STUDY OF GANTRY OPTICS
FOR PROTON AND CARBON ION BEAMS.

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Abstract

GANTRY magnet optic schemes are proposed for transportation of proton and carbon ion beams. There is a possibility of active scanning of the target surface 200mm*200mm with parallel beam. GANTRY has small size and weight (L=9m, D=7m, 20-60t for protons and L=15m, D=11m, 50-160t for carbon ions). This scheme can use beam with emittance at least up to 10^{-5} mrad having the same weight and size.

1 INTRODUCTION.

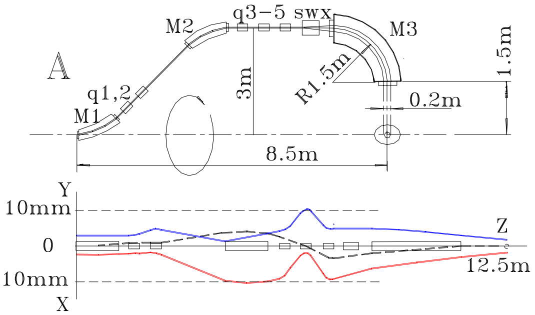
GANTRY dose delivery systems are now acknowledged as a necessary part of a medical hadron therapy facility. Since GANTRY is a most expensive part of such a facility, it's parameters should be carefully chosen and optimized [1,2].

This paper presents new optic scheme of isocentric GANTRY equipped with the active dose delivery systems for beams with phase space of the order of 3mm*mrad and momentum spread dP/P=0.5%. Only warm magnets are considered. The geometry of "barrel" type GANTRY [3] was chosen as a prototype for this design, but optic scheme is new. It was assumed that the beam has circular shape in initial point. There are no quadrupoles before M1.The beam is bent with three magnets (M1, M2, M3) at -45, 45 and 90 degrees correspondingly, is focused by five quadrupoles (q1-q5) and swept by two scanning magnets (swx and swy). For active scanning of the target surface fast beam movement in one direction in the bending plane is proposed. After the irradiation in full depth in first version of GANTRY the coach with patient is moved slowly (up to 2 cm/sec) in second direction and procedure is repeated. In second GANTRY version there is scanning of the target surface in two directions with two scanning magnets.

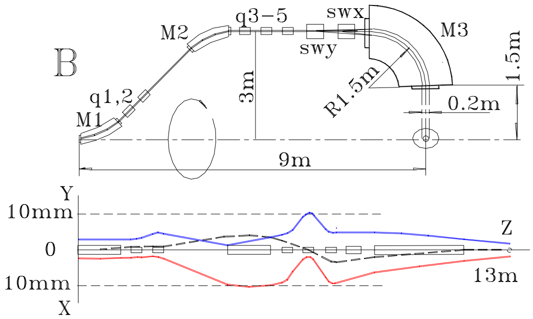
2 GANTRY DESIGN

Figures 1-2 presents the layout of the GANTRY elements in bending plane. Main beam parameters, GANTRY overall dimensions and weight, scanning system, optical schemes and magnetic element parameters are also presented on these figures. TRANSPORT computer code was used for optics calculations [4].

First the beam path from scanning magnets to the exit from magnet M3 is considered. In order to achieve quasiparallel (with the angles less than 0.005 rad) beam scanning, centers of scanning magnets should be located near to the points of the reverse broad beam focuses. Magnetic field gradient $n= -(dB/dR*R)/B$ and/or yoke angles can be chosen as parameters for the optimization [5,6]. Small defocusing values of n (of the order of 0.4) in magnet M3 were used for schemes presented on Fig.1-2.



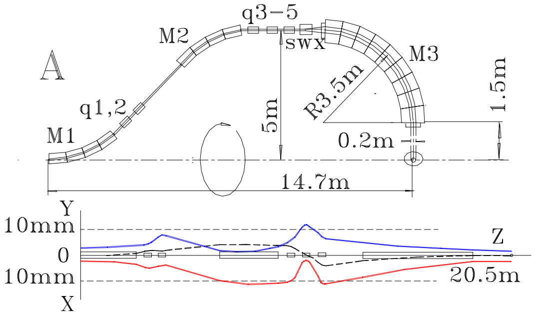
A. Fast electromagnetic scanning in X direction,
mechanical scanning of treatment coach
on 200 mm in Y direction,
X*Y(M3)=20mm*240mm, weight(M3)=5t,
total rotated weight is about 20t
total sizes - L=8.5m, D=7m.



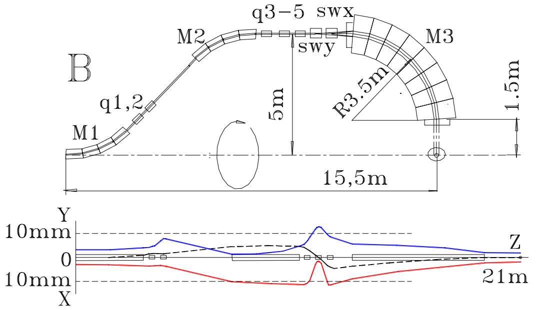
B. Electromagnetic scanning 200 mm in X and Y directions.
X*Y(M3)=200mm*400mm, weight M(3)=20t,
total rotated weight is about 50t,
total sizes - L=9.0m, D=7m.

Figure 1. GANTRY for proton beam.
P<0.73GeV/c,
X*X'=Y*Y'=3mm*1mr, dP/P=±0.2%
B(M1-M3)<1.65Tl, X*Y(M1)=X*Y(M2)=20*50mm,
weight (M1) = weight (M2) =0.6t,
L(q1-q5)=0.3m, R(q1-q5)=20mm, B(q1-q5)<0.35Tl

With magnet M3 parameters fixed, five qudrupoles are optimized in order to obtain rather small beam size in magnet M2, in quadrupoles and in the target. Additionally, both linear and angular dispersion at the magnet M3 exit should be suppressed. Calculations showed that all these conditions may be met regardless of beam phase space orientation and that small angular divergence in the initial point is preferable. Magnetic properties of M1 and M2, as well as Q1 and Q2 positions can be used as additional parameters for optimization.



A. Electromagnetic scanning in X direction
mechanical scanning of treatment coach
200 mm in Y direction,
X*Y(M3)=25mm*240mm, weight M(3)=13t,
total rotated weight is about 60t,
total sizes - L=14.7m, D=11m.



B. Electromagnetic scanning in X and Y directions
200 mm,
X*Y(M3)=200*400mm, weight M(3)=50t,
total rotated weight is about 160t,
total sizes - L=15.5m, D=11m.

Figure 2. GANTRY for carbon ion beam
P<1.9GeV/c,
X*X'=Y*Y'=3mm*1mr, dP/P=±0.2%
B(M1-M3)<1.85Tl,
X*Y(M1)=X*Y(M2)=20*70mm,
weight M(1) =weight (M2)=1.4t,
L(q1-q5)=0.4m, R(q1-q5)=25mm, B(q1-q5)<0.65Tl

It can be seen the same optic scheme is shown on Figure1 and Figure 2 both for transport of proton and carbon ion beams indipendently from method of scanning.

Figures 1 and 2 demonstrates that GANTRY overall dimensions are mainly determined by the distance from magnet M3 to the target center H=1.5m, by curvature radius in magnets, which is a function of the magnetic rigidity of particles and maximum magnetic field, and by the length of the path where q3-q5 and scanning magnets are placed. It is impossible to decrease H considerably without loss of irradiation comfort. Warm magnet field is limited by the value of 20 kG. Therefore, this GANTRY type dimensions depend mainly upon magnetic particle rigidity and don't exceed (L=9m, D=7m) for protons and (L=15.5m, D=11m) for carbon beam. Further attempts to decrease GANTRY length by moving q3-q5 to the path between q2 and M2 lead to a substantial increase of these lenses weights and power and of those of M2 too [5].

Last magnet properties are the critical parameters of GANTRY design. It must have minimum weight and good magnetic field in big volume for scanning and at any field value. There is a description of the last magnet with wide aperture for GANTRY (B<2.0Tl, X*Y=200mm*200mm, $\Delta P/P=\pm 10^{-3}$, R=3.2m, 45dr, 20.2t, J=5A/mm^2) [6]. All estimations of magnets properties in this work were done by analogy with [6].

Corresponding magnet weight estimations are presented of Figures 1-3. Estimations showed that the weight of the magnet M3 constitutes 80-90% of the total magnetic system weight. This simplifies GANTRY frame design. As it has been shown, M3 gap directly depends on the target size and on the scanning mode (unidirectional or bidirectional). M3 weight increases 4 times in the latter case. M3 weight doesn't exceed 5t (unidirectional case) and 20 t (bidirectional case) for protons and 13 t and 50 t for carbon beams.

Figure 3 presents beam envelopes for different phase volumes of the beam. It can be seen that considerable phase volumes variation (10 times) only doubles beam lateral dimensions, and M3 cross section is still determined by the target size and by the scanning mode. Therefore, magnetic system weight only slightly depends on the phase volumes of the beam.

The experience of GANTRY design has shown that total GANTRY weight exceeds the weight of the magnetic system 3 times. Corresponding estimations shown on Figures 1,2 demonstrate that proton GANTRYs weight and size (L=9m, D=7m, W=20-60t) can be considerably decreased comparing to the existing models, and those parameters for carbon beam gantry (L=15.5m, D=11m, W=50-160t) are comparable with existing proton GANTRYs.

These proposed GANTRY versions are surely preliminary ones and can be further optimized.

There are many GANTRY structures considered in the literature. It seems to be useful to introduce criteria for their optimization and comparison. The value inversely proportional to the GANTRY volume and its' momentum of inertia $K=(L*R^2)^{-1}(M*R)^{-1}$ seems to be relevant (for the same values of particle magnetic rigidity, maximum magnetic field, the distance from the GANTRY nozzle to the patient, target size, beam phase volume and momentum spread).

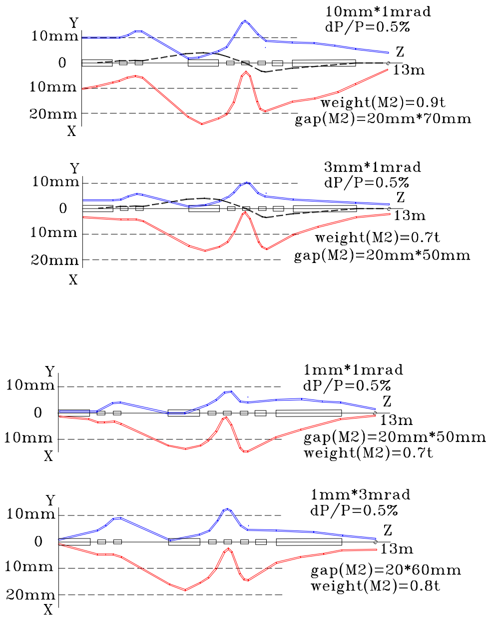


Figure 3 Beam envelopes for different phase volumes of the beam.

3 CONCLUSION

GANTRY is a device for the optimal patient irradiation. GANTRY properties must take into account the requirements of the medical personnel in the first place. Right in this way this GANTRY scheme was designed . It permits irradiation from any direction with scannig of the target up to 200mm*200mm with parallel beam. The distance from the target to the magnet is of about 1.5 m.

Radius of rotation of its magnets center of gravity is minimal. The last magnets weight depends on irradiation zone size and scanning method. All other magnets weight is inessential. So GANTRY construction according to this scheme will not meet great difficulties.

The volume of the GANTRY described above is not big as its diameter is minimum.

The proposed scheme permits the transportation of beams with various phase volumes and so it can be used practically with any accelerator. The decision was made now to use this GANTRY scheme in the project of the Moscow Center for the Proton Therapy [8].

4 ACKNOWLEDGEMENTS

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