COMPACT PROTONTHERAPY UNIT PREDESIGN

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Abstract
Conceptual guidelines lead to treatment unit descriptions based on (i) 3 GHz traveling wave acceleration in 4 sections of 10.5 m total length fed by 2 klystrons, (ii) treatment cell which moves with a 270°dipole for large SAD, low weight, single optical component. RF structure for test is reviewed.

I.INTRODUCTION

Radiotherapy uses beams of electrons cheaply produced by RF linac at 3 GHz. One would like to take advantage of the existing industrial basis to accelerate protons of low & variable velocity & high rigidity. Following earlier proposals based on proven solutions [1-3] we propose innovations as simpler accelerating RF geometries [4-5], improved focusing [6], an original combination between head optics & treatment bed & access [7]. A very compact therapy unit predesign which delivers an high quality beam emerges. It is able to spread proton uses within hospitals.

II CONCEPTUAL GUIDELINES

1. High frequency of 3 GHz increases simultaneously the shunt impedance and the maximum permissible field gradient.

2. Acceleration in traveling wave removes the coupling cells: simultaneous acceleration & focusing becomes feasible.

3. Use of forward or backward waves magnetically coupled in a new way increases the acceleration efficiency. Figure 1 shows the half cross-sections for two adjacent cells in two cases.Reference [4] quantify the gain.

4. Minimal length is fixed by maximum allowable field gradient (3 GHz RF high peak power is available). It minimizes size/ cost and alleviate the synchronism problem.

5. RF auto-focusing by alternate dephasing of the bunch to the RF wave is obtained in the simplest manner: using groups of cells of same length. However the effect remains modest and must be complemented by quadrupolar magnetic FODO or innovative helical focusing [6].

6. Optical transport components between the linac and the treatment head vanishes. Switching from one treatment room to the other does not requires a dedicated magnet when they follow each other along the beam axis.

7. Enge 270° dipole at room temperature has excellent optics. It allows a very large Source to patient Axis Distance (SAD): focus in two planes and in energy occur at 2.74 x curvature radius from the dipole exit.

8. Bending can precede the transformation from the narrow beam to distributed one. This reduces dipole weight and structural cost.

9. Energy stabilisation is achieved by beam analysis within the required narrow bandwith (+/- 0.3%). Neutrons are controlled as beam loss occurs opposite to the patient.

10. Patient moves symetrically to the magnet inside a treatment cell which is a part of the rotating head. This non-isocentric choice (as made at PSI, Villigen, Switzerland) allows reproducible error at the level of the rollers rotation mechanism, the linac-head colinear adjustment being electronically controlled.

11. The treatment cell is a chamber large enough (2.5 m dia.) to allows bed rotations and human assistance at set-up location.

12. The rotating part has low weight (<10 tons) and its mechanical structure can be best designed as hollow rolled metal box.

13. The patient crosses the wall protection, takes an elevator, installs in a treatment chamber: he sees, without trauma, a "segmented corridor" of rather constant cross-section.

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14. The neutron protection uses diaphragms plus nearby absorbers at phase selection at the end of the first linac sub-section, at radial selection at the end of the linac, at energy analysis. Patient protection from thermal neutrons is helped by chamber walls made of hydrogeneous material.

II TREATMENT UNIT DESCRIPTIONS

Two designs are based on available subcomponents or [foreseeable ones]. Figure 2 shows the instrument block diagram:

1/ Beam line:
1.1/ 50kV source + 4 MeV RFQ, 3.5 m length [150kV proton source + preaccelerator made of 3 gaps DTL inside each TW cell at 3 GHz, 1 m]

1.2/ 4 TW waveguides, 10.5 m length. Each waveguide is fed by one klystron arm, the first waveguide is made of two segments in serie. The expected shunt impedance is [4]: $ZTT \simeq 200\ \beta \simeq 100$ MΩ/m avrg. or 70 MΩ/m including dynamics, load loss etc.

1.3/ Doublets, adjustment dipoles, current monitors. [low energies: supercon. solenoidal focusing or sub-sections bridging + quads]

2/ RF sources:
2.1/ 0.5 or 0.75 GHz
2.2/ Twin modulator 100 Hz 4.5 μs
[Single modulator 3 μs]

2.3/ 2 klystrons TH 2132 42 MW 20kW
[1 klystron 85 MW 30kW]
Energy gain is given by:
$V = (PZL)^{0.5} = (80 \times 70 \times 10.5)^{0.5} = 242$ MeV.
With T transit factor, d nose to nose distance $\simeq 2\pi/3$, l cell length $= 5\pi/4$ in the direct coupling $3\pi/4$ case, see [4] & fig.1, Es peak field on surface, Ez on-axis field, V full energy, L total lenth:

$$Es = \frac{1}{T} \times \frac{l}{d} \times \frac{Es}{Ez} \times \frac{V}{L} = \frac{1}{0.8} \times \frac{5\pi/4}{2\pi/3} \times 2.5 \times \frac{242}{10.5}$$

Es = 135 M V/m

2.4/ waveguides + phasors Φ 20 MW 180°

3/ Therapy fixed head:
3.1/ 270° Enge dipole, curvature radius 1.3 m Br max 1.8T, hollow ring of reduced cross-section 0.15 m side, weight 2 tons
3.2/ 50 kW DC source stab. 5 10-4
3.3/ Hall Bz measurement and current monitor
3.4/ Beam medicalisation components easily located in a truncated cone of 3.5 m height
3.5/ Beam optical + radiological simulations

4/ Therapy mobile head:
4.1/ Components of 3/
4.2/ Rotating hollow structure to insure dipole to bed center of rotations rigidity. 3.5 m radius for large treatment room of dia. 2.5 m. Limit of 3.0 m minimum (due to dipole).

5/ Controls & commands:
5.1/ The linac is energy controlled with help of Bz measurement and current monitor (the dipole selects a +/- 0.3% energy window inside the accelerated spectrum of <+/- 1%)
5.2/ The energy change from nominal to -25% is obtained on section no.4 by TW asynchronism, end to head, produced by 2.4/ phasor rotation over 180°. Lower energy levels are obtained on section no.3 by phase rotation of the klystron amplified signal then by its suppression etc.

III IMPLEMENTATION STRATEGY

A test must be performed to confirm our simulations of efficiency and dynamics on the most critical low energy acceleration part. It uses backward wave at $-\pi/4$ coupling ($7\pi/4$ required bunch cell to cell dephasing).

The first waveguide subdivides into two segments designed to accelerate from 4 MeV to 12 MeV (x3) and then to 36 MeV (x9). Elegant simplification occurs as: (a) constant group velocity is possible with a moderate field decrease as the cell shunt impedances increase when the RF power decreases, (b) groups of 6 to 10 cells of same length introduces a back and forth dephasing of the accelerated bucket with respect to the wave at the mid-plane of each cell. This RF autofocusing is however limited to a narrow 10° phase acceptance band.

Provision must be made to superimpose magnetic focusing. Taking advantage of the absence of (side) coupling cells, adjustable FODO seems relevant for test. In the future fixed helical quadrupolar geometry could be used. To this must be added the proton source of 4 MeV and a standard S-band RF source of 20 MW.

IIII REFERENCES

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(4) D.Tronc, Traveling wave acceleration of protons, Nuclear Instr. & Methods, A327 (1993) 253.

(5) Patent F 91 09292
(6) Patent F 92 06290
(7) Patent F 93 03152

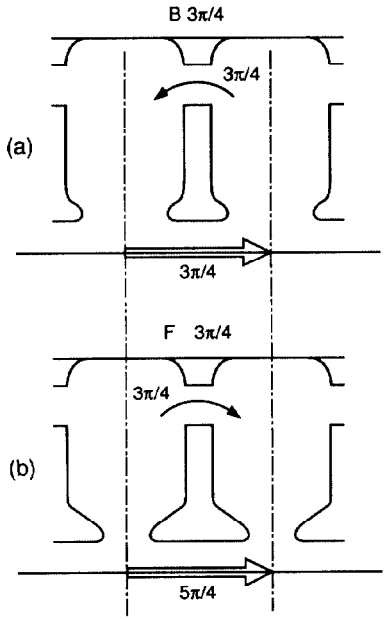

Figure 1. Half-views of adjacent TW cells for two cases: (a) RF coupling $3\pi/4$ backward accelerates high velocity protons with same on-axis delay value [already used for electrons] (b) same coupling forward can accelerate lower velocity ones delayed by $2\pi - 3\pi/4 = 5\pi/4$.

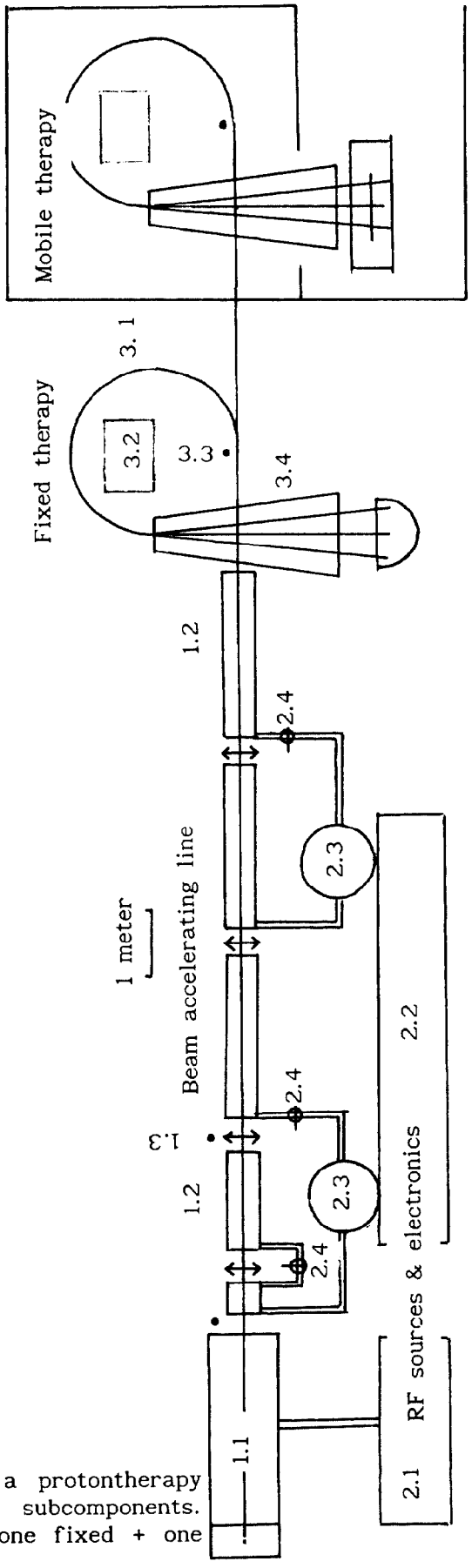

Figure 2. Block diagram of a protontherapy instrument made of available subcomponents. Total length 25 m including one fixed + one mobile treatment facilities.