15th International Particle Accelerator Conference,Nashville, TN JACoW Publishing
ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-MOPC57

DEVELOPMENT OF AN S-BAND MULTI-BEAM ACCELERATOR FOR STATIONARY CT APPLICATION

L. Zhang[1,2,3], H. Wang[1,2], F. Liu[1,2], H. Zha[1,2†], J. Shi[1,2], Q. Gao[1,2], Q. Li[1,2], X. Zhang[3], Y. Liu[3]
[1]Department of Engineering Physics, Tsinghua University, Beijing, People's Republic Of China
[2]Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education, Beijing, People's Republic of China
[3]Nuctech Company Limited, Beijing, People's Republic of China

Abstract

Stationary CT is a novel CT technology to significantly improve scanning speed, by using distributed multiple ray sources instead of conventional helical rotation with single source. This work presents an S-band multi-beam accelerator as a multiple MV-level X-ray source for industrial stationary CT application. This accelerator consists of 7 parallel-distributed acceleration cavity and 6 coupling cavity, operating in pi/2 standing-wave mode with a centre frequency of 2998 MHz. This structure can generate 0.7 MeV electrons with 100 mA peak current at each beamline according to the imaging requirement. The novel multiple high-energy X-ray source will fill in the blank of source requirements in industrial stationary CT application.

INTRODUCTION

In conventional spiral CT, X-ray tube rotates rapidly around the inspected object, which increases the effective focal spot of the source and produces motion artifacts in the image. Stationary CT replaces the mechanical rotating structure of spiral CT with distributed X-ray source, which is performed by electronically triggering to generate multi-angle X-ray. This method improves the scanning efficiency of CT, eliminates the motion artifact of spiral CT, and reduces the dose for inspected object by optimizing the imaging algorithm. Therefore, distributed X-ray source have great application prospects in the fields of medical, security and industrial non-destructive testing [1].

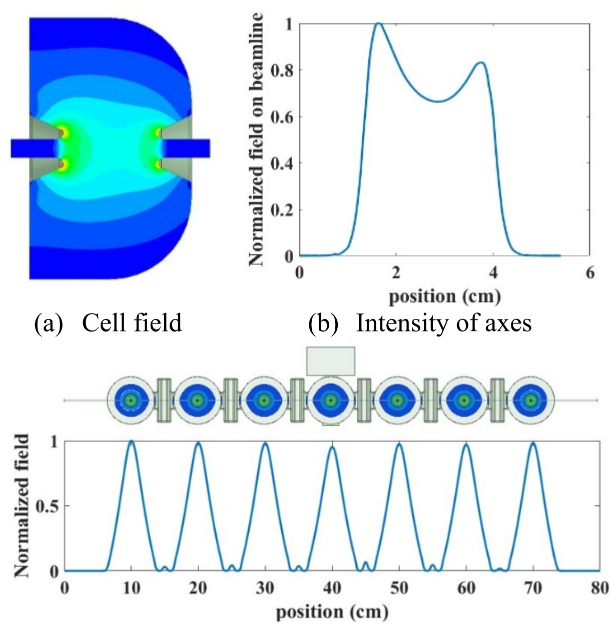
For stationary CT, nearly all design still applies X-ray tube as the light source. New technology includes the use of nano-carbon tube cathode and Photon-counting, but they all have the same downsides. CT using X-ray tube is constrained by the poor radiation quality, especial for industrial detection. For most X-ray tubes, they have acceleration voltage at 100 KV, peak current at 10mA, the generated X-ray is hard to penetrate material with high Z. For industrial uses like the scanning of shipping container, we need new source to create more powerful X-ray [2].

To tackle this problem, we present a new design, which uses RF accelerator to create the X-ray needed. Using RF acceleration technology we can easily generate electron beam with energy at MeV scale. This can further produce much more powerful X-ray that can be used in many industrial environments [3]. We believe our design can provide a novel technological way for stationary CT development.

ACCELERATOR DESIGN

As a new acceleration structure, we adopt the form of side-by-side cavity chain to realize multiple acceleration paths. The traditional linear electron accelerating tube usually has only one electron accelerating beamline, and the accelerating cavity is arranged in series. In this new accelerating structure, the original series cavity is distributed side by side to form a plurality of electron accelerating beamlines. Through the acceleration of standing wave field, the beam output of multiple beamlines can be realized.

Our acceleration design contains 7 single acceleration cells with 6 coupling cells. Through cavity and field distribution simulation, the axial field strength shown in Fig. 1 (b) is obtained. The field distribution of the 7 cavities is shown in Fig. 1 (c) is obtained by theoretical calculation. From the simulation results, the field distribution of each cavity is consistent.



(a) Cell field (b) Intensity of axes

(c) Multi-cell field

Figure 1: Acceleration field simulation.

The working frequency of the accelerator tube is set at 2998 MHz, and it can output 7 X-ray channels with good

†zha_hao@mail.tsinghua.edu.cn

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-MOPC57

energy consistency. The input microwave power is set at about 2 MW. As a result, the accelerating electron beam energy is 0.7 MeV, and the instantaneous accelerating current intensity is 100 mA. The specific design parameters are shown in Table 1.

Table 1: Design Parameters

Name	Value	Unit
Frequence	2998	MHz
Cell number	7	
Input power	2	MW
Beam energy	0.7	MeV
Peak current	100	mA

According to the above cavity design, the acceleration tube can realize the array beam output of 7 points. If there is a larger power source or higher application demand, the side-by-side cavity can continue to be increased. The designed acceleration tube outline structure is shown in Fig. 2 below.

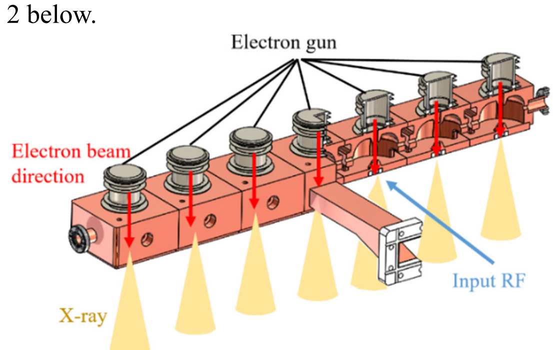


Figure 2: System schematic.

In order to facilitate the processing and consistency, the 7 cavities are processed separately, the 6 acceleration cavities are completely consistent in structure, and the tuning holes are left on the side to facilitate the adjustment of the working frequency consistency of each cavity, and the machining stop between the cavity and the cavity is convenient for subsequent welding. All the cells were machined by high-precision machine tools., which will take cold test and tunning in the next few weeks. The machined acceleration cells are shown in Fig. 3.

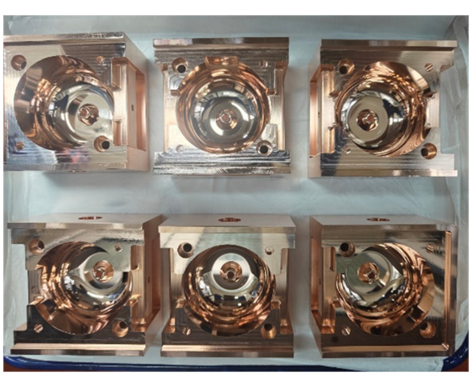


Figure 3: Machined cells of accelerator tube.

ACCELERATOR SYSTEM DESIGN

The layout of the accelerator system based on the acceleration structure is shown in Fig. 4 below. The solid state pulse modulator generates -high voltage pulse, the primary high voltage drives the power source to generate microwave power after being boosted by the pulse transformer, and the standing wave field is established after the microwave power being fed into the coupling cavity of the accelerator tube. The system integrates 7 high voltage power supply components for each electron gun. By adjusting the timing of the high voltage of electron gun, the corresponding primary emission of electron is controlled. The emitted electrons further accelerated by standing wave field will interact with target, which can generate the 0.7 MeV X-ray.

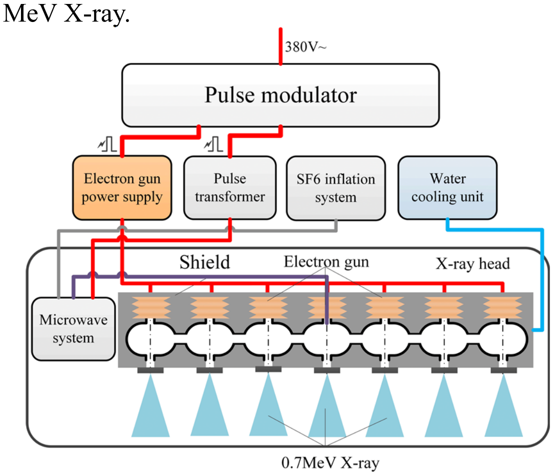


Figure 4: Accelerator system block diagram.

Based on the above system layout scheme, the accelerator system design is carried out around the multi-beam accelerator. The accelerator tube in Fig. 5 is arranged with beam downwards, the S-band magnetron is connected with a four-terminal circulator, and microwave power is fed into the accelerator tube through the waveguide. The pulse transformer and RC matching structure are also displayed in the figure. In order to generate 7 independent X-ray beams, we designed an electron gun power supply component that can provide 7 independent high voltage pulses. For it is a prototype, the overall shielding is not displayed in the design.

We only need one magnetron power source to drive the 7 acceleration tubes, which greatly reduces the volume and the cost of the system the overall X-ray system integration can achieve miniaturization.

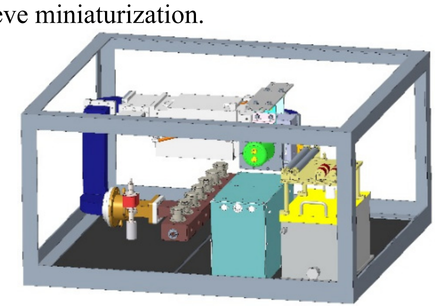


Figure 5: Accelerator system design.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-MOPC57

The schematic diagram of a 7-point light source accelerator system, designed based on the acceleration structure, is depicted in Fig. 6 below. In the illustration, the accelerator is positioned at the upper left corner. Upon entry of the detected object into the detection area, beams are emitted by the accelerator to generate X-rays. Subsequently, array detectors located on the lower and right sides capture penetrated X-rays, ultimately forming images. This system effectively caters to static CT ray sources with an energy level of approximately 0.7 MeV and finds extensive applications in security inspection and industrial non-destructive testing.

Figure 6: System design and application scenarios.

The number of light sources that the accelerator system can carry is limited, in order to meet the number requirements of more point sources and the spatial density of light sources for static CT imaging, we designed the following combined system scheme. Figure 7 shows the schematic diagram of 3 independently distributed 7 points light source accelerator systems, which can realize the imaging requirements of 21 points.

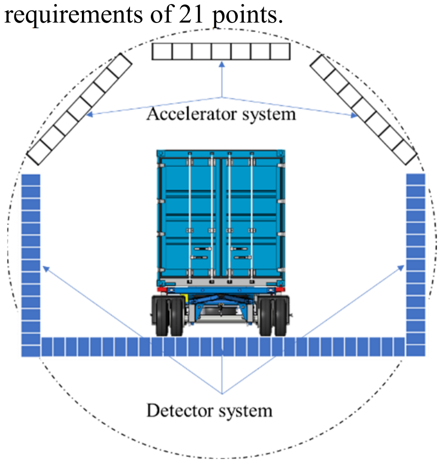


Figure 7: Multi-accelerator system structure diagram.

CONCLUSION

In this article, a new acceleration structure is introduced, and a multi-beam accelerator design scheme is proposed. The feasibility of the scheme is verified by theoretical calculation and computer simulation. It can realize 7 or more points light sources output, and the operating frequency is set in S-band. Each beam can be independently accelerated to an energy of about 0.7 MeV, and the beam intensity can be achieved at 100 mA. Any combination of 7 points light sources can be achieved by controlling the high voltage of the electron gun. The accelerator system scheme proposed in this paper can provide an accelerator system with higher energy than the conventional static CT ray source, which can fill the gap in the energy range of 0.5~1 MeV for container inspection, non-destructive testing and medical fields [4-8]. In the future, we will weld the accelerator tube and test the beam quality, and the corresponding prototype will also be developed.

REFERENCES

[1] P.-Y. Wang *et al.*, “Fitz-Hugh-Curtis syndrome: clinical diagnostic value of dynamic enhanced MSCT,” *J. Phys. Ther. Sci.*, vol. 27, no. 6, pp. 1641–1644, 2015. doi:10.1589/jpts.27.1641

[2] L. W. Goldman, “Principles of CT and CT Technology,” *Journal of Nuclear Medicine Technology*, vol. 35, no. 3, pp. 115–128, Sep. 2007. doi:10.2967/jnmt.107.042978

[3] L. De Chiffre, S. Carmignato, J.-P. Kruth, R. Schmitt, and A. Weckenmann, “Industrial applications of computed tomography,” *CIRP Ann.*, vol. 63, no. 2, pp. 655–677, 2014. doi:10.1016/j.cirp.2014.05.011

[4] “Spiral CT: Principles, Techniques and Clinical Application,” E. K. Fishman and R. B. Jeffrey, Eds. New York: Raven Press, 1995. doi:10.1118/1.597589

[5] W. A. Kalender, “Thin-section three-dimensional spiral CT: is isotropic imaging possible?,” *Acad. Radiol.*, vol. 197, no. 3, pp. 578–580, Dec. 1995. doi:10.1148/radiology.197.3.7480719

[6] J. A. Brink, J. P. Heiken, D. M. Balfe, S. S. Sagel, J. DiCroce, and M. W. Vannier, “Spiral CT: decreased spatial resolution in vivo due to broadening of section-sensitivity profile.,” *Acad. Radiol.*, vol. 185, no. 2, pp. 469–474, Nov. 1992. doi:10.1148/radiology.185.2.1410356

[7] J. Stöhr, The Nature of X-Rays and Their Interactions with Matter. Springer International Publishing, 2023. doi:10.1007/978-3-031-20744-0

[8] T. Matsumoto and H. Mimura, “Point x-ray source using graphite nanofibers and its application to x-ray radiography,” *Appl. Phys. Lett.*, vol. 82, no. 10, pp. 1637–1639, Mar. 2003. doi:10.1063/1.1558969