COMPACT AND NON EXPENSIVE TRANSPORT SYSTEMS FOR MEDICAL FACILITIES USING PROTON AND ION BEAMS

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Abstract

All known ion beam transport systems for medical applications with or without gantry are very large, complicated and expensive. Its cost is comparable with facility accelerator itself. It stimulates search of beam transport and distribution systems that allow reducing their cost and sizes considerably keeping treatment efficiency. Two such transport system are considered in the present paper. The first one is based on bend magnets that are rotated around their center of mass with movement of patient in horizontal position around of magnets. The second one uses stationary magnets with movement of patient in horizontal position in vertical plane. It is shown that the proposed ion transport systems provide treatment efficiency comparable with gantry at considerably lower sizes, mechanical complexity and cost.

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 several treatment rooms (for example 5) 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 consist 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 (Figure 1). Any directions of irradiation are available via frame rotation.

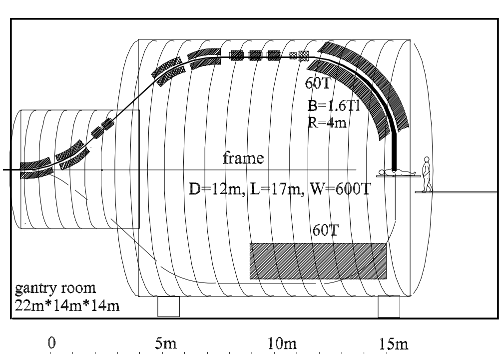

Figure 1: Gantry for ion beam with warm magnets.

This equipment requires very large space for placement. A typical room measuring is about 20x14x14 m (like a five-story building), the rotatable weight comes up to 600 tones. It requires up to 1 megawatt of electrical power and it costs approximately €30’000’000. It is impossible to design considerably smaller, simpler and less expensive gantry with those requirements.

Obviously, there is a necessity to find a better solution.

COMPROMISE EQUIPMENT REQUIREMENTS

In order to choose optimal irradiation direction main part of treatment rooms should allow multiple directions. It is important to highlight that availability of any direction (as it is using gantry) is not necessary. It is possible to change irradiation direction discretely (for example with a 5 degrees pitch) instead of continuous change.

The requirement of patient immobility in one position (as in GANTRY) is also not obligatory. Patient fixed on the horizontal treatment table may be transported slowly by moving the treatment table in new position. It can be done in absence of irradiation during the change of beam direction. Precise beam position (within ±0,1 mm) can be achieved by accurate turn of the beam direction and accurate displacement of the treatment table. Exact match between the beam and the target centre can be confirmed by usual instruments that are displaced towards the beam direction together with the treatment table.

Irradiation directions may vary during different irradiation fractions (days of irradiation).

These conditions allow to design systems of beam transport that can provide beam parameters comparable with gantry with much lower sizes and cost.

ECCENTRIC GANTRY

The main idea is decreasing the rotation diameter of heavy magnets and necessary equipment. Magnets rotation axis goes through their center of mass (Figure 2). The diameter of heavy rotatable equipment is equal to the radius of beam turn within the magnet plus about a half of the magnet width. The diameter is about R = 2m for protons and R = 5m for ions. The patient is moved on a treatment table alongside circle with 5m diameter for protons and 8m diameter for ions. Combination of rotatable equipment and movable patient are much easier in terms of mechanical design. Quick access of personal to the patient can be designed at any position of treatment table.

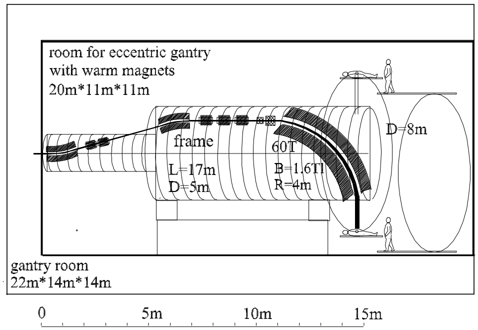

Figure 2: Eccentric gantry for ion beam with warm magnets.

SYSTEMS WITH SUPERCONDUCTING MAGNETS

Systems with superconducting magnets do not have considerable advantages in transport of protons. However for heavy ion beam they can reduce the size of equipment, rotating weight and the power consumption, but not the overall cost.

Eccentric Gantry for Ion Beam with Superconducting Magnet

The diameter of heavy rotating equipment is only R=2 m. Patient is moved alongside the circle with D= 5 m. It makes easier an access to the patient (Figure 3).

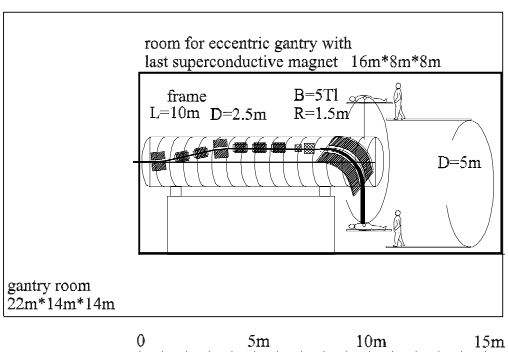

Figure 3: Eccentric gantry for ion beam with super conductive magnet (5Tl).

PLANAR SYSTEMS

Beam turns are provided in planar system only in vertical plane by using stationary magnets.

Simple Planar Systems SPS(F)

Instead of using gantry, a treatment room with the usual horizontal beam has additional stationary magnet placed in front of the patient. The magnet has increased gap (up to 20cm.) for scanning. The magnet is used for beam turn in the vertical plane against the horizontal plane on any angle f, which is within -F < f < F. The patient is fixed in the horizontal position on the treatment table and is moved in the vertical plane towards the beam direction when the irradiation direction changes and the beam is switched off (see Figure 4). F angle is chosen by compromise. Bigger F provides SPS(F) system the capacities close to gantry, but it also requires bigger and heavier magnet and more moving for the patient. Medical staff can always access the patient in any position of the treatment table using the stairs from permanent floor to floor around of the table. New patient is placed on the treatment table when the beam is switched off and the stair is in the horizontal position.

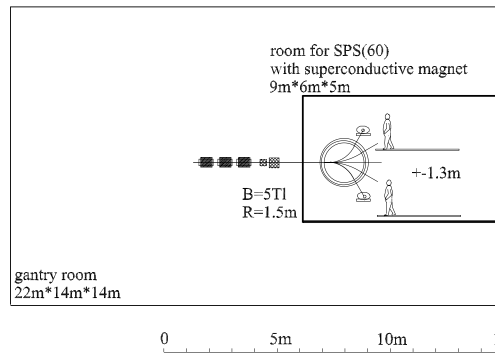

Figure 4: Simple Planar System SPS(60) for ion beam with superconducting magnet.

The first disadvantage of this system is the coupling of transport channel regime and the irradiation direction. The second one is unbalanced linear dispersion in plane of turn. The irradiations in top-down and bottom-top directions into cone with angle (90°-F) are impossible. The more important disadvantage of all planar and eccentric systems is that patient is movable that is unusual for medical staff. According to medical opinion the patient must be fixed in a way that allows the target center to remain in one point and the beam must be rotated around the patient. This opinion does not have any physical base.

SPS(F) can be designed in different versions using warm as well as superconducting magnets for proton and ion beams (see Figure 5) without any difficulties.

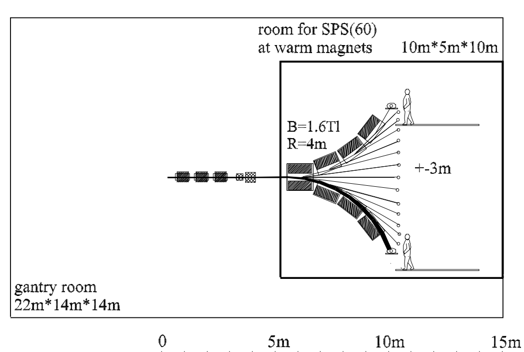

Figure 5: SPS(60) for ion beam with 7 small warm magnets.

The size of a treatment room with SPS(F) does not depend on the equipment that provides the beam. Mainly they depend on the space that is required to serve the patient. Comparing with the classic gantry scheme, the volume of required room is 10 times smaller. Magnetic optic of SPS(F) is much more simple in comparison with gantry. The average power supply for magnets of SPS(60) is 10 times less. It is due to total turning angle of beams in gantry for any irradiation directions is always 180 degrees, angle for SPS (and the power) depends on the direction. The average beam turn for SPS(60) can be estimated as 30 degrees. The first magnet in planar systems can have a reduced gap. Instead of rotation with high precision of heavy frame with magnets in gantry, SPS uses simple small stationary magnets and simple slow displacement treatment table (with weight not more then 300kg) in vertical plane. It allows to keep horizontal position of the patient, and all results of tomography and planning. Unbalanced beam dispersion can influence the vertical beam size only with big turns of the beam in SPS and with big variations of particles energy into the beam. It is not significant for beam after slow extraction from synchrotron ($dP/P=\pm0.1\%$). Patient displacement (on a treatment table) between fixed positions and the direction pitch equal for example 5 degrees can have a precision better then ±0,1mm. In order to achieve better beam precision in the target point it is possible to use device of nuclear magnetic resonance (NMR) to control magnet fields with precision $\pm10^{-4}$.

Obvious simplicity, compact size, low power consumption and low cost are the advantages of the simple planar system.

Comparing Available Irradiation Directions for Various Types of Equipment

Any target can be irradiated through SPS(60) with approximately the same result as use conventional GANTRY (Figure 6).

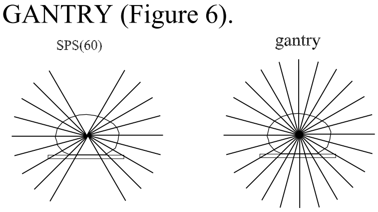

Figure 6: Comparison ability of SPS(60) and gantry.

SPS(60) has the advantage in comparison with equipment with one or two fixed directions for irradiation. SPS(30) has considerably better abilities comparing with those of a horizontal beam (Figure 7).

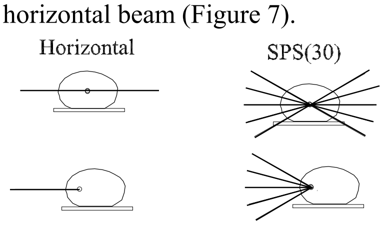

Figure 7: Comparison ability of horizontal beam and SPS(30).

New Planar System

The performance of SPS (F) may be improved using the preliminary beam turn in the vertical plane (Figure 8). It allows to choose optimal range of directions (with less direction from below) F+A>f>-F+A instead of F>f>-F and to compensate the linear dispersion.

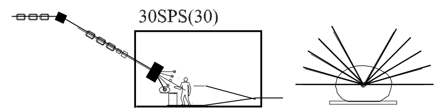

Figure 8: Scheme of planar system with preliminary bend.

The preliminary beam turn in the vertical plane can serve as a channel for transport of the beam into the required treatment room. New Planar System uses preliminary beam turn in the vertical plane for transporting beam to several treatment rooms that are placed on different levels and have SPS (F) systems inside (Figure 9). Magnets with small gaps can be used for the preliminary beam turns. SPS(F) systems with small F values use magnets with increased gaps, but with relatively small weight and power consumption. Each SPS(F) is positioned towards the beam coming into this room. Every room has its own range of available irradiation directions. The use of several rooms helps to provide any required direction of irradiation. This system with several treatment rooms occupies very small space within the building; it is very attractive in the number of magnets and the power consumption.

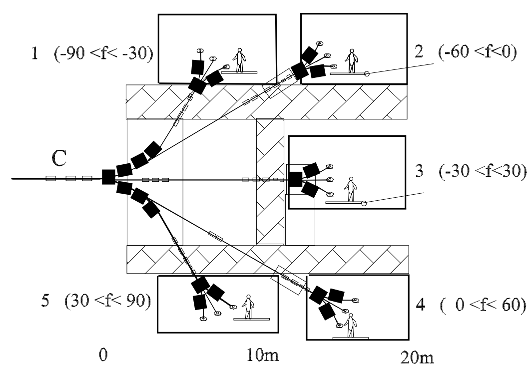

Figure 9: Scheme of New Planar System for ion beam with warm magnets with 5 treatment rooms in vertical plane and possible directions of irradiation for each room.

CONCLUSION

Wide use of proton and ion beams for medical purposes today is limited by the huge size, cost and complexity of equipment, especially of beam transportation systems from the accelerator to the patient. New solutions are vital to simplify design of all future centers of proton and ion therapy.

The most perspective solutions are the planar systems in its various modifications.

It is useful to upgrade every existing system with horizontal beam by means of the SPS(30).