

GANTRY FREE TRANSPORT LINE FOR A PROTON/ION THERAPY

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Abstract

For a long time a gantry was considered as a mandatory element for proton/ion therapy facility. However medics from MGH (Boston) suggested alternative concept which leads to decrease both cost and size of the facility [1]. The concept is based on the following provisions:

- immovable isocenter;
- active scanning of a target volume;
- different positions of patients at different fractions:
- using CT on the place of irradiation after each change of positions of the patient for improvement plan;
- using small change direction of the beam (like $\pm 10^\circ$).

The "Planar isocentric system" developed by author can be used to enlarge the flexibility of the concept [2]. It's relatively chip, small and can be realized for short time. It can be used for treatment for 90% of localizations. The system can replace gantry in centers of proton/ ion therapy providing significant decreasing of treatment price. The details of the system are presented and discussed.

INTRODUCTION

A therapy by beams of protons and ions is the technology of the twenty-first century. It is effective and necessary method to save human life. Its benefits in a cancer radiation therapy were known for a long time (see Figure 1). It is implemented in the radiation treatment for 20 years. But with the current technology today and in two years later the proportion of patients to whom it can be applied is about 1% of patients who are treated with beams of gamma rays [1-3].

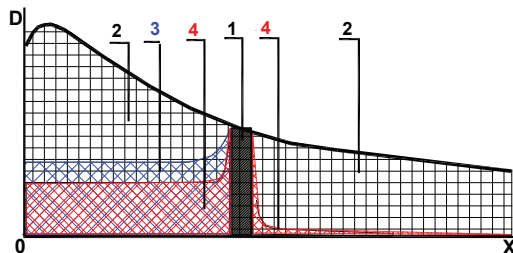


Figure 1: A scheme of energy distribution in the patient's body at irradiation by one direction at using different beams. 1 - target, 2 – gamma, 3 - protons, 4 - ions.

To generate beams of protons and ions useful for the treatment and for the further transportation of the beams to the patient it is necessary to use expensive and bulky equipment. Therefore, the treatment by proton and ion beams is significantly more expensive in a comparison with the treatment by gamma rays. In USA insurance companies pay now for the use of this treatment only for certain cancer locations, which need particularly

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important accuracy dose distribution (e.g., eyes), or for children treatment in order to prevent (on many years) reactions on small doses in healthy parts of the body.

In the world specialists are searching for more compact and less expensive equipment for proton and ion therapy. Compact and easy to use accelerators with superconducting magnets have been proposed. But beam transportation systems to the patient from different directions stay still bulky and expensive. Why a choice of directions of irradiation is necessary? In order not to irradiate those parts of body that must not be irradiated, and to spread the inevitable release of the energy in healthy parts of the body in a large volume, to different organs, in order to remain them at a relatively safe level.

Many years ago doctors formulated requirements for such equipment: the patient lies horizontally, motionless, the beam is transported from any direction of the plane perpendicular to the longitudinal axis of the patient. Systems that implement these requirements are generally called as a gantry. The gantry is expensive and bulky equipment because conventional electromagnets can rotate a beam of protons with a radius of about 1.5m and a beam of ions with a radius of about 4m. As a result, the standard gantry for proton's has a size of about 10m³ and the weight of the equipment rotated precisely in this volume is about 100t. Similar parameters of the HIT gantry for ion beam transport is 13m*13m* 18m and 660t. An optimal scheme for the proton's gantry is shown in Fig. 2.

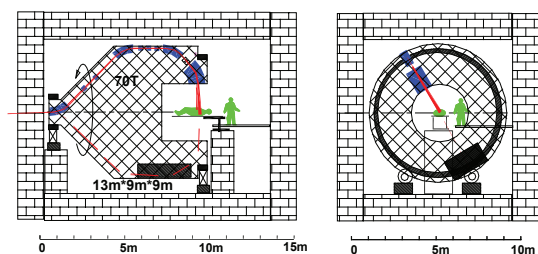


Figure 2: An optimal scheme of the gantry for a proton beam.

A significant part of the cost of a treatment is associated today with gantry systems (up to 70% for centers with four gantries). Attempts to develop a simple low-cost compact gantry based on superconductivity had not real success so far. A special conference of experts of this topic took place in the autumn of 2015 in Switzerland [4]. The problem is the necessity of fast enough distribution of the beam energy for the target volume ("scanning").

It were proposed in the form of compact "one room's" complexes by IBA, VARIAN, MEVION firms during recent years. But these complexes with one accelerator

and one treatment room can work only with beams of protons, have a limited annual productivity and can not significantly reduce the price of the treatment.

Does a therapy by proton and ion beams have a real future in a competition with a gamma therapy? Yes, if its treatment cost will be comparable to the cost of treatment by gamma rays. Much less expensive and more compact equipment is necessary instead of the gantry.

PREVIOUS SOLUTIONS WITHOUT GANTRY

V.E. Balakin proposed a system with a fixed horizontal beam, which is directed to the standing or sitting patient (see Figure 3). An initial horizontal beam is focused by quadrupole lenses and deflected by scanning magnets. The patient turns around a vertical axis in this system to change the direction of irradiation. A CT scanner with vertical displacement was proposed to control the shape of the body and of the target.

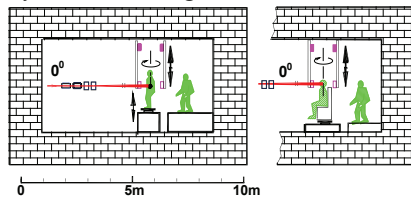


Figure 3: Balakin's scheme of changing the direction of irradiation.

In 2002 we proposed a "Simple Planar System" - "SPS (F)" [5]. Initial horizontal beam is focused by quadrupole lenses and deflected by scanning magnets too. A fixed magnet with increased gap is used to bend the beam in a vertical plane at an angle of less than F. A treatment table (with the patient fixed on it) is shifted in the vertical plane so as the rotated beam hits the target (see Figure 4). It is compact system with a possibility to change direction of the irradiation in the interval $(-F < f < +F)$. A CT scanner shifted vertically together with the treatment table was proposed to control the shape of the body and the target. The scanner has additional possibilities of horizontal displacements.

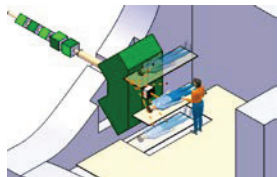


Figure 4: Three dimensions scheme of a simple planar system.

NEW REQUIREMENTS AND A NEW SOLUTIONS

In 2016, the doctors of MGH (Boston) analyzing the experience of a treatment of 4300 patients with different cancer localization [6], take thought about the appropriateness of the cumbersome and expensive gantry

and its replacement by a new equipment with the following requirements to it:

1. Motionless irradiation center.
2. An active dose distribution in the target volume (scanning).
3. The admissibility of various positions of the patient in different fractions (the patient lying with limited $(\leq \pm 15^\circ)$ turns of the table relative to the horizontal longitudinal axis of the patient or if the patient is sitting under rotations around of the vertical axis).
4. The use of a CT scanner in the place of irradiation after each change of the position of the patient.
5. The use of beam direction changes in a small interval (like $\leq \pm 10^\circ$).

In addition to the new doctor's requirements we proposed in 2016 the use of a "Planar Iso-centric System" with a fixed irradiation center and with three significantly different fixed beam directions in the vertical plane ("PIS"). The patient in this system can be irradiated both in lying and sitting positions. Each additional magnetic channel has small magnets and a simple optic. The patient can be irradiated from its second side in the next fraction. (About 20 fractions are in treatment process). A lot of designs versions are possible (see Figure 5 for example).

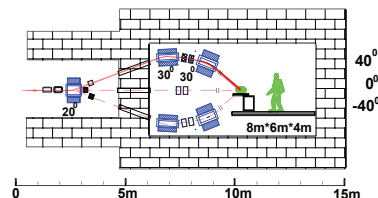


Figure 5: A scheme the PIS for a proton beam with three fixed directions.

Compared with the conventional gantry system in PIS at the beam direction of $\pm 40^\circ$ the beam rotation into PIS is decreased from 180° to 80° . There is no complex and expensive mechanical system for precision turns of heavy magnets in a large volume and no complex magnetic focusing of a beam. There is no practically power consumption at the irradiation in a horizontal direction. The position of the scanning magnets allows reduce the weight, power and cost of the last magnet at saving scanning distance of about 3m. This limits the weight, power and cost of the entire PIS system. Dimensions of a treatment rooms with the PIS system are mainly determined by the patient's comfort transportation and installation to the working position. They are 5-10 times smaller than the dimensions of the room for the gantry.

Small rotations (like $\leq \pm 15^\circ$, without discomfort to the patient) of the treatment table around a horizontal axis with the fixed lying patient can be used under the control of a body shape and a target by sliding horizontally the CT scanner to increase a possibility directions of the irradiation (see Figure 6).

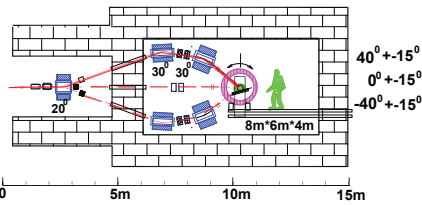


Figure 6: A scheme of the PIS with the patient lying on an inclined table under the control by a CT scanner.

A treatment armchair with sitting fixed patient can be rotated around a vertical axis under the control of the body shape and the target with shifted vertically CT scanner (see Fig. 7) for the expansion of choices of the irradiation direction in addition to three fixed directions.

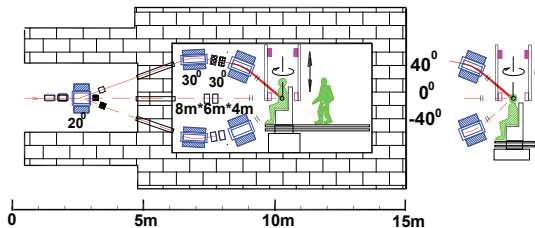


Figure 7: The scheme of PIS with sitting patient and with a CT scanner sliding vertically.

Using the PIS allows for any selected fixed position of the patient after one application of a CT scanner to clarify irradiation plans for all three possible directions of the irradiation. The proposed system allows to choose different directions of the irradiation in different fractions in a rather wide spread for the treatment of any cancer sites.

PIS SYSTEM FOR ION TRANSPORT

The same system can be easily realized by using more long warm magnets for the transport of ion beams. It has low cost, small size and low power consumption compared with all versions of a gantry (see Fig. 8), even in comparison with HIMAC gantry based on superconductive magnets.

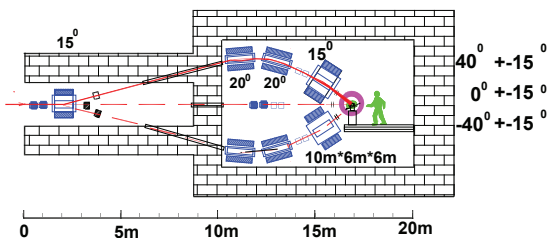


Figure 8: The scheme of PIS for ion beam with warm magnets.

CONCLUSIONS

The main progress in the radiation treatment in the future can be produced by a wide use of a proton therapy instead of a gamma therapy. For this purpose it is necessary to design compact and not expensive systems for the beam transportation to a patient by many spatial

directions, to reach the price for a treatment by a proton beam comparable with the price of a treatment by a gamma equipment. Construction of a new gantry is not useful for this aim. New solution of a transport system (PIS) was suggested here instead of a gantry according to a new medical requirements. It used three beam directions in vertical plane with fixed center of irradiation at scanning the target volume. It used different positions of the patient in different fractions under the CT scanner control. For change direction of irradiation at sitting position of a patient the treatment chair can be rotated around of the vertical axis. For change direction of irradiation at a lying position of a patient the treatment table can be rotated on limited angles around of the horizontal axis. Three independent directions of irradiation are possible in any fraction at any fixed patient position. PIS ideas can be used to design more compact systems for ion transport by usual magnets.

An future equipment for low cost cancer therapy by proton beam can be designed on base of one simple accelerator with transport its slowly extracted beam to many (4-6) treatment rooms equipped by PIS systems.

The center of proton therapy with similar equipment is necessary in Moscow now.

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