD of 1 m yields a field size of 30 by 30 cm.

To position the Bragg peak at the specified depth, a range modulator is placed directly after the second magnet. It consists of a number of plexiglas slabs with varying thickness which in different combinations are pushed into the beam by compressed air. The change of range modulation is done after the magnetic scan at each depth is finished and is consequently the slowest part of the scanning procedure.

In treatments with a scanned proton beam the total prescribed dose to the target is given with a number of scans, each with a constant setting of the range modulation. In general the particle fluence for each scan has to be inhomogeneous, even if a constant dose is required in the target.

Due to the mechanical movement of the second magnet, it is not possible to use a spot scanning technique. The reason is that it would require high mechanical accelerations of the second magnet, causing vibrations and mechanical stress in the bearings. Therefore, the second magnet moves continuously during the scan.

4. THE CONTROL SYSTEM

When using a scanning system it is much more complicated to verify that a treatment is given as planned in comparison to systems using passive scattering, as numerous variables have to be monitored continuously during the treatment. The control system is complex as it must contain several separate systems in order to assure full control of the treatment even if one of them should fail.

The treatment is controlled from a computer which for each proton pulse from the cyclotron reads out several parameters (*e.g.* the currents in the magnets, the position of the second magnet, and the charge of the proton pulse before entering the gantry and scanning system and after exiting, as well as its position at exit). These parameters are then compared with precalculated values, and if any deviation is found, which can not be compensated for during the scan, the treatment is interrupted. The treatment can then be continued later where it was interrupted since the parameter values are continuously stored in a log-file during the treatment.

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