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DEVELOPMENT OF CIRCULAR PROTONS ACCELERATOR FOR OCULAR TELETHERAPY

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ABSTRACT

The proton therapy has been used for ocular tumors providing tumor control in most cases and vision preservations. The protons show high doses in depth depict lower scattering from beam than other particles, electrons and photons. The cyclotron is a type of accelerator that increases the kinetic energy of the charged particle, recirculating it on a magnetic field and crossing an accelerating electrical field. It can be used to produce radioisotopes to hospitals. The goal of this study is to investigate a unit of circular accelerator to be coupled in existing national cyclotrons to generate a proton beams suitable to ocular therapy. Herein, physical parameters are evaluable, including relativistic corrections. That result shows the viability of developing an accelerator unit to ocular proton therapy.

Key Words: accelerator, therapy, protons, ocular tumor.

1. INTRODUCTION

Elementary particles can be accelerated by equipment called particle accelerators, where they gain energy by crossing an electric potential and "travel" by the accelerator through electromagnetic fields. The design of an accelerator varies according to the purpose for which it was intended, and was ranked according to energy and the way the particles are accelerated.

Some applications of these devices are done in medicine and radiotherapy in non-invasive diagnostic. The cyclotron is a type of accelerator used for nuclear production of medical radioisotopes. About seventy-five of them were sold recently in the world for the production of FDG (fluor-D-oxi-glucose), which is compact and reliable. This device produces protons to energies that reach 16.5 MeV, using a current of 60 mA.

The cyclotron for radioisotope production increased primarily due to the possibility of accelerating protons within the energy range compatible with the spectra of cross sections of the targets in the reactions (p, n), (p, α), or (p, γ) addition to being compact machines. Magnetic fields are produced by ferromagnetic material, while electric fields are generated by radio frequency in resonant cavities. The cyclotron requires large amounts of energy to operate. These and other factors make these devices expensive products both for marketing and for the production of radionuclides. The use of proton therapy of ocular tumors is desirable because these particles have higher deposition of ionizing energy at depth with limited lateral spread, compared to gamma rays or electrons. These characteristics are represented by a curve called the Bragg Peak (Figure 1). The peak occurs just before the particles come to rest. In the peak region, the protons lose most of its kinetic energy and velocity due to Coulomb interaction with electrons and with nuclei of atoms of matter. When the charged particle moves through matter, it ionizes atoms of the material and it's deposited a shot over his way. Due to the large difference in mass of the proton relative to the electron (~ 1 / 2000) the deflection of the particle is very small. The Bragg peak occurs because the cross-section of interaction with the proton increases as the energy of particles decreases. This characteristic is essential for proton therapy, which makes these particles are accelerated to energies sufficient to reproduce the Bragg peak in the tumor region and ionize the malignant cells without affecting surrounding healthy cells (Figure 2).

The dose received by the patient in an eye tumor treatment is approximately 60 Gy, which is fractional, may vary with the type and size of the tumor. There are specific software to analyze transportation of proton beam inside the human body and are based on Geant4 code.

Radiotherapy with protons has been used in tumors of the head, neck and pelvic region. According to the statistic has been achieved healing of ocular melanomas with preservation of vision in 95% of cases. The installation of a proton center therapy requires an investment of millions of dollars, which hinders their implanting in most countries. The objective of this study is only to investigate a unit of acceleration that can be coupled to a cyclotron producing radioisotopes to generate beams of the order of 64 MeV for use in teletherapy eye.

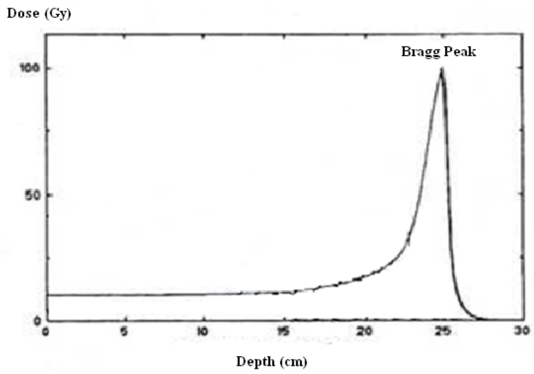

Figure 1: Examples of relative dose according to the depth by a variety of energies ofphotons, protons and ions.

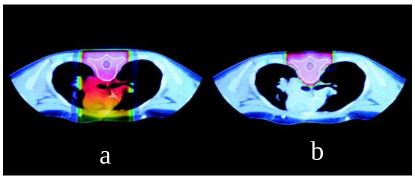

Figure 2: Spatial distribution of dose on the beam of photons *(a)* and protons *(b)* in the spine [3].

2. MATERIAL AND METHODS

Consider a proton beam charge q and rest mass m_o, issued by an ion source and pre-accelerated to an initial kinetic energy E_o of 15 MeV (energy of the accelerated proton Cyclotron which will be attached to the circular accelerator under development) proton beam feed, this unit acceleration to achieve kinetic energies of 63.5 MeV. The circular accelerator under development was divided into two parts: a region where there is a baffle uniform magnetic field which allows the movement of the proton, and an acceleration region where an electric field is present, said resonant cavity. Both regions are coupled and distinct. The particle initially enter the resonant cavity with a magnetic field and zero electric field, with a speed v_o, as their motion is perpendicular to the uniform magnetic field, the particle describes a circular path. The larger the particle velocity, the greater the radius of curvature *R*. The particle traverses the cavity resonant at a time t_d (time inside the cavity). Then it goes out with a speed *v*, as shown in Figure 3. And after, the particle cavity returns to complete a round circular radius *R* in a time t_f (time outside the cavity). Whenever charged particle to complete one loop and passes through a resonant cavity its initial kinetic energy E_o of 15 MeV.

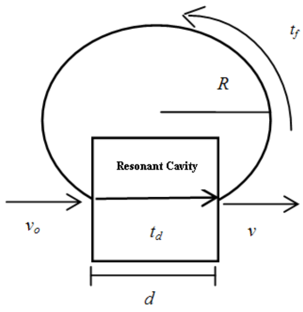

Figure 3: Schematic illustration of the way inside the particle accelerator.

In the initial stage of the project is intended to analyze the physical and geometrical parameters associated with the movement of protons in the regions mentioned. The main parameters associated with the project are being evaluated, according to Table II. However, some of these equations serve classical mechanics and some corrections must be made. For when the particle mass increases and approaches the speed of light, relativistic effects, which make beam focusing, must be counted. Corrections are applied on the particle mass *m* and momentum to calculate the radius *R* and velocity *v* relativistic.

Table I: Physical quantities involved in the proton accelerator.

Magnitudes	Values
Proton mass (m_o)	1,673 x 10^{-27} Kg
Proton charge *(q)*	1,6 x 10^{-19} C
Speed of light*(c)*	3 x 10^{8} m/s
Electrodes distance *(d)*	0,06 m
Potencial difference *(V)*	800 kV
Initial Kinetic Energy (E_{ci})	15 MeV
Final Kinetic Energy (E_{cf})	63,5 MeV
Magnetic Field *(B)*	5 T

Table II shows the equations were divided into two groups: the group that governs the particle movement in the region, and the group of equations that operate the acceleration of protons (resonant cavity). In the region of movement, being perpendicular to *v* |B|, the particle will evolve into a circular path, with centripetal force acting. Substituting of momentum in equation radius we have the radius of each turn that describes the particle. In the region of acceleration, resonant cavity, for simplicity we adopted a potential *V* and an electric field |E| constant. Total time required for the particle to complete the course within and outside the cavity, just add the two times: the time inside the cavity *(td)* and the time taken to complete the turn out of the cavity *(tf)*.

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Table II - List of equations governing the area of movement and acceleration of particles in the circular accelerator.

Equations	According to Classical Mechanics		According to relativity
Region of Circulation	Where is *v* perpendicular to |B|, the particle will evolve into a circular path, with a centripetal force acting	$a = \frac{v^2}{R}$	
	The motion can be described by eq. Lorentz	$F = ma = qvB$	
	Calculate the radius *R* of the próton in the region of movement, every turn *i*, where *p* is the momentum of the particle, equal to *mv*	$R = \frac{p}{qB}$ $p = \sqrt{2m_0 E_c}$	$R = \frac{p_r}{qB}$ $p_r = \frac{1}{c}\sqrt{E_c{}^2 + 2E_c m_0 c^2}$
Acceleration region	The Newtonian particle kinetic energy near the resonant cavity	$E_c = \frac{1}{2} m_0 v^2$	$E_c = m_o c^2(\gamma - 1)$ $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
	The gain in energy with every lap *i* is given by the relationship, where *Ei* is the Kinetic energy back in *i*	$E_{i+1} = E_i + q\Delta V$, $i = 0,1,\ldots n-1;$	
	The electric field in the cavity resonant	$\|E\| = qV$	
	To calculate the particle velocity *v* at each turn, applies the following equation	$v = \frac{\sqrt{2m_0 E}}{m_0}$	$m_r = m_0 \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$ $v_r = \frac{pc}{\sqrt{m_0 c^2 + p^2}}$
Time of precursor	$t = t_d + t_f$	$t_d = \frac{(p_{i+1} - p_i)d}{vq}$ $t_f = \frac{dx}{v} = t_f = \frac{2\pi R}{v_r}$	

RESULTS

The results of applying the equations are reported in tables III and IV.

Table III: Results of the calculations using the equations described above.

	Energy equal to 15 MeV		Energy equal to 64 MeV	
Magnetic field (T)/Applied potential(kV)	5/800	3/400	5/800	3/400
Initial energy (MeV)	15 MeV	15 MeV	15 MeV	15 MeV
Radius (m)	0,112092	0,18681965	0,232497	0,387495
Relativistic momentum (kg.m/s)	$9,0 \times 10^{-20}$	$9,0 \times 10^{-20}$	$1,89 \times 10^{-19}$	$1,89 \times 10^{-19}$
Momentum (kg.m/s)	$8,97 \times 10^{-20}$	$8,96 \times 10^{-20}$	$1,86 \times 10^{-19}$	$1,86 \times 10^{-19}$
Relativistic speed (m/s)	52968397	52968397,2	$1,06 \times 10^{8}$	10580339
Speed (m/s)	53600376	53600376,4	$1,11 \times 10^{8}$	11117620
Acceleration time (μs)	0,00125	0,00125	$5,66 \times 10^{-4}$	$5,66 \times 10^{-4}$
Circulation time (μs)	0,0133	0,0221	0,0138	0,0230
Time opposite the cavity (μs)	0,00113	0,00113	$5,67 \times 10^{-4}$	$5,67 \times 10^{-4}$
Total time (μs)	0,0155	0,0244	0,0149	0,0241

For the magnetic field equal to 5T are needed 64 turns to the particle with an initial energy of 15 MeV reach with final energy equal to 64 MeV. And for the magnetic field equal to 3T are needed 126 turns to the particle with energy of 15 MeV reach with energy to 64 MeV.

CONCLUSIONS

With an initial kinetic energy of 15 MeV is possible to accelerate protons to energies sufficient for the treatment of ocular tumor in a compact accelerator in the order of 65 MeV after 60 turns of the proton beam in a resonant cavity. Further studies will be made with lower initial energy of the particle.

The present study is encouraging because the idea of a unit of acceleration coupled with FDG cyclotron producers, whose initial energy is around 15 MeV, can produce proton beams for ocular therapy low cost, facilitating the implementation of this treatment in the country Hence may be offered by hospitals.

Currently, ocular tumors have been treated children in the state of Minas Gerais by enucleation (removal of the eyeball). The possibility of installing a production unit of 63 MeV protons in the state is of extreme social relevance. The idea and physical principles discussed in this article brings up the possibility of developing technology for producing national quality of life in patients suffering from neuroblastoma or ocular melanoma. The technical project is under development, and it is expected that issues concerning the implementation hospitals be answered soon.

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