AN X-BAND LINEAR ACCELERATOR WITH CONTINUOUSLY-ADJUSTABLE BEAM ENERGY *

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Abstract

An X-band linac is designed to produce beam energy between 0.5MeV and 1.5MeV, and the output beam energy is continuously adjustable within this range. Two sections of linacs are combined and powered by a single microwave source. By tuning the RF phase and amplitude of the second section of the linac, the electron beam can see either acceleration or deceleration, which tunes the output energy. This paper presented the principle and the design of the linac, as well as the production of the whole system.

INTRODUCTION

In x-ray imaging, appropriate x-ray energy is required for different substances to meet a better sensitivity. The energy varies from several hundreds of keV to several MeV. In the low energy end, x-ray tubes has been well developed. However, tubes with energy higher than 500keV is not easy to obtain. Linacs with energy at MeV levels are also adopted in the industrial for radiographic applications such as non-destructive test and cargo inspection.

From non-destructive testing for industrial inspection, to the industrial CT, to the container inspection, security, and even material inspection, all need to use two or more kinds of energy accelerator as X-ray source[1].

We propose an electron linac that may produce electron beam with energy between 0.5MeV to 1.5MeV. It has a wide range of applications in such aspects as medical imaging, non-destructive flaw detection.

MAIN PRINCIPLE

Being different from single accelerating tube, the accelerator tube is separated into two sections. By changing the amplitude and phase of the second linac section, it is possible to realize the change of energy continuously.

The principle of changing the beam energy is described as follows: The energy of the electron beam is correlate with the acceleration phase. If the accelerating tube is divided into two segments, the first section accelerates the electron energy to E_1, and the second section of the accelerating tube can accelerate the electrons to an Energy of E_2 while the phase is adjustable, so the final energy is (see Eq. 1):

$$E = E_1 + E_2 \cos\varphi . \tag{1}$$

For example, we accelerate the second part's energy to E_2 and switch its phase position to 0°, so the final energy is E_1+E_2. If we switch the second part's phase position to 180°, so the final energy is E_1-E_2. By choosing E_1=1MeV and E_2=0.5MeV, the total energy can be continuously adjusted between 0.5 and 1.5MeV.

Figure 1 shows the schematic diagram of the system configuration of the X-band linac. The RF power is supplied by one source, which is a magnetron in this design. The power is divided into two parts: one is fed into the first accelerating section directly; the other is fed into the second accelerating section through an attenuator and a phase shifter, which are used to change the amplitude and the phase of the second tube.

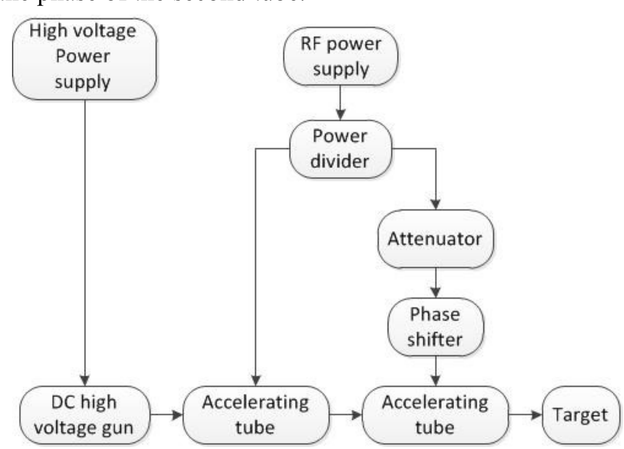

Figure 1: Schematic diagram of the linac system.

THE ACCELERATOR TUBE

The first accelerator section is a 6-cell pi-mode structure. The electron beam from the DC gun is bunched by the first cell and further accelerated by the following 5 cells. The second section is a 2-cell pi-mode structure.

We choose on-axis magnetic coupling through kidney shaped holes between the cells. The coupling coefficient is designed to ensure a large mode separation between the π-mode and the π-1 mode. Since there are only 6 cells in the first section. It is not difficult to have a 10MHz mode separation if the coupling coefficient between the adjacent cells is 0.02.

Cell geometries are simulated in SUPERFISH and the field is exported into PARMELA to do a particle tracking simulation. The longitudinal electric field on axis used in

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ISBN 978-3-95450-171-7

simulation is plotted in Figure 2. The energy variation with respect to the. RF phase of the second in Pamela simulation is plotted in Figure 3. The capture ratio from the DC beam is about 30%.

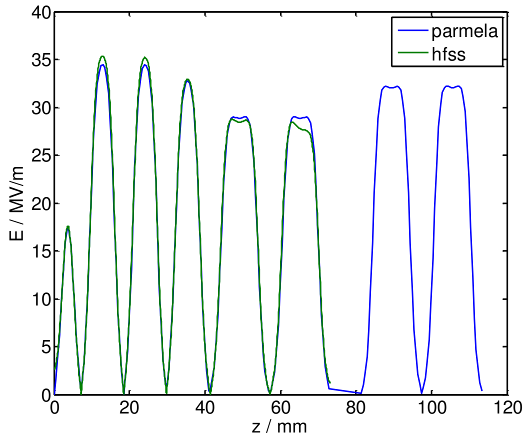

Figure 2: The field distribution of accelerator tube.

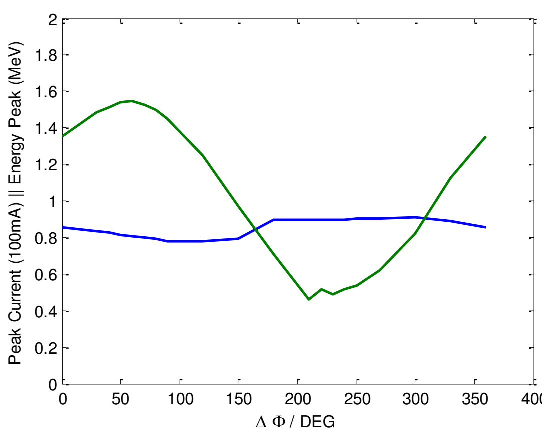

Figure 3: The energy (Green) and the Peak current (Blue) variation with respect to the phase in Pamela simulation.

The disks of the structure are brazed together, as well as all kinds of flanges, RF windows and water cooling plates. Figure 4 shows the picture of the accelerator tube. The left figure is the CAD design, while the right figure is the real product.

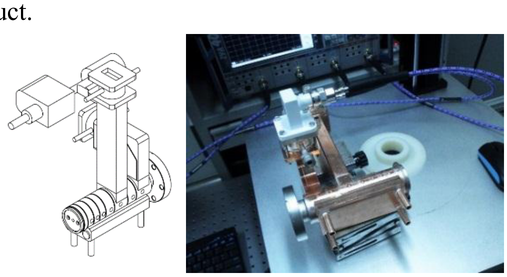

Figure 4: Photo of the accelerator tube.

After the accelerating tube is brazed, we measured the frequency of the tube, and it is tuned by tuning holes outside the cell wall with push-pull set up. A snapshot of the measurement data is shown in figure 5. The frequency of the first section is 9.296657GHz, and the frequency of the second section is 9.296662GHz, the frequencies are meet the requirement of design, since the frequency range of the magnetron is 20MHz.

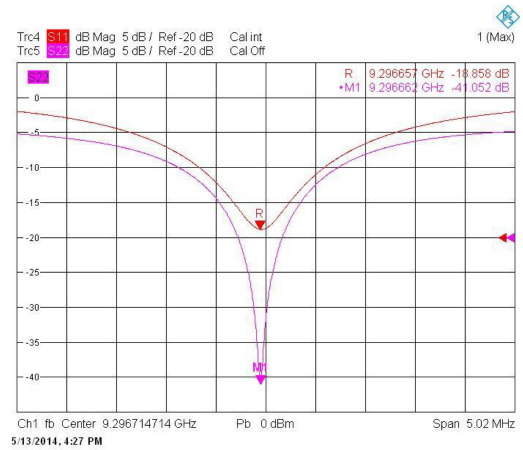

Figure 5: Frequency of the accelerating tube.

THE MODULATOR

The high voltage pulse modulator is the critical component for linac. It can generate high voltage pulse with appropriate amplitude, width, repetition frequency and power. The modulator's loads are magnetron and electron gun.

The direct current high voltage power supply charges the PFN（pulse forming network）through a charging inductance at first, the charging voltage is about twice as the supply voltage. After this process, a low voltage pulse is added to switch gird to make switch turn on. The pulse shaping network discharges through the conductive switch and makes a high voltage pulse on the load. The functional block diagram is shown in figure 6.

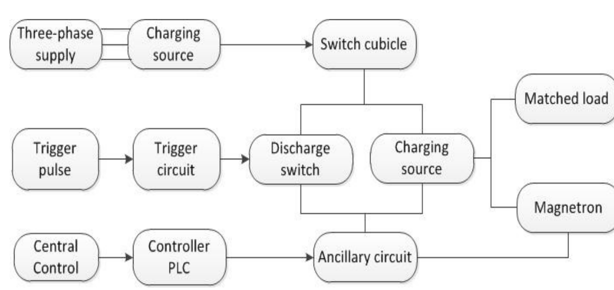

Figure 6: Functional block diagram.

The high voltage pulse modulator control box consists of 4 layers (Figure 7), with the bottom layer as charging source and switch cabinet. The middle layers are electronic gun power supply and alarm system. The upper end layer is the control system for PC.

ISBN 978-3-95450-171-7

Figure 7: Layers of modulator control box.

CONSTITUTE OF ACCELERATOR

The accelerator system is composed of following four main devices and an interconnected system: X-ray equipment; modulator; control system; water-cooling system; water pipe and cable.

The X-ray equipment is composed of following elements: the electron gun; accelerating tube; ceramic window; titanium pump; target; water jackets. The microwave system is composed by magnetron; attenuator; phase shifter; power coupler; four-pole circulator; power divider; waveguide; AFC system.

The control system adopt programmable logic controller and its extended module based on fieldbus technology to achieve the operational control and safety interlock protection. By using PC and optical network control technology, the signal can be isolate and stable. The whole system consists of parameter display; parameter setting; operation reminding; fault self-diagnosis; monitoring equipment and so on.

BEAM ENERGY MEASUREMENT

During the measurement of electron beam energy, we can use current-thickness curvilinear to extrapolate the energy. Experiment results show that if we take aluminium as the absorbing material, we can get the database diagram about the current and the thickness of the aluminium plate. It is shown in Figure 7 [2].

According to GB/T16814-1997, for aluminium, when the electron energy is between 1.0MeV to 10MeV [3]. We can use the quadratic equation (see Eq. 2) to get the relation between the range R_p and the energy E:

$$E = 0.256 + 4.91R_p - 0.0248R_p^{\,2} \qquad (2)$$

CONCLUSION

The X-band Linac can change energy continuously between 0.5MeV to 1.5MeV, by tuning the RF phase of the second section of the accelerator. The linac system is under development and will be tested very soon.

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ISBN 978-3-95450-171-7