COMPROMISE SYSTEMS FOR TRANSPORT PROTON AND ION BEAMS IN MEDICAL AIMS

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Abstract

A center of treatment by proton and ion beams must be equipped by a few (4-6) treatment rooms and in most of them must be used equipment for choose optimal directions of irradiation. Usually it is gantry. In gantry patient is immovable and any directions of irradiation are possible. But any modern gantry are so large, complex and expensive, that it is necessary to suggest new solutions – more compact, less heavy, less expensive, but with enough wide choose of direction of irradiation. Similar system can be designed only with compromises: with displacement of treatment coach at horizontal position of the patient and at limited directions for irradiation. Planar systems are seems as most suitable for treatment centers. Layouts of proton and ion centers with 5-6 treatment rooms equipped by planar systems at hot magnets are suggested.

INTRODUCTION

The number of patients requiring beam therapy is very high. Future centers for medical irradiation by proton or ion beam should be highly effective and it requires 5-6 treatment rooms that use one accelerator and are able to have high quality irradiation for every room.

It is necessary for successful treatment in most cases to choose direction of irradiation and change this direction several times within one fraction of treatment. The second important condition of optimal irradiation is to use active dose distribution on the target volume (3-D scanning by the narrow beam).

Equipment used today to provide these conditions is called gantry. Gantry consists of a beam transport channel with magnets for beam scanning placed on the rotatable frame. Classical gantry, according to the medical requirements, assumes that horizontally fixed patient is placed immovable with center of the target at center of irradiation, at the axis of frame rotation Any directions of irradiation are available via frame rotation. But any modern gantry are so large, complex and expensive, that it is necessary to suggest new solutions – more compact, less heavy, less expensive, but with enough wide choose of direction of irradiation. Similar system can be designed only with compromises: with displacement of treatment coach at horizontal position of the patient and at limited directions for irradiation. It is important to highlight that availability of any direction (as it is using gantry) is not necessary. Three versions of compromise solutions were observed.

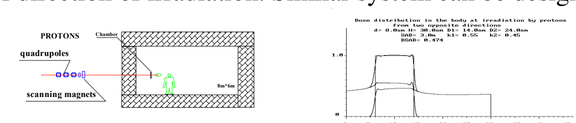

Figure 1. Scheme of treatment room with horizontal beam and scheme of doses distribution at irradiation from two opposite directions.

EQUIPMENT WITH FIXATED DIRECTIONS OF THE BEAM

Simplest equipment with fixated direction is a horizontal beam. There is clear defect of similar system. Doses level in healthy parts of the body is comparable to doses into the target at irradiation in only one direction targets with large sizes. So, it is very useful to produce irradiation from two or three directions. At horizontal beam doses level can be decreased two times at irradiation by two opposite directions after rotation of treatment table around of vertical axis (see Figure1). But volume of irradiated healthy parts of the body will be increased more then two times. Sometimes the second direction of irradiation at horizontal beam is closed by value of maximal range (30cm) or by medical reasons.

There are systems with beam transport to patient from vertical or bent directions. Sometimes the beam can be transport from two directions in one room, in one common iso-center. Two directions have more possibilities in comparison with one direction, but quantity of possible directions are small and magnetic channel for similar system has magnetic optic and volume of the room comparable to gantry. Increasing of quantity of transport channels with different fixated directions of irradiation to one iso-center does not seem as optimal solution.

ECCENTRIC GANTRY

For decreasing diameter of rotated heavy equipment in gantry it was suggested to rotate it around of the axis which pass through center of heavy mass and displaces treatment table with horizontally fixated patient around of magnets in order to direction of bended beam pass through the target center (see Figure 2).

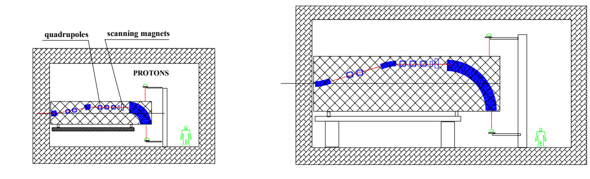

Figure 2. Spatial schemes of eccentric gantry for proton and ion beams.

In such eccentric gantry design diameter of heavy rotated equipment is like to radius of particles bend in magnetic field (at 1.6Tl R=1.4m for protons and R=4m for ions). So, in comparison with usual gantry mechanical difficulties will be significantly decreased. Treatment table must be displaced in vertical plane around of circle with radius like R/2+1.5m (2.2m for protons, 3.5m for ions). An industrial manipulator or similar device can be used in all versions of transport system for precision displacement of horizontally fixated patient. As result, direction of the beam after bends into gantry must pass through center of the target. Optical scheme of eccentric gantry is similar to usual gantry and any directions can be used for irradiation. Of course, it is compromise solution with displacement of treatment table on significant distances.

EQUIPMENT WITH BENDS OF A PATIENT BODY

Transport systems with bends of treatment coach or table around of vertical axis, which pass through center of the target, are well known and it used usually for targets placed into the head. Only like 10% of targets placed into the head.

V.Balakin suggested rotation patient in vertical position around of the vertical axis. For treatment by such equipment each patient must be in rather good condition and specific “vertical” tomography is necessary.

B.Astrachan suggested fixation of the patient into rigid thin cylinder between two air bags and then rotation of this cylinder. Unfortunately, such fixation is very uncomfortable to the patient.

Those methods are not universal.

SIEMENS company suggested bends of treatment table with fixated patient around of horizontal longitudinal axis on limited angles for increase possibility of transport systems with fixated directions of the beam (see Figure 3). But even at rotation like 10 degrees there are displacements of inner parts of the body. Therefore firm SIEMENS suggested after each rotation to use additionally movable tomography and recalculation of plan of irradiation. Similar systems will be installed in two new centers of ion therapy in Germany. But each tomography and planning take some time in treatment room, and some unnecessary irradiation will be caused by every tomography (after each rotation into each fraction). Of course, it is interesting compromise solution.

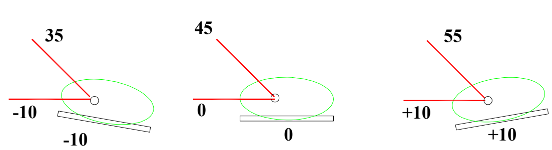

Figure 3. Scheme of possible directions of irradiation at two fixated directions of the beam and at rotation of treatment table.

PLANAR SYSTEMS

Planar systems are based on bends of the beam by immovable magnets only in vertical plane simultaneously with displacements of treatment table with a patient, which fixated horizontally. Bended beam is directed to the center of a target and plan of irradiation is saved.

SIMPLE PLANAR SYSTEM, SPS(F)

A magnet with increased gap is placed in a room with initially horizontal beam just in front of patient for bend of the beam only in vertical plane. Size working gap of the magnet is equal to maximal sizes of the target (20cm*20cm). The beam can be bend from horizontal plane at any angle f according of magnet strength, in limits –F < f < F. Treatment table with horizontally fixated patient is displayed in vertical plane after any changes of beam direction (see Figure 4). Angel F is main compromise of SPS(F). As bigger F the efficiency of SPS(F) is close to gantry, but with large magnet and large treatment table displacements. The second compromise is displacements of treatment table with patient.

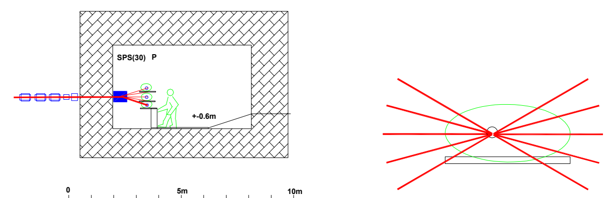

Figure 4. Scheme room with SPS(F).

SPS(F) can be designed with hot magnets for proton and ion beams in many versions. Super conductive magnet with $B \leq 5$Tl can be useful for decreasing sizes and weight of SPS(60) for ion beam (see Figure 5).

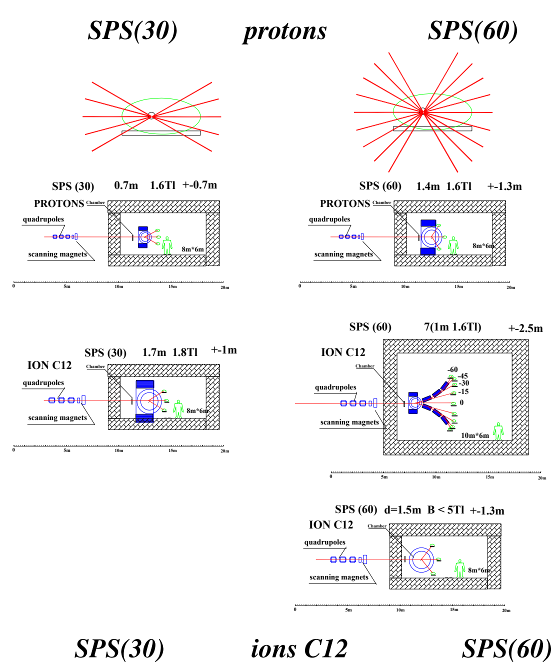

Figure 5. Spatial schemes of Simple Planar Systems.

Optical scheme of SPS(F) in comparison with gantry optical scheme is rather simple. Symmetrical input beam is not necessary.

PLANAR SYSTEMS WITH PRELIMINARY BENDS OF INITIAL BEAM IN VERTICAL PLANE

Spread of directions for irradiation by SPS(F) can be changed by preliminary bends of the beam on angle H in vertical plane from -F < f < F to -F+H < f < F+H by using additional magnet with small gap. In such conditions SPS(F) must be installed along of direction of bended initial beam (see Figure 6).

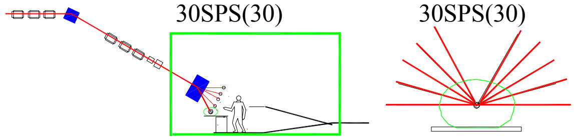

Figure 6. Scheme a room with SPS(F) and preliminary bend of initial beam.

Preliminary bends of the beam can be used for transport beam to a few treatment rooms placed on different levels. Preliminary bends of the beam can be used for increasing total spread of directions in systems with a few treatment rooms equipped by SPS(F) with small value of F. For example, it is possible to design two treatment rooms with SPS(30) into each. Initial beam direction in the first room is horizontal. Initial beam direction in the second room is H. Total spread of directions for irradiation in system of two rooms is (-F < f < F) + (-F+H < f < F+H). Each room can be used as separate treatment room with its spread of possible directions for irradiation. It can be useful at design of ion transport system at hot magnets.

CENTER OF PROTON THERAPY WITH 5 ROOMS EQUIPPED BY SPS(60)

For center of proton therapy with high productivity at enough high quality it was suggested to use 5 treatment rooms near one accelerator (see Figure 7). Magnet for protons SPS(60) can have the length like 1.3m at maximal field ≤1.8Tl and working gap 20cm. For displacement of treatment table (±1.4m) each room must be equipped with specific (industrial) manipulator. Each room equipped by scanning system. Approximately the same scheme can be used for center of ion therapy at using in each SPS(60) super conducted magnet (diameter 1.3m, gap 20cm, maximal field less 5Tl).

CENTER OF ION THERAPY WITH 6 ROOMS EQUIPPED BY SPS(30)

Radius of ion with maximal energy rotation in field 1.8Tl is 3.5m. Therefore sizes, weight, power of hot magnet for SPS(60) will be unsuitable. It was suggested to use pairs of rooms on two levels with SPS(30) into each. Spread of directions into each room (60 degree from two sides) is enough large for using each room as independent treatment room in most fractions for any patients. For center therapy with high productivity at enough high quality it was suggested to use 3 pairs of treatment rooms near one accelerator (see Figure 8). Magnet for ion SPS(30) can be with length like 1.7m and maximal field like 1.8Tl at gap like 20cm For displacement of treatment coach (dZ < ±0.9m) each room must be equipped with specific (or industrial) manipulator. Each room equipped by scanning system.

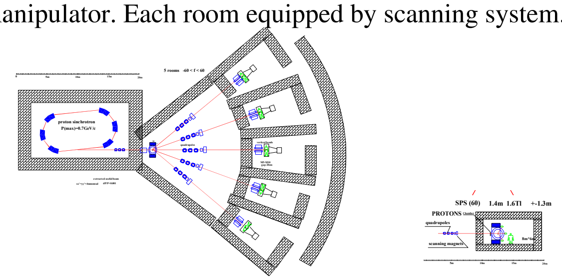

Figure 7. Scheme of transport system for proton therapy center with 5 treatment rooms.

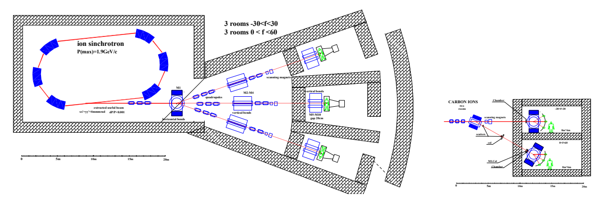

Figure 8. Scheme of transport system for ion therapy center with 6 treatment rooms.

Medical ion accelerator and its transport system (P/Z≤1.9GeV/c) can be used for acceleration and transport of proton beam (P/Z≤0.7GeV/c). But using more complex and more expensive equipment, than necessary, does not seems to be the best solution.

Two different accelerators with its two different transport systems need for optimal center of therapy by protons and ions beams.

Next possibility is using two extraction directions from common ion accelerator and two different transport systems with 5-6 treatment rooms in each (see Figure 9).

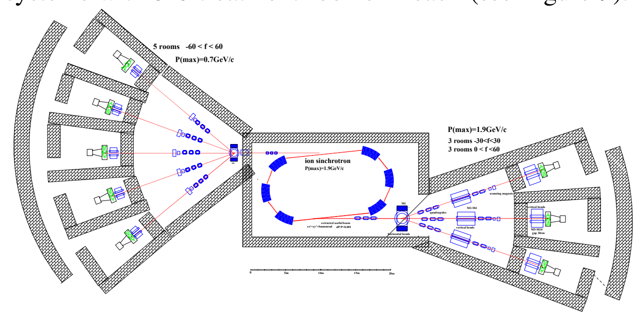

Figure 9. Scheme of transport system for proton and ion therapy center.

CONCLUSIONS

The most perspective solutions of transport systems for center proton and ion therapy are based on planar systems in its various modifications.