ELECTRON GUN USED IN THE ACCELERATOR FOR CUSTOMS INSPECTION SYSTEMS

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Abstract

This paper introduces the characteristics of the electron gun used in the 9MeV traveling wave electron linear accelerator for fixed customs container inspection system. With the scandate cathode, the electron gun meets the accelerator characteristics with the vacuum system not needing high-temperature roasting to degas. The electron gun can work normally at a vacuum of about 10^{-5} Pa and can be reinstalled after exposure to air. In the accelerator, the electron gun emits a beam which strikes the target to produce an X-ray beam with a dosage rate of over 30Gy/min.m. and a beam focus spot of less than Φ 2mm. The beam intensity and characteristics ensure the high resolution needed in the inspection pictures. The EGUN code was used to simulate the structure and properties of the electron gun, providing the reference size and debugging parameters for replacing the electron gun.

1 INTRODUCTION

Fixed large container non-destructive inspection systems with on-line real-time image processing are installed at customs stations to inspect cargo for smuggling prevention. The customs inspection stations require accelerator systems produce high-energy X-rays reliably for a long time. The accelerator beam at the target should have high beam intensity and small beam spot to produce detector images that are clear with high resolution. Therefore, the electron gun currently used should have large emission current, relatively small beam emittance, long service time, steady emissions and is easily serviced.

2 ELECTRON GUN STRUCTURE AND CHARACTERISTICS

2.1 Structure and Characteristics

The gun is a three-electrode Pierce-type with an indirectly heated cathode heated by a filament, Fig.1. Scandate ($Sc_2O_3/\ BaO$) diffused-material is used in cathode to reduce the average effective work function of the emission surface below the normal B-type cathode by 0.3eV and to reduce the working temperature by 100°C. So the electron gun has the following characteristics:

1) Large cathode emission current, relatively low working temperature of about 950°C and long service time.
2) Magnetic lens added behind the electron gun provide long emission range and focusing of the electron beam.
3) The vacuum-tight seal structure facilitates the electron gun disassembly and testing.
4) The electron gun is well insulated at high voltage, comparatively small in size and light in weight.

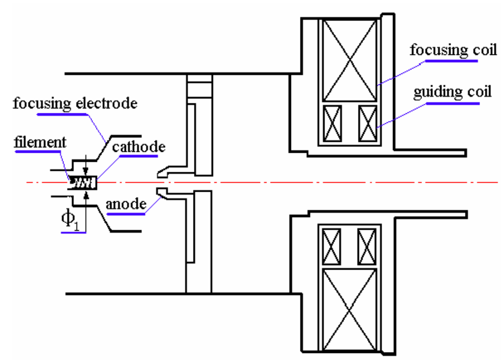

Fig.1. Electron gun structure

2.2 Applied Characteristics

The electron gun with the scandate cathode used in the travelling wave electron linear accelerator complements the accelerator structural characteristics. The system does not need high-temperature roasting to degas. The electron gun can work normally at a vacuum of about 10^{-5} Pa, and if exposed to air at ordinary temperatures, can be reactivated for normal use. Eight travelling wave electron linear accelerators have been installed with this type of electron gun with the scandate cathode and each is providing long-term steady emissions with good dosage stability over 120 hours of continuous operation. For a filament current of about 2.4A and an anode voltage of –40kV, the pulse current emitted by the electron gun to the accelerator entrance is 300mA, which provides the desired X-ray dosage rate when the electron beam strikes the target. Some experimental data is given in Table1.

Table 1: Electron gun filament current and X-ray dosage

Accelerator serial number	Current I_f/A	Dosage CGy/min.m
1	2.41	3600
2	2.40	3600
3	2.42	3900
4	2.42	3900
5	2.41	3600

3 ELECTRON GUN SIMULATION

At present each electron gun installed on the accelerator is operating steadily. However, the heated-filament will eventually burn out and the cathode will stop working after a long period of time. When such problems arise, alternate parts must be quickly installed to replace the faulty parts. The replacement parts must be carefully produced to retain the original emission capability after reinstallation. Therefore, the EGUN code was used to simulate the changing of the relative position between the focusing electrode and the cathode, which influences the beam intensity and emittance. The influence of relative position between the cathode and the anode was also studied.

3.1 Influence of the relative position between the focusing electrode and the cathode

The first simulation calculated the electron trajectories in the original structure and size of electron gun for the original operating conditions. As Fig.1 shows, putting the filament inside the cathode creates a gap between the cathode and the focusing electrode, which deforms the equipotential surface close to the cathode edge. Fig.2 shows that this design disturbs the edge electron trajectories, so that, the trajectories of the edge electron will diverge from the ideal lines which converge to the center of the electron beam, which results in the "blurring" of the electron beam edge and increases the anode intercept current.

The distance between the focusing electrode and the cathode in the original electron gun design was reduced from 5.3mm to 3.9mm. The computer simulation showed that the new beam distribution at the electron gun exit obviously reduced the current intercepted by the anode reduced. Fig.4.

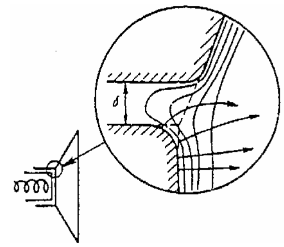

Fig.2. Disturbance of the edge electron trajectories, caused by the change of the distance between the cathode and the focusing electrode

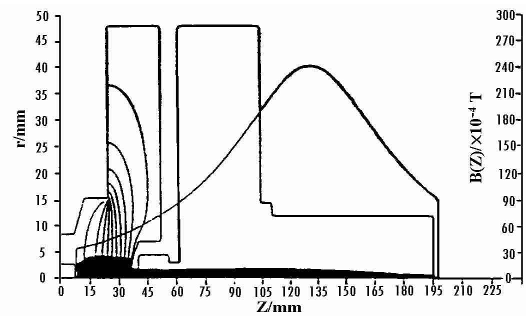

Fig.3. Electron trajectories in the electron gun at the focusing electrode (ϕ_1 =16.8mm)

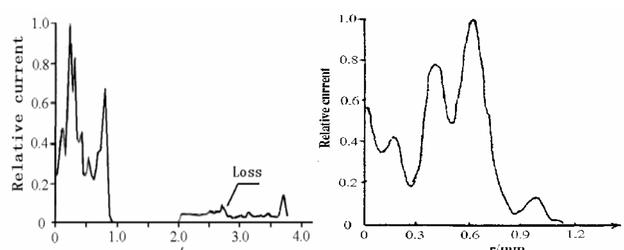

Fig.4. Beam distribution at the electron gun exit at the focusing electrode (Left: ϕ_1 =16.8mm, Right: ϕ_1 =13.8mm)

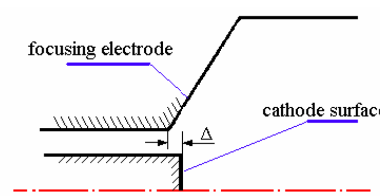

Fig.5. Relative position of focusing electrode and cathode

3.2 Influence of the change of the gap between the cathode and the anode on the beam emission

In the Pierce Gun, the current density (J), the anode voltage (U_a) and the distance (d) between the cathode and the anode are related as:

$$J = A\frac{U_a^{3/2}}{d^2} \tag{1}$$

Therefore, the gap between the anode and the cathode is critical to the beam emission current. Table 2 gives detailed data:

Table 2:Relation between the current at the electron gun exit and the distance between the cathode and the anode

Δ =0, δ =4mm

d/mm	I/mA	ε /mm • mr	k× 10^{-8} /A • $V^{-3/2}$
20.0	432	148.6	5.40
21.0	375	135.1	4.68
21.5	351	125.6	4.58
22.0	329	119.3	4.12
23.0	294	108.4	3.67

where Δ is the position of the cathode surface relative to the end of the parallel part of the focusing electrode, illustrated in Fig.6. When the two are aligned, Δ is equal to 0, and if the cathode surface extends beyond the focusing electrode, then Δ is positive as in Fig 5.

3.3 Influence of the relative position of the focusing electrode and the cathode surface on the beam characteristics

The replacement parts include the focusing electrode and the cathode. The distance between the reinstalled parts influences the characteristics of the rebuilt electron gun. The appropriate position of the assembly and the allowed tolerance were determined by simulating the influence of the relative position of the focusing electrode and the cathode surface on the emission beam assuming that the gap between the cathode and the anode was fixed. Table 3 give results for d constant at 21.5mm.

Table 3: Electron gun emittance characteristics as a function of the distance between the cathode surface and the focusing electrode

d=21.5mm, δ =4mm, Ua=40kV

Δ /mm	I/mA	ε /mm·mr
-0.5	288	77.0
-0.25	316	114.4
0	351	110.3
0.25	391	147.0
0.5	424	173.1
1.0	450	195.1

The simulation results show that the distance between the cathode and the anode greatly affects the emission current. While the emittance as well as the emission current increases as the distance gets smaller. The distance between the cathode surface and the focusing electrode also influences the beam emission and emittance. Therefore, the cathode surface and the focusing electrode should be optimized to produce a smaller emittance.

4 CONCLUSIONS

The simulation and theoretical analysis on the electron gun structure shows that:

1) Reducing the distance between the cathode and the focusing electrode improves the beam characteristics and decreases the anode interception of the beam current. But the distance (δ) should not be so small that the heated focusing electrode produces parasitic emissions.

2) Reducing the distance between the cathode and the anode increases the beam current at the electron gun exit.

3) The relative position of the focusing electrode and the cathode surface also affects the beam emission characteristics.

4) The position and size of the focusing magnetic field can be adjusted to produce an electron beam with good emission and large current.

Simulation of the electron trajectories from the electron gun with the EGUN code provided a further understanding of the electron gun characteristics. Considering the influence of the relative positions of the electrodes on the emission beam and the convenience of the actual repair process, the focusing electrode diameter was chosen to be 14mm as d equal to 21.5mm, and Δ equal to 0. With this structure, increasing the anode aperture produced an exit beam intensity (I) of 300mA and a normalized emittance (ε) of 56.5mm.mr. with the lens magnetic field strength of 280 Gauss. The results provide a reference for the assembly and reinstallation of the electron gun parts. The electron gun characteristics can be estimated with this analysis to assure the electron gun reliability and emission stability.

Reference

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