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A PROPOSAL OF USING IMPROVED RHODOTRON AS A HIGH DOSE RATE MICRO-FOCUSED X-RAY SOURCE*

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Abstract

High energy X-ray computer tomography has wide application in industry, especially in quality control of complicated high-tech equipment. In many applications, higher spatial resolution is needed to discover smaller defects. Rhodotron have been used to produce high power CW electron beam in hundreds of kilowatts level. In this paper, we propose to use an improved Rhodotron to generate high brightness electron beam with high average power. Beam dynamics study shows that when producing tens of kilowatts electron beam, the normalized RMS emittance can be lower than 10 μm, and the relative RMS energy spread can be lower than 0.2%. The beam can be focused to a spot size of about 100μm, and converted to X-Ray by using a rotating target within several kilowatts beam power. Improved Rhodotron proposed in this paper is a good candidate of X-ray source for high resolution high energy industrial CT systems.

INTRODUCTION

High energy industrial CT has shown to be of great value in the research and development of the high-end equipments (large locomotives, engines, nuclear weapons, etc.). But it is still urgent need for higher resolution to detect smaller defects in high-end equipments. To meet the needs, a micro-focused accelerator with high dose rate will be needed.

Traditional used accelerator used for this purpose is RF traveling or standing wave linear accelerator. There are many commercial companies such as VARIAN in American, GUHONG in China, providing linear accelerators for high energy CT inspection. The typical beam energy for high energy CT inspection is 9-15MeV, the dose rate for 9MeV is about 3000 Rad/min, and the X-ray spot size is about 1-2mm. There are also many micro-focused X-ray source products using a DC acceleration tube and a rotating target, the X-ray spot-size can be small as 0.2mm at the electron beam power of 750W and the beam energy of 750kV. For the CT inspection of large equipment with large aerial density, especially in the case of high resolution is needed, one need a X-ray source with high energy (not less than 9MeV), and with high dose rate (not less than 3000 Rad/min), and a very small spot size (not more than 0.2mm).

To generate micro-focused high dose rate X-ray, high brightness electron beam is needed. More specific, electron beam with high average power, low emittance and low energy spread is needed, so one can use a not so complicated focus system to get a small spot size such as 0.2mm. On other side, one should deal with the target temperature rise when producing high dose rate X-ray at a very small spot size. Even use the rotating target system, high duty factor accelerator is needed to avoid the target melting problem.

Some type of accelerators such as Rhodotron [1-8], Rdigetron [9], Fabitron [10], can accelerate electron beam many times using the same RF structure, and can work at very high duty factor, and sometimes work at continuous wave mode. In this paper, it is proposed that using Rhodotron and a rotating target to generate a high dose rate micro-focused X-ray. A layout is shown in Figure 1. The Rhodotron is designed to produce high power electron beam with high brightness.

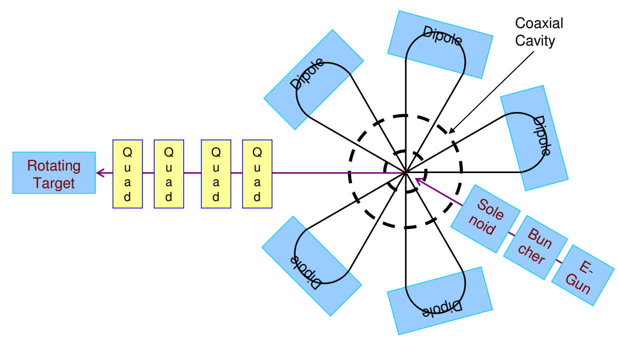

Figure 1: Layout of the proposed micro-focused X-ray source.

Main specification of the proposed micro-focus X-ray source is listed in Table 1.

Table 1: Main specifications of the proposed X-ray source.

Parameters	Value
electron beam energy	9 MeV
dose rate of X-ray at 1m from target	≥ 3000 Rad/min
X-ray spot size (FWHM)	≤ 0.2mm
time structure	10% duty factor, and at 100 Hz

PRELIMINARY BEAM DYNAMICS DESIGN

To generate the proposed dose rate, the needed average power of the electron beam is about 1kW. This value is far less than that has been achieved at high power Rhodotron, in which several hundreds of kW electron beam was produced. So the beam current in our design is relatively low, and the electron beam can be bunched to shorter phase width to acquire high brightness, and a smaller cathode can be used to archive smaller emittance. Additional to the buncher used in low energy section, the acceleration phases in the RF cavity are also chosen to

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bunch the electron beam. In other words, the acceleration phase choice and the non-zero R56 of the dipoles make every dipole can work as a magnetic compressor.

The code PARMELA was used to simulate the beam dynamics in the accelerator. At the end of the accelerator, the normalize RMS emittance of x and y direction are both lower than 8 mm·mrad, the peak current is about 1 Ampere, and the RMS energy spread is about 0.2% (Figure 2).

Using the focus system consisting 4 quadroples, the electron beam can be focused to be smaller than 0.15mm (FWHM, see Figure 3). The dispersion effect and the chromatism effect are included in the simulation by the code PARMELA. At the rotating target, the electron beam is scattered by the target material, and the spot size of X-ray beam may be larger than the beam size simulated by the beam tracking code. The diffusion process of the electron in the target is simulated by the code GEANT4. The simulation shows that there is not obvious difference between the X-ray spot size and the electron beam spot size even with a focus spot of 0.1mm.

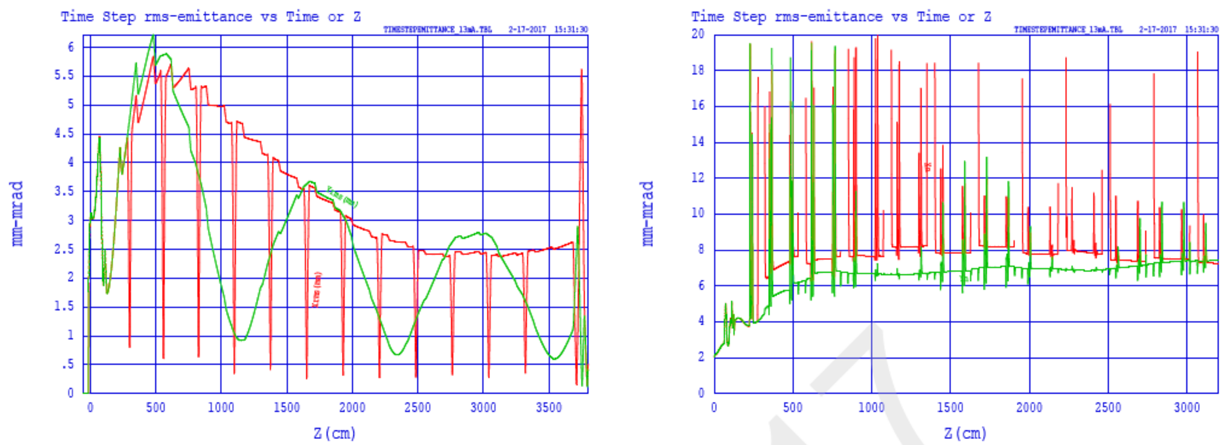

Figure 2: The beam envelope and emittance of the electron beam in the accelerator.

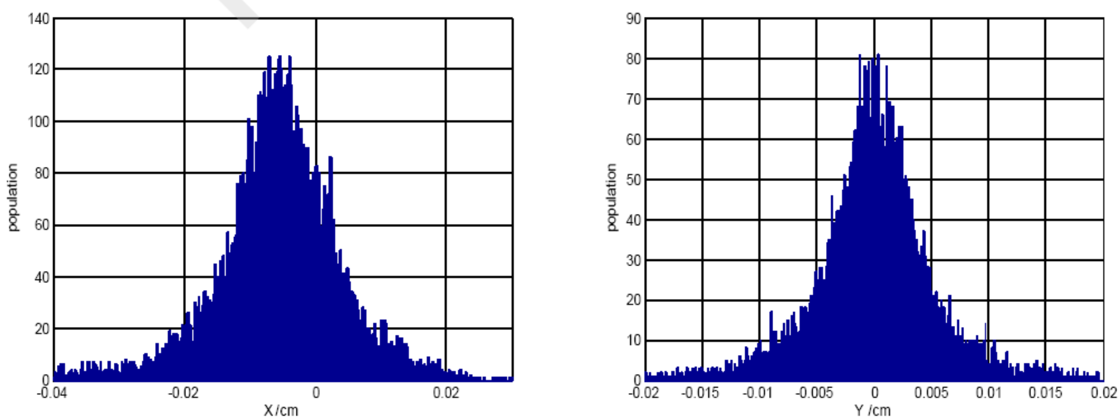

Figure 3: Distribution of the electron focus spot in x and y direction.

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KEY TECHNOLOGY NEEDED TO REALIZE THE PROPOSED DESIGN

Main technologies needed are coaxial cavity with large dimension, dipole magnet with high accuracy to provide proper transverse focusing, rotating bremsstrahlung targets in vacuum. Besides these key technologies, high voltage pulsed power supply with very high repetition rate may be needed to avoid the overlapping of the beam track in the center of the accelerator. To avoid the overlapping, we proposed to generate one electron bunch every 10 RF cycles. That is to say, for a RF frequency of 108MHz, the power supply of the grid should work at repetition rate of 10.8MHz, and produce a pulse of FWHM less than about 3 nanosecond which is about 1/3 one RF period. There is a R&D project in progress to develop key technologies including the generation of electric pulse with needed repetition rate, RF cavities, the high accuracy dipole magnet, rotating target, and also the beam dynamics optimization.

CONCLUSION AND FUTURE WORK

Methode of using improved Rhodotron as micro-focused X-ray source is proposed. Beam dynamics design of the improved Rhodotron are carried out to generate X-ray with high dose rate and very small focus spot. Beam dynamics study shows that when producing tens of kilo-watts electron beam, the normalized RMS emittance can be lower than 10 μm, and the relative RMS energy spread can be lower than 0.2%. The beam can be focused to a spot size of about 100μm.

There is a R&D project in progress in CAEP to develop key technologies including the generation of electric pulse with needed repetition rate, RF cavities, the high accuracy dipole magnet, rotating target, and also the beam dynamics optimization.

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