

RESEARCH AND DESIGN OF AN X-BAND 100-MeV COMPACT ELECTRON ACCELERATOR FOR VERY HIGH ENERGY ELECTRON THERAPY IN TSINGHUA UNIVERSITY*

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Abstract

A 100-MeV Compact Electron Accelerator scheme based on the Tsinghua X-band (11.424 GHz) High Power Test stand (TPot-X) was proposed for Very High Energy Electron (VHEE) radiotherapy. A pulse compressor with correction cavity chain was designed to compress the 50 MW, 1500 ns microwave pulse from the X-band klystron to 120 MW, 300 ns. The acceleration system consists of 3 parts, a buncher which bunches and boosts the electron from a thermionic cathode gun to 8 MeV, and two accelerating structure which further boost the electron energy to 100 MeV. The detailed design and consideration are presented in this article.

INTRODUCTION

The VHEE radiotherapy is a method that use electron beam with energy higher than 50 MeV to treat tumors throughout the body. It's a very potential candidate to realize very high dose rate therapy technique (FLASH) in the future. VHEE are getting more and more attention recent years. For example, the CERN Linear Accelerator for Research (CLEAR) [1] has been serving as a facility to study VHEE and have fruitful achievements. SLAC is propelling a multi-linac program named PHASER [2] for VHEE radiotherapy. LAL is planning a platform named PRAE [3] for future VHEE study. The RF teams in Tsinghua are also exploring the possibility to construct a compact VHEE facility based on the TPot-X.

ACCELERATOR LAYOUT

The primary layout of the system is shown in Fig. 1. The RF source is an X-band klystron. The pulse compression system, consisting of correction cavities and a storage cavity, compress the 50-MW, 1.5- μ s RF pulse to 120-MW, 300-ns pulses. The power outputted from the pulse compression system would be divided into a buncher and 2 X-band linacs. These 3 sections will accelerate the electron beam from a thermionic gun to 100 MeV. The proposed current inside each pulse is 150 mA. Deducting the 100 ns filling of the main accelerating structure, the duration time of the electron bunch is 200 ns. Major parameter of this accelerator is listed in Table 1. To serve as a FLASH tool with dose rate > 100 Gy/s, the maximum irradiated area of this accelerator based on the proposed parameter is 24 cm².

* This work was supported by the National Natural Science Foundation of China (NSFC) No.11922504

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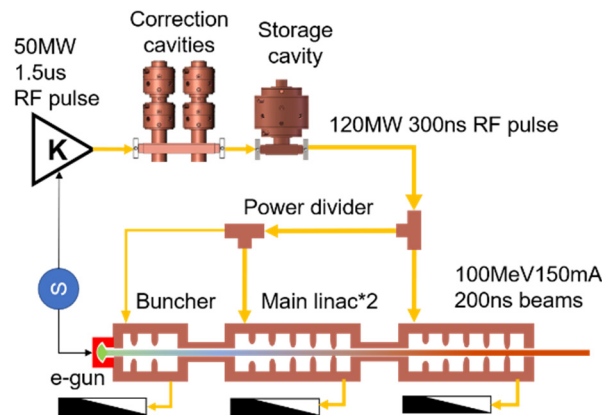


Figure 1: Layout of the 100-MeV accelerator scheme.

Table 1: Major Parameters of the Accelerator

Parameter	Value
Frequency	11.424 GHz
Power from Klystron	50 MW
Power after compression	120 MW
Available Power considering loss	100 MW
Pulse width after compression	300 ns
Beam current	150 mA
Maximum repetition rate	40 Hz
Average current	1.2 μ A
Dose rate with 24 cm ² field	100 Gy/s

The detailed parameters of the buncher and the 2 linacs is listed in Table 2. About 10-MW of the compressed power was distributed to the buncher, which bunches and boosts the 20-keV electron beam from a thermionic cathode gun to 8 MeV. The 2 accelerating structures adopt a constant-gradient scheme. Each of them will accelerate the bunches by 46 MeV with an input RF power of 45 MW. To overall length of this accelerator is less than 2 m.

In the following sections, the progress of the pulse compression system and consideration of the buncher are presented.

Table 2: Parameters of the Accelerating Structures

Parameter	Value
Bunching Structure	
Length	0.25 m
Beam energy gain	8 MeV
Require power	10 MW
Main Accelerating Structures	
Length	0.65 m
Shunt impedance	$\sim 100 \text{ M}\Omega/\text{m}$
Beam energy gain	46 MeV
Require power	45 MW
Filling time	$\sim 100 \text{ ns}$

THE PULSE COMPRESSION SYSTEM

The first stage of the pulse compression system is to construct a 200-ns correction cavity chain and a spherical storage cavity. The CAD models of them are shown in Fig. 2. The storage cavity is a spherical cavity work on TE_{114} mode. The correction cavity chain consists of 4 spherical cavity pairs, with each cavity working on TE_{113} mode. This structure is similar to the one in Ref. [4]. Each cavity pairs contributes 2 resonance frequencies with its 0 mode and π mode. Two cavity pairs are attached to one polarizer. Because each cavity pairs works on the different frequency, the polarizer coupled to each cavity pairs individually in the frequency domain. Therefore, the correction cavity chain has 8 resonance frequencies. The calculated S12 parameter of the correction cavity chain with High Frequency Simulation Software (HFSS) is shown in Fig. 3.

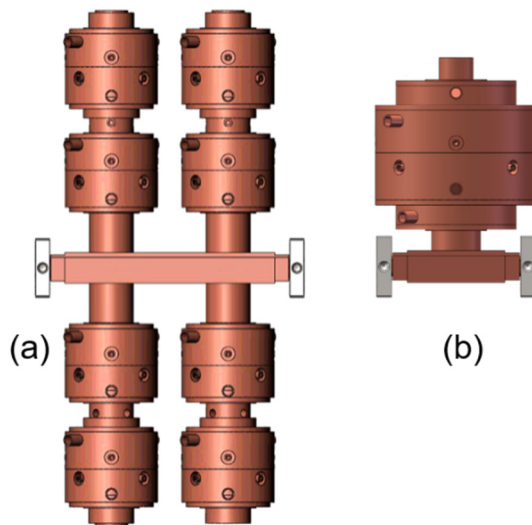


Figure 2: CAD model of the (a) correction cavities and (b) storage cavity.

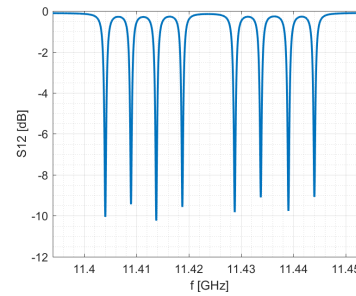


Figure 3: S12 parameter of the correction cavities calculated in HFSS.

The correction cavities and the spherical storage cavity are under fabrication now. Figure 4 is a photo of the brazed correction cavity pairs. The plots listed in Fig. 5 shows the function of the correction cavity in a pulse compression system. A pulse compressor with only one storage cavity will have a decreased output waveform. Utilizing amplitude modulation method, a flat-top output can be achieved, but the power gain is small. A pulse compressor with correction cavities and a storage cavity will have rippled output waveform. Utilizing amplitude modulation method into such a system could attain a higher flat-top power gain, compared with the storage-cavity-only pulse compressor. The parameter used in Fig. 5 is: $Q_{0,sc} = 9.6 \times 10$, $\beta_{sc} = 4.2$, $Q_{0,cc} = 4.5 \times 10$, $\beta_{cc} = 2.0$. The subscript “sc” and “cc” is short for storage cavity and correction cavity respectively.



Figure 4: Photo of brazed correction cavity pairs.

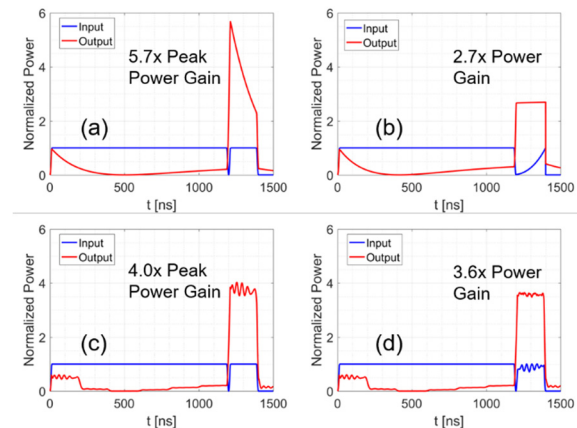


Figure 5: (a) Waveforms of a one-storage-cavity pulse compressor. (b) The amplitude-modulated waveforms of a one-storage-cavity pulse compressor. (c) The amplitude-modulated waveforms of a pulse compressor with correction cavities. (d) Waveforms of a pulse compressor with correction cavities.

THE BUNCHER

Considering the 100-ns filling time of the main accelerating structure, the filling time of the buncher should not exceed 100 ns. Two schemes are being taken into account. The sketch of them are shown in Fig. 6. The first one is a traditional travelling structure with varying phase velocity and accelerating gradient. This scheme could capture up to 90 percent of the electron from the DC electron gun theoretically. But the low- β section of this structure is too narrow, which makes it very hard to fabricate and tune. What's more, strong longitudinal magnetic field is needed to focus the beam in the beginning to make up for its dispersion. The second scheme is an integrated one, which combines the standing-wave structure and travelling structure. Due to the electro-static focusing effect of the standing-wave section, only weak or no focusing magnetic field is needed. What's more, due to the low Q value of the input coupler, there's less reflection during the filling time and no circulator is needed compared with a traditional standing-wave structure. The filling time of the standing-wave section is a major problem for the integrated structure. An over-coupled scheme was under studying.

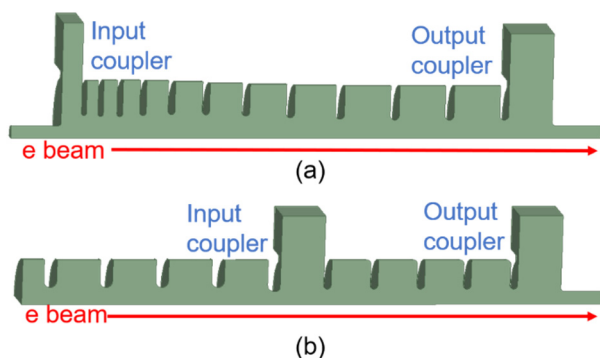


Figure 6: (a) Sketch of a travelling structure with varying phase velocity. (b) Sketch of an integrated structure.

CONCLUSION

A compact electron accelerator for VHEE radiotherapy was proposed based on the Tsinghua X-band High Power Test stand. As the first stage of the pulse compression system, a 200-ns correction cavity chain and the storage cavity are under fabrication. Attention are being paid to design a short-filling-time electron buncher. An integrated structure with an over-coupled standing-wave section was proposed and will be studied in the future.

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