OVERALL QUALITY COMPARISON OF C-BAND AND X-BAND MEDICAL LINACS.

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INTRODUCTION

Some tumours can be effectively treated with combination of low and high-energy photons or of photons and electrons. The single machine that can provide both low and high energy x-rays together with a wide range of electron energy is the electron linear accelerators. Accordingly, the electron linear accelerator has become the dominant device for radiation therapy since it was introduced in the 1950's. There are more than 5500 electron Linacs are used for medical purposes worldwide.

Most of medical Linacs use S-band frequency but such Linacs cannot fit to modern advanced treatment techniques such as Tomotherapy [1] and Stereotactic [2] radiotherapy, which allow physicians to locate the tumour position during treatment and enable for beam modification based on real time analysis.

For that reason the need of new generation of electron Linac that fit to new radiotherapy techniques becomes necessary. C-band and X-band Linacs are promising new generation of electron Linacs that fulfill the ambitions of radiotherapists to use a fast, accurate, and cheap radiation therapy tool.

In this proceeding we will highlight on the overall comparison of S-band, C-band, and X-band medical accelerator and special concern will be devoted to C-band type because of its promising applicability in modern treatment techniques.

S-BAND MEDICAL LINAC VS. C-BAND & X-BAND MEDICAL LINAC.

The S-band (3 GHz) has been the prevailing frequency for Linacs in medical and industrial applications. This is mainly attributed to the availability of stable high power microwave sources in S-band frequency range. Unfortunately, S-band Linacs are usually long, e.g. only 4.5 MeV bi-periodic on-axis coupled structure has 74 cm length [4], and 14 MeV bi-periodic on-axis structure composed of 30 accelerating cells with 29 coupling cells is 145 cm long [5]. Such long, and heavy Linacs cannot be used in the modern treatment techniques such as Tomotherapy where the accelerator structure is built in rotating ring, see fig. 1 or Stereotactic therapy where the accelerator structure is built in rotating arm, see fig. 2. It is also worth to note that the RF power source (klystron, pulsar, and modulator) in S-band frequency is fairly stable but it is seriously huge and expensive; this is another disadvantage in medical S-band Linac, which necessitates large space for installation.

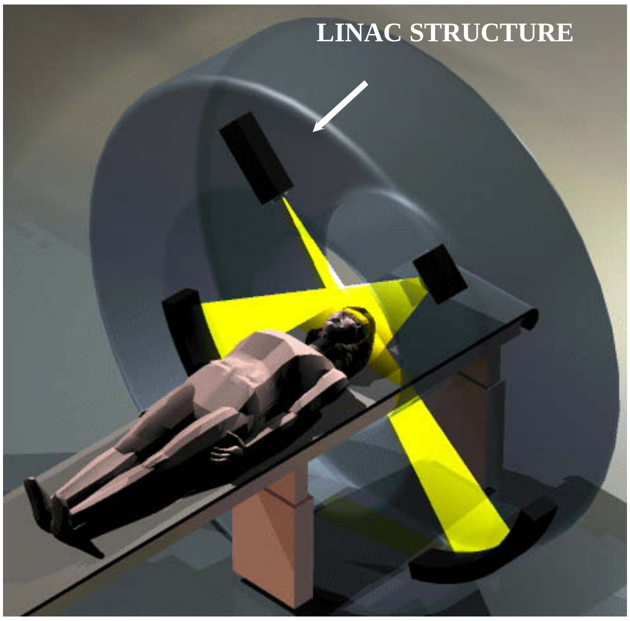

Fig. 1. Tomotherapy concept [3]

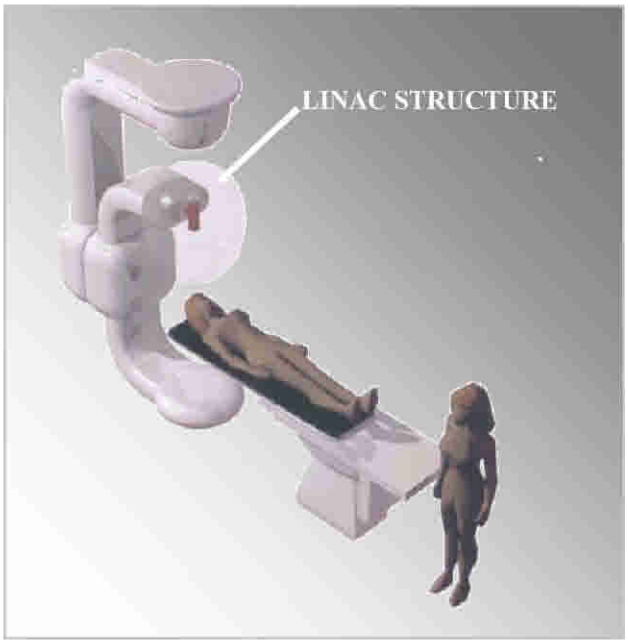

Fig. 2. Stereotactic concept

Accordingly, and due to the need of Linac structures that fulfil new treatment technology demands, higher RF frequencies C-band (5.7 GHz) and X-band (11.4 GHz) have been proposed for electron Linacs to be used in such sophisticated treatment techniques. C-band and X-band frequency have been chosen for new Linacs due to the following advantages:

- Compact size: leads to less weight, which enables the Linac motion to be controlled more precisely.
- Higher shunt impedance hence;
- The beam energy is increased for fixed input RF power
- Higher breakdown voltage threshold levels: consequently this leads to higher field gradient between the accelerating cavities and hence;

For that reasons C-band and X-band are recommended for new generations medical Linacs.

C-BAND MEDICAL LINAC VS. X-BAND MEDICAL LINAC.

The earlier X-band Linacs uses magnetron as RF power source. Such type of RF source in this high frequency ranges is low powered and unstable. Recently X-band klystron become available but still difficult to make them operating reliable at higher peak power due to several shortcomings such as s tighter mechanical tolerance and higher power transmission loss. Meanwhile the High Energy Accelerator Research Organization (KEK) in Japan has developed C-band components and accelerators that bring solution to the aforementioned problems. This includes:

- C-band Klystron
- Pulsed modulator for C-band klystron
- C-band accelerating structure

Also, since the accelerator structure will be built in rotary gantry, that is necessitates to use RF rotary joint to feed the RF power from RF power source to the accelerator structure; this RF rotary joint still is not available in X-band frequency while it is currently available in C-band frequency.

Accordingly, and due to the several technical advantages of C-band frequency technology rather than X-band, C-band Linac could be the best choice for the future application in radiotherapy.

Tanabe, et al. [6] proposed compact high power accelerator for medical application, which utilizes the hybrid standing wave structure. Table 1 summarizes the design parameters of proposed structure.

GENERAL STRATEGY OF THE C-BAND ACCELERATOR DESIGN

In this chapter and thereafter we will highlight on the design of the C-band medical Linac with describing a case study for a simulation of C-bnad structure. Instead of travelling wave structure we chose the side-coupling SW structure because of its high shunt impedance, high phase stability versus temperature variations, short length, and high efficiency of RF power conversion to electron energy gain. C-band (5712 MHz) has been chosen to for the advantages mentioned in the previous chapter. In following chapter we will represent the simulation results of 9 MeV C-band, 24 cm long standing wave accelerators for medical application as a case study for C-band Linac design.

Table 1: specification of C-band accelerating structure proposed by Tanabe et al.

Accelerator length	23
Structure.	Hybrid SW
Number of accelerating cavities.	9
Frequency.	5712
Energy (MeV).	10
Beam current.	600
Beam pulse width (μsec).	4
Repitation rate.	240
RF peak power (MW).	11
Shunt impedance (MΩ/m).	140
Load line (MeV).	15-8i

SIMULATION RESULTS OF 9 MEV C-BAND LINAC

The structure consists of 9.5 cells as follows: **a)** 3 on-axis coupling standing wave cells for buncher section. The on-axis coupling cells has been chosen for the buncher in order to suppress the effect of non axial symmetric electromagnetic field in the cavity. **b)** 6.5 side-coupling cells for the regular accelerating section. Simulation is carried out using PARMELA and SUPERFISH codes.The beam hole diameter (2b) is 4 mm with total length of cell (*L*) 2.62 cm; the gab (g) between the two successive noses is 1.3 cm, which equal to l/4 λ of the wavelength of the resonance frequency. Fig. 3 shows a schematic diagram of the resonance cavity.

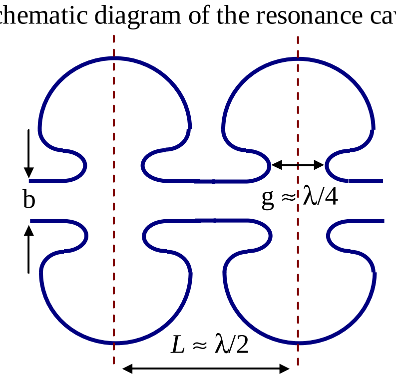

Fig.3. C-band resonance cavity

The cell structure has been optimized using SUPERFISH code and the resonance frequency was calculated at π/2 mode. Table 2 represents the cavity parameters.

Table 2: Cavity parameters calculated by SUPERFISH code

Effective Shunt impedance	56.1 MΩ/m
Transient time factor	0.66
Quality factor	9991
Peak to average ratio (E_{max}/E_0)	2.99

The simulation has been carried out taking in consideration space charge effect with 10^5 electrons per bunch with 10^4 bunches per pulse. The beam pulse width supposed to be 4 μ seconds. Fig. 4 represents the beam profile in x-y plan and fig. 5 represents the energy spectrum at the end of accelerator structure.

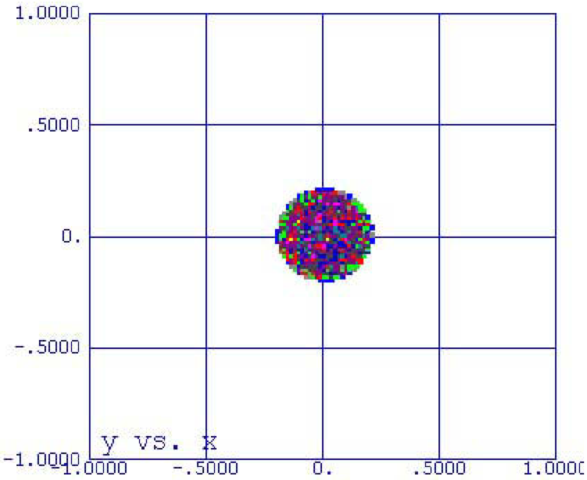

Fig. 4. Beam profile in x-y plan at the end of Linac structure

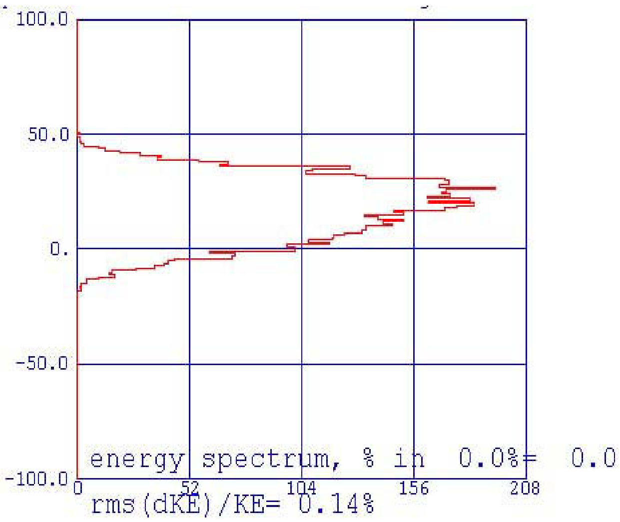

Fig. 5. Energy spectrum at the end of Linac structure

Table 3 summarizes the specifications of simulated C-band accelerator structure. Simulations results indicates that the structure needs some modification to make it closer to the structure proposed by E. Tanabe, et al. in table 1.

Table 3: specification of the simulated C-band accelerating structure

Total structure length (cm)	24
Number of buncher cavities	3 (On-axis coupling)
Number of regular accelerating cavities	6.5 (Side-coupling)
Frequency	5712 MHz
Beam energy (MeV)	9
Beam pulse width (μsec)	4
Effective Shunt impedance	56.1 M Ω/m

SUMMARY

C-band and X-band Linac structure could be the best choice in advanced radiotherapy treatment such as Tomotheraby and Stereotactic because of its advantages such as: compact, and high shunt impedance, high breakdown voltage. X-band structure still shows some shortcomings in X-band Klystron, and in RF rotary joint as well, consequently C-band is preferred to be applicable in the near future due to availability of stable RF power source (klystron type).

Using SUPERFISH and PARMELA codes we carried out preliminary simulation to optimize the cavity structure at C-band frequency and this enable us to design hybrid standing wave compact size, 24 cm long, electron accelerator with final energy 9 MeV. The simulation results indicate that more enhancements in cavity parameters are required to increase the effective shunt impedance, which is important factor in determining the required power of the klystron.

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