PHYSICAL DESIGN OF 4 MeV/2.5 MeV DUAL-ENERGY X-BAND SW ACCELERATOR *

Jianfei Hua#, Dechun Tong, Qingxiu Jin, Jiaru Shi, Huaibi Chen, Department of Engineering Physics, Tsinghua University, Beijing, P. R. China
Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education

Abstract

On the basis of an X-band 2MeV on-axis standing wave electron linear accelerator [1], a compact 4MeV/2.5MeV X-band accelerator is being developed at Tsinghua University for non-destructive testing. The single tube can deliver two kinds of x-rays, with dose rate of >100cGy/min@m at 4MeV or >50cGy/min@m at 2.5MeV. To suppress the nearby modes, the coupler is set in the middle of the long coupled cavity chain. The coupled circuit model is applied to analyze the RF characteristic and the dynamic is investigated by CAV code. The prototype has being machined and tuned at our laboratory.

INTRODUCTION

Interest in higher-frequencies electron accelerators has been grown not only for high gradient research but also for compact application, which leads to renewed R&D activities with X-band accelerators [2-6]. The many advantages of using higher RF frequency include higher shunt impedance, higher breakdown threshold level, smaller size and short fill time.

The x-ray non-destructive testing (NDT) are one of the main application fields for low-energy electron accelerators, which can be used for inner check of the industrial products. As is known, different-thickness objects need appropriate x-ray energy to provide accurate and clear image information. A compact dual-energy 4MeV/2.5MeV X-band accelerator for on-site NDT is under development at our laboratory working at 9.3GHz. The physical design and RF characteristic are described below.

PHYSICAL DESIGN

The on-axis coupled SW structure, operated in the π/2 mode at 9.3GHz, is chosen based on our experience [1, 7], which offers a significantly smaller diameter than the side-coupled structure. Besides the consideration of compactness, the structure is convenient to machine and braze.

The x-ray NDT system is required to obtain dose rate of >100cGy/min@m for 4MeV, or >50cGy/min@m for 2.5MeV, respectively. According the parameters of the x-ray converter target and the RF power source, the peak pulse currents of this tube should be arrived at 50mA for 4MeV and 90mA for 2.5MeV.

The cavity configuration and the dynamic are designed by CAV, coded by our laboratory. It is optimized for high shunt impedance and a relative large coupling coefficient. Based on the input RF power>0.9MW, the X-band tube is designed to approximately 320mm long, including 21 accelerating cavities and 20 on-axis coupling cavities. The first five accelerating cavities and 4 coupling cavities work as a buncher. The design of the buncher and the selection of the operating parameters are compromised for the dual energy 4MeV or 2.5MeV output. The average effective shunt impedance is more than 125 MΩ/m. It is required to achieve the field flatness >95% between the buncher and acceleration section. The maximum on axis field in the tube is 30MV/m, corresponding to a peak field on copper of 102MV/m, which should be far from the breakdown limit at X-band.

In addition, the RF alternating phase focusing is applied to improve the beam spot without external magnetic focusing devices. And the asymmetrical first cavity is adopted to provide an asymmetrical electric and magnetic fields, which makes the RF phase-focusing technique more effective. Thus the spot size can be controlled at 1.5mm in diameter.

The dual energy shift can be easily accomplished only by changing the injection voltage of the gun and the input RF power. As a result, some parameters for the dual-energy X-band tube are listed in Table 1.

Table 1: Parameters for the Dual-Energy Tube

Output Energy	**4MeV**	**2.5MeV**
Input RF power (MW)	0.9	0.74
Peak beam current (mA)	50	100
Injection Voltage (kV)	9.5	18
Capture efficiency	30%	25%
Dose rate(cGy/min@m)	>100	>50

Taking into the limited input RF power, it will require enough accelerating cavities to provide the demanded energy. So it is necessary to analyze the pass band performance caused by the long cavity chain. The coupler has been specially designed for the long X-band tube with 41 cavities as follows.

COUPLER DESIGN

The equivalent circuit method [8] is used widely to analyze the microwave characteristic of the periodic or non-periodic coupled cavity chain, such as the dispersion frequencies and the reflection factor of the cavity, the field distribution of the each mode and so on. Short chain,

* Work supported by National Science Foundation of China (No. 10775079)
# jfhua@mail.tsinghua.edu.cn

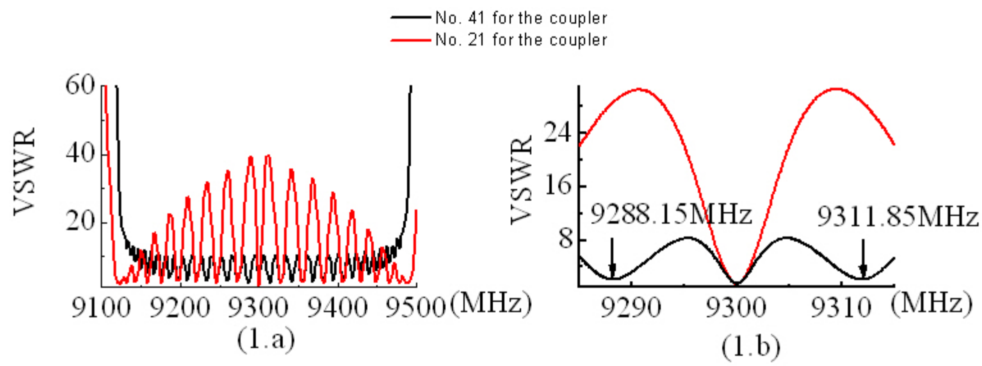
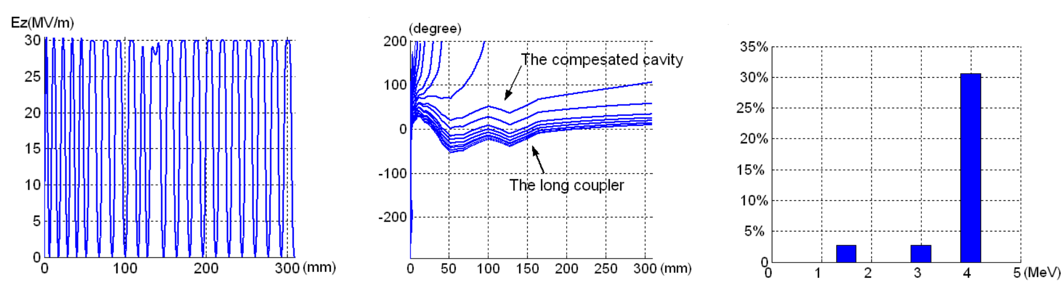


Figure 1: The pass band performance of the long chain for the 450Mhz (1.a) and 30MHz (1.b) bandwidth. The black line is for the coupler located at the end of the chain, while the red line for the location in the middle.

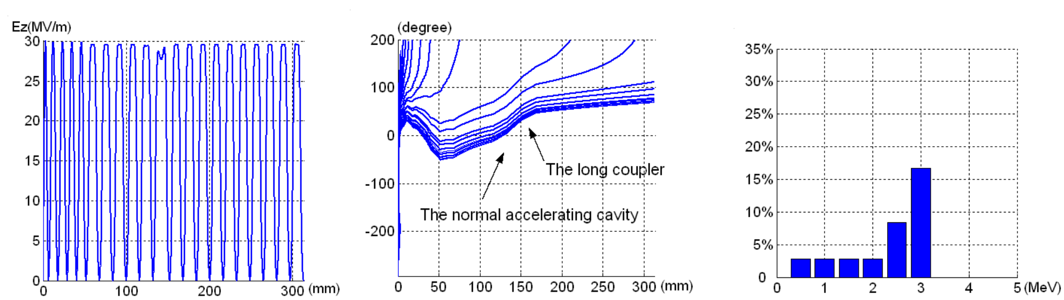
large coupling coefficient and the high quality factor contribute to the large mode space, so as to ensure stability of operation.

The location of the coupler will affect the pass band performance. The mode overlapping caused by nearby modes can be to some extent reduced when the coupler moved from the end to the middle of the long chain. Figure 1 shows the pass band performance for the different locations of the coupler. The black line is for the coupler located at the end of the chain (No. 41), while the red line for the location in the middle (No. 21). Here the number of cavities is 41 and the nearest neighbour coupling is 3.5% according to the design parameters. And the rapid diagnosis technology based on the external characteristic obtained from the coupler is being studied, which will help the next tuning for the long chain.

Considering the small configuration of the X-band accelerator, the coupler is difficult to fabricate as the same length as the normal light velocity cavity (16.12mm). When the coupler (>20mm) located inside the accelerating chain, which is equipped with separate cooling slot, will be inevitably introduce the phase slippage. So a short cavity is added near the coupler to compensate the dynamic deterioration caused by the



(2.a) The field distribution, phase slippage and capture efficiency for 4MeV with the compensate cavity.



(2.b) Without the compensate cavity, the corresponding dynamic process

Figure 2: The 4MeV dynamic for the compensate method (2.a), including the field distribution, the phase slippage and the capture efficiency. The corresponding poor dynamic without the compensate cavity for (2.b).

phase slippage.

The 4MeV dynamic for the compensate method is presented in Fig. 2.a, which the field of the bunch are optimized to provide the transverse focusing as well as longitudinal bunching and accelerating. The compensate effect of the phase slippage, compared with the normal light velocity accelerating cavity (seen in Fig. 2.b), is obvious and facilitate to produce good beam quality.

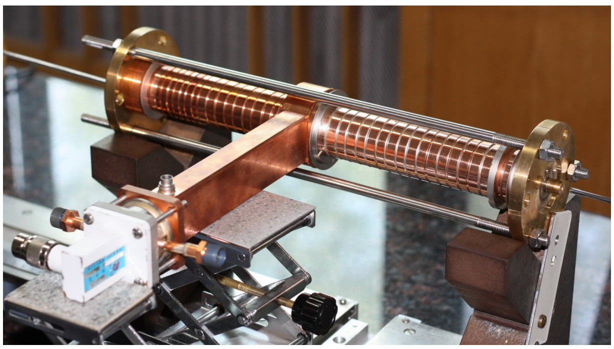


Figure 3: 4MeV X-band accelerating tube assembly

The coupler is adjusted for overcoupling of 1.5 at zero beam loading as a compromise between the dual energy mode.

Figure 3 shows the assemble tube on the tuning phase.

CONCLUSION

We have designed a 320mm-long X-band accelerator tube for NDT with 0.9MW RF input. With the coupler located in the middle of the long chain, a short compensate cavity is used to reduce the phase slippage effect. The single tube can produce two kinds of x-ray: dose rate of >100cGy/min@m for 4MeV case and >50cGy/min@m for 2.5MeV case, respectively. It is convenient to carry out on-site testing of the different-thickness industrial products using such X-band system. Now the tube is under cold test and tuning.

ACKNOWLEDGEMENTS

The authors thank Mr. Yang Zou for the help during the brazing and sealing, Mr. Wei Sheng and Mr. Jiaqi Qiu for the help during the cold measurement, Mr. Jin Lv for the help in fabrication.

REFERENCES

[1] X. Sun, D. Tong, Q. Jin, et al., “A Portable X-band on-axis standing wave linac structure”, PAC’97, Vancouver, p. 1221 (1997);

[2] F. Sakamoto, M. Uesaka, et al., “Beam generation and acceleration experiments of X-band linac and monochromatic KeV x-ray source of the University of Tokyo”, PAC’07, Albuquerque, New Mexico, p. 2784 (2007);

[3] S. Dobert, C. Adolphsen, et al., “High gradient performance of NLC/GLC X-band accelerating structures”, PAC’05, Knoxville, Tennessee, p. 372 (2005);

[4] http://indico.cern.ch/conferenceDisplay.py?confId =30911;

[5] A. Saverskiy, H. Deruyter, et al., “Portable X-band linear electron accelerators for radiographic applications”, PAC’05, Knoxville, Tennessee, p. 1985 (2005);

[6] T. Natsui, T. Yamamoto, et al., “Experiment of x-ray source by 9.4GHz x-band linac for nondestructive testing system”, PAC’07, Albuquerque, New Mexico, p. 2781 (2007);

[7] X. Sun, D. Tong, Q. Jin, et al., “The design and development of a 6MeV X-band on-axis coupling standing wave linear accelerator”, PAC’01, Chicago, p. 3900 (2001);

[8] D. E. Nagle, E. A. Knapp and B. C. Knapp, Rev. Sci. Instrum., 38 (1967), p. 1583

[9] X. Tao, D. Tong, “A pass band performance simulation code of coupled cavities”, LINAC’04, Lubeck, p. 183 (2004);