PROGRESS REPORT ON THE IBA-SHI PROTON THERAPY SYSTEM

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ABSTRACT

The current status of the proton therapy facility developed by IBA and SHI is presented. This includes general aspects of the machine already presented in previous papers as well as more recent features such as the closed gap, the extraction device and the central magnetic field. Two types of isocentric gantries, one for scanning and one for scattering are at the design stage.

1. INTRODUCTION

A proton therapy facility using a compact, high-field non superconducting cyclotron was first presented by Ion Beam Applications (IBA) at the Proton Therapy Cooperative Group (PTCOG) meeting held in Loma Linda in June 1990. In December 1990, funding was secured to start the design of a prototype at IBA. In October 1991 a collaboration agreement was signed between IBA and Sumitomo Heavy Industries (SHI).

The main features of this accelerator were presented elsewhere[1-3] and are summarized and updated where necessary in table 1. A general view of the accelerator is presented in Fig.1.

Table 1 **Magnet system**

number of sectors	4	
sector angle at r=150 mm	36	°
sector angle at extraction	57	°
maximum gap heigth	48	mm
maximum hill field	2.9	T
minimum valley field	0.9	T
average field at extraction	2.165	T
average field at center	1.74	T
Spiral angle at the center	0	°
at extraction radius	~60	°
magnetic induction	5.324 10^5	A.t
apparent current density in coils	155	A/cm^2
actual current density in coils	200	A/cm^2
power per coil	87.5	kW
total copper weight (2 coils)	20.8	tons
weight of the iron	190	tons

R.F. System

resonating system	2 dees in opposite valleys	
harmonic mode	H=4	
dee voltage	100	kV
frequency	106.11	MHz
length of resonator	60	cm
estimated capacitance per resonator	58	pF
estimated RF power for 100 kV	65	kW

Miscellaneous

operation vacuum	5 10^{-6}	mbar
source type	hot filament PIG	
source turn on/off time	15	µs
extracted intensity	1...100	nA
output vertical emittance	1...2	π mm.mrad
output horizontal emittance	1...2	π mm.mrad

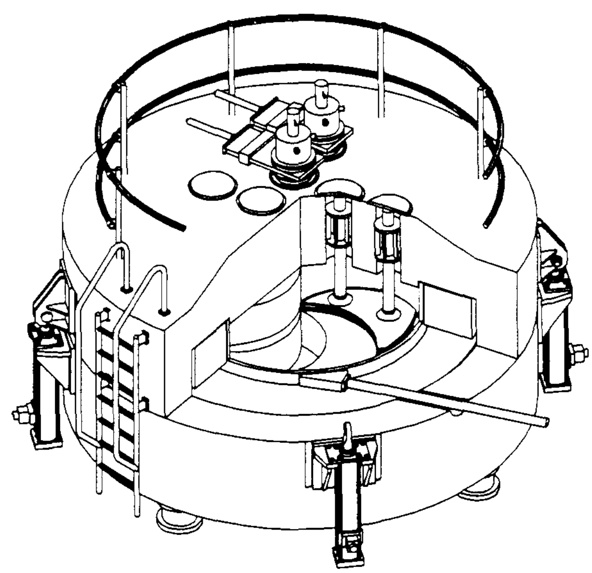

Figure 1 General view of the proton therapy cyclotron

The induction profile in the vicinity of the extraction radius was improved by the introduction of a magnetic shunt resulting in a completely closed gap at the median plane. The extraction system is also described in this paper.

First calculations on the central region were performed with the PE2D code using a simplified 2-D model with stacking factors in order to describe its actual 3-D geometry.

Two types of isocentric gantries namely a scanning gantry as initially proposed by IBA and a scattering gantry are currently designed. Their status is also presented in this paper.

2. NEW FEATURES IN THE CYCLOTRON DESIGN

2.1. Magnetic Shunt

As mentioned earlier[1-4], the hill gap profile is elliptical. The two main advantages of this design is the fact that the iron contribution to the field is uniform within the hills or valleys and that the induction radial gradient only depends on the coil field. The other advantage is the steep induction decrease outside the pole which allows an extremely easy extraction.

The ideal fied profile obtained with an elliptical shaped magnet gap is somewhat distorted if one opens the ellipsoid in the median plane in order to allow the beam extraction. Indeed, instead of the steep field decrease outside the pole, the maximum of the radial field profile flattens and is moved towards the inside of the machine (fig. 2a).

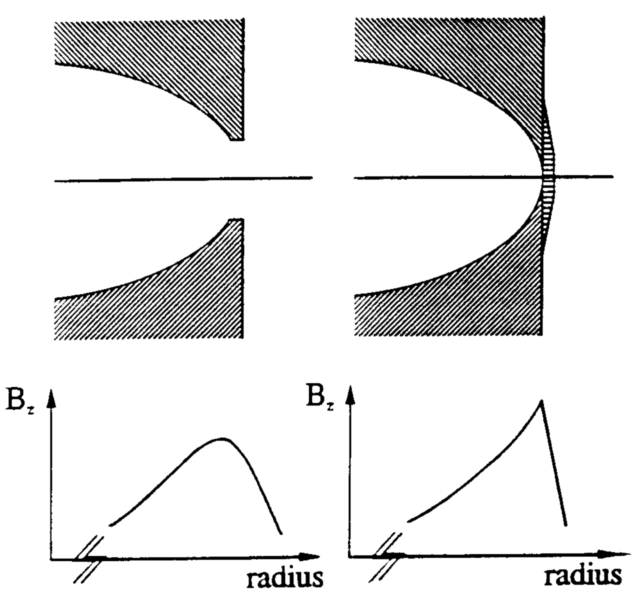

Figure 2 Behaviour of the magnetic field with gap opening and with a magnetic shunt

This prevents the use of the isochronous field up to the maximum radius of the pole . This decreases the maximum energy of the machine and also increases the distance between the last accelerated trajectory and the extracted trajectory, complicating therefore the extraction.

To avoid this problem, we found convenient to use a magnetic shunt that completely closes the median plane and whose thickness, height and shape allows a very accurate control of the bypassed flux (fig. 2b).

Both 2-D (PE2D*) and 3-D (TOSCA*) codes were used to compute the best dimensions for this shunt. The accuracy of the field in that region is very important as there are many turns in that area. The shunt thickness at the median plane is 6 mm and has a triangular profile for a height of 60 mm from the median plane.

From a mechanical standpoint, this part is intended to be removable from the main pole in order to allow an easy adjustement of the shunt during the field mapping/shimming phase.

2.2. Extraction System

The radial betatron frequency ν_r is about 1.3 in the extraction region. With this ν_r value one can expect some precessional extraction contribution induced by an off-centering of 1...3 millimeters. Such an amount of uncentering is practically unavoidable due to small central region errors and to the residual first harmonic in the field

The field gradient just outside the pole amounts to 0.3 Tesla per mm. This very steep decrease shortens the path from the pole region to the field-free region to only 250 mm ie 13° instead of a large fraction of a turn as in other cyclotrons of this energy.

An in-valley electrostatic deflector 570 mm long, 5 mm wide with a 0.1 mm thick septum deviates the beam to a specific window managed through the magnetic shunt. After passing the high gradient region, the beam enters a magnetostatic iron bar channel intended to compensate the quadrupole component of the fringe field.

The extraction efficiency without any precessional contribution is above 62%, and could be close to 100% with the precession.

2.3. Central Region

We performed a PE2D study of the central region. Its main goal was to provide access for an axially introduced ion source radially adjustable, and to provide a magnetic fied bump at the centre in order to produce weak focusing at radii where the flutter is insufficient.

A central plug with two symmetrical holes 180° apart was designed to obtain a 0.1 Tesla field bump at the centre. The field reaches back its normal isochronous value at a radius about three times the plug radius.

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3. THE DOSE DELIVERY SYSTEM

3.1. Main Energy Degrader

In order to uncouple the gantry optics and the upstream transport optics, the main energy degrader has been placed at the entrance point of the gantry. Unlike previous gantry designs, the resulting emittance degradation is not a major problem but is rather used as a means to obtain quasi-identical emittance ellipses in both planes at the entrance point of the gantry. Similar scattering angles are obtained for different output energies using different degrader materials (lead above 200 MeV, diamond below 150 MeV and copper in between).

3.2. Scanning Gantry

The basic design of the scanning gantry proposed by IBA[5-6] remains unchanged but some points were revised to address different concerns.

3.3. Scattering Gantry

Though attractive in principle, the safety, complexity and even usefulness of the scanning method are still beeing debated. As a consequence, many proton therapy teams still prefer the classical scattering method.

A large, uniform beam is produced by a combination of scatterers and patient-specific collimators and bolus.

To meet the needs of these groups, IBA designed a 2.8 m radius compact isocentric gantry[7] allowing for large field irradiation (35 x 20 cm) using the double scattering method proposed by Gottschalk[8].

The first scatterer is placed at the entrance point of the gantry (see above) and the second one before the last analyzing section ie last quadrupole and last 90° magnet. This second scatterer is a sandwich of high and low Z materials whose thicknesses are patterned to provide a radially non uniform scattering effect but a constant energy loss. The radially dependent scattering is optimized to give a flat intensity profile at the patient location.

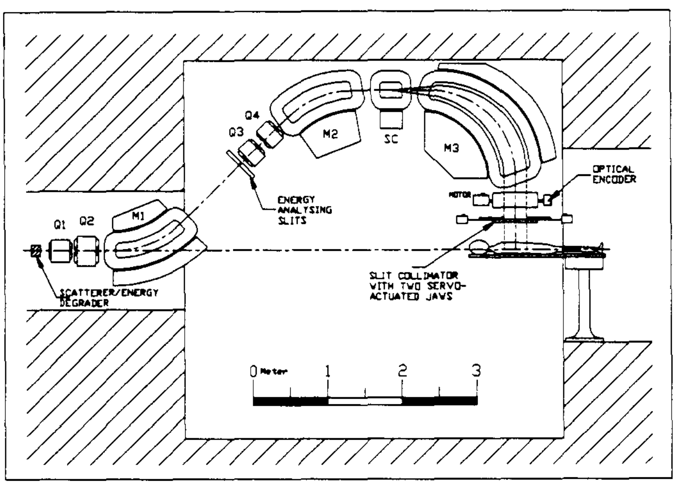

Figure 3 The scanning gantry

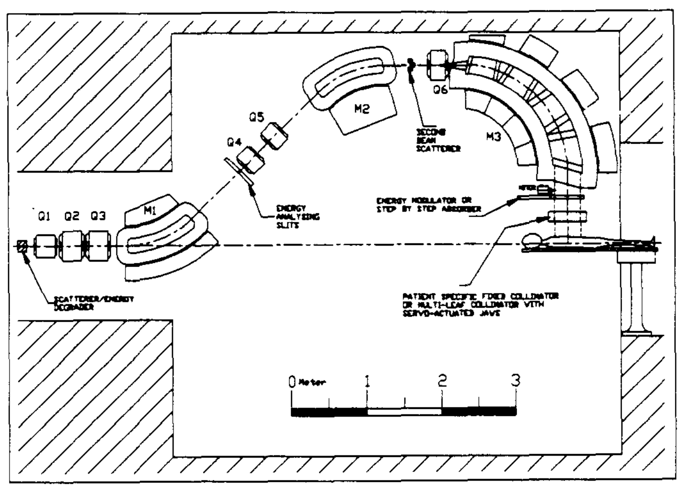

Figure 4 The scattering gantry

In order to address the problem of possible dose errors at the voxels boundary a large amount of voxel overlapping is included in the design. To achieve this, the pencil beam size is increased and a slit shaped collimator is introduced to maintain a very sharp lateral fall-off.

The gantry optics is designed with a large admittance of 70 π mm.mrad. This allows handling of large beam emittances from the energy degrader with an intensity reduction factor of 3...5, depending on the final energy, instead of a factor of 2...50 in the previous design.

The distal fall-off degradation created by the absorber is corrected by an analyzing section which allows an energy selection of ±2% and thus a distal fall-off only sligthly larger than that of a monochromatic beam.

The magnifying properties of the last analyzing section allow to achieve a large field size with a divergence of only 22 mrad at the second scatterer exit thus a mere energy loss of 2.5 MeV at 220 MeV.

4. REFERENCES

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