THE EFFECT OF BACK-STEAMING ELECTRONS TO CATHODE SURFACE TEMPERATURE IN RF GUN

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Abstract

Back-streaming electrons give serious effect to a cathode. In this study, the back-streaming electrons power onto a thermionic cathode of the IAE RF gun was evaluated quantitatively by using an infrared radiation thermometer. Time evolution of cathode surface temperature during RF macro-pulse was also calculated by using 1-dimensional heat conduction model and result of a 2-dimentional particle simulation. It was found that the use of a hollow cathode with external magnetic field would reduce the effect well.

1. INTRODUCTION

RF guns can generally accelerate electrons with much higher electric field than electrostatic electron guns. However, it is serious problem that some electrons escape from accelerating phase and stream to the cathode surface. Thus, the cathode is heated up during macro-pulse, the extracted beam current increases, and the energy of the electrons cannot be kept constant. It is so-called "Back-bombardment problem". Due to the problem, long pulse operation is typically restricted up to 4 μs.

To solve the problem, photocathode with short pulse laser is generally used. With the cathode, higher energy beam is got than with the thermionic cathode. However, the cathode has short life, high cost is required and apparatus get complicate. On the other hand, a group at Stanford University [1] proposed and tested a method to avoid this problem by applying transverse magnetic field. However, it is thought that accelerated electrons also bend.

Our group had developed 2-D particle simulation code KUBLI [2,3,4] and electron trajectories in the 4.5-cavity S-band thermionic RF gun [4,5,6] were calculated. It was found that the back-streaming electrons having high energy converged to the center of cathode surface and the electrons having low energy didn't converged on the cathode surface. For the result of analysis, we have used solid cathode and hollow cathode having a hole on the cathode surface.

The objective of this study is to solve the back-bombardment problem with thermionic cathode, which is easy to use and does not spoil the compactness of the system. First of all, we measured the surface temperature of the cathode with and without a hole during beam production by the use of an infrared radiation thermometer, and the average back-streaming beam power was evaluated with a simple 0-D energy transporting model. And then, the temperature evolution during the beam macro pulse, which affects strongly the beam quality, is calculated with 1-D heat conduction model and results of the 2-D particle simulation

2. EXPERIMENTAL SETUP

Fig.1 shows our experimental arrangement. An electron beam generated by S-band RF gun having 4.5 side-coupled cavities (AET MG-500) goes through two *Q*-magnets, bending magnet and enters Faraday cup. We used two types of cathode; solid cathode and hollow cathode having a hole of ϕ 1.5 mm. These cathodes are made of tungsten, are shaped with 6 mm diameter and 1 mm thickness. The surface temperature of the cathode was measured with infrared radiation thermometer (CHINO).

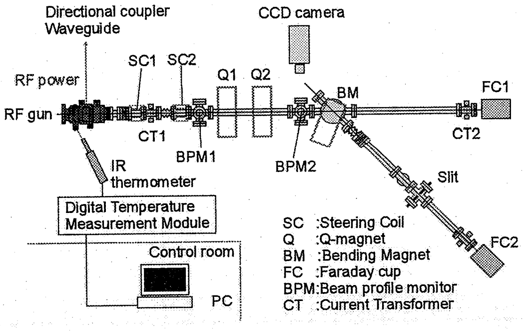

Figure1: measurement system

3.DICCUSSION

3.1 0-D ENERGY TRANSPORTING MODEL

To evaluate the Back-bombardment effect, we made 0-D energy transporting model shown in Fig.2. [7]

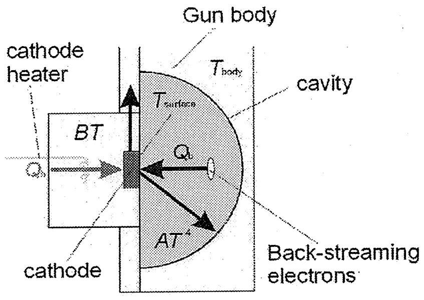

Figure 2: 0-D energy transporting model

With this model the energy balance equation is expressed as

$$C\frac{\partial T}{\partial \tau} = Q_h + Q_b - (AT^4 + BT + X) \quad (1),$$

where Q_h is the energy supply from the cathode heater, Q_b is the energy supply from the back-streaming electrons. T is the surface temperature in K, and τ is time. We simply assumed A, B, and X to be a constant for the thermal radiation, thermal conductivity, and the characteristics of body of RF gun, respectively. C is a constant of the cathode properties including density, specific heat, and the shape of cathode. The constants A, B and X should be determined by comparison with experimental data, since emissivity and conductivity of the cathode are different from those in the ideal condition.

As a first step of the analysis, we calculated the average beam heating $\overline{Q_b}$. In order to evaluate the constants, we measured the temperature evolution after cutting off the cathode heater. The constant C was evaluated using a temperature when RF power was not supplied; Q_b=0 and $dT/d\tau$ =0. Then, $\overline{Q_b}$ was evaluated from the average temperature during beam production.

Fig. 3 shows the average back-streaming beam power $\overline{Q_b}$ using the 0-D transporting model.

As the result of the calculation, it is found that the power of the back-streaming electrons is not negligible compared to the supplied power to the cathode heater. Especially, in the case of high repetition rate operation, power of back-streaming electrons is comparable to the input heater power.

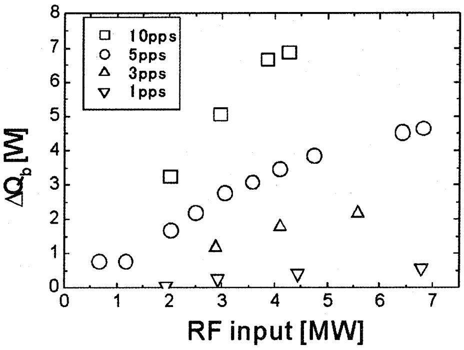

Figure 3: average back-streaming beam power $\overline{Q_b}$

3.2 1-D ENERGY TRANSPORTING MODEL

To evaluate a back-bombardment effect quantitatively, it is important to obtain the temperature profile during a macropulse. However, a typical thermometer has a longer response time than the macropulse duration. Thus, we used a 1-D thermal conduction model (Fig. 4) to evaluate the time evolution of the cathode temperature.

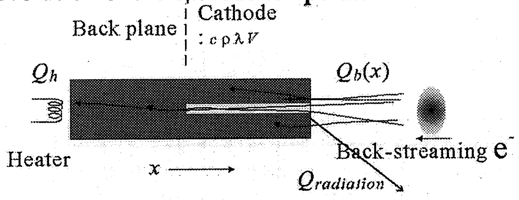

Figure 4: 1-D energy transporting model

In this simple model, the heat conduction along the beam direction, x is described as

$$c\rho V\frac{\partial T}{\partial \tau} = \lambda\frac{\partial^2 T}{\partial x^2} + Q_b(x) \qquad (2),$$

where c is the specific heat, ρ is the density, V is the volume, λ is the conductivity of the cathode, and $Q_b(x)$ is the heating from the back-streaming electrons as the function of the position in the cathode. As the boundary conditions, the heater input power was set to be the same as the radiated power from cathode surface to satisfy the energy conservation law.

A typical particle distribution of the back-streaming electrons in the IAE RF gun given by the 2-D simulation code KUBLAI is shown in Fig. 5. In this case, input RF power was 4 MW and current density on the cathode surface was 10 A/cm^2.

As shown in Fig. 5, most electrons have only a few 100 keV, but the contribution to the total heating power is less than half. Typical beam heating powers for several groups of electrons were also calculated and they are listed in Table. 1.

By using these parameters, the time evolutions of

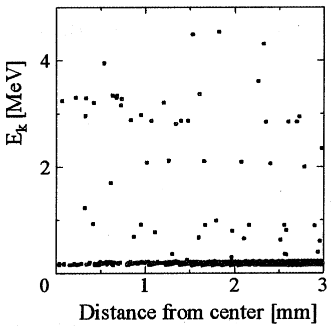

Figure 5: the distribution of back-streaming electrons

Table 1. Contribution to the cathode heating from electron in 3 groups of energy

	Solid	Hollow
E_k: 0~300keV	0.054J	0.049J
E_k: 300keV~1.5MeV	0.010J	0.009J
E_k: 1.5MeV~	0.072J	0.046J
Total Power (all electros)	0.136J	0.103J

the surface temperature of solid and hollow cathode were calculated. Although, a deposited power should be calculated for each electron, it is important to evaluate contributions of electrons with low and high energy. Thus, on calculating the beam heating in the cathode, heated area were assumed as below; low energy component (E_k < 300 keV) deposits the energy only near the surface (surface - 0.1 mm), middle energy component (300 keV < E_k < 1.5 MeV) deposits the energy in the half of the cathode (surface - 0.5 mm), high energy component (E_k > 1.5 MeV) deposits the energy in whole cathode (surface – 1 mm). Because of technical difficulties, a hoe could not made on the back plane of the cathode. Thus, the beam power of the electrons passing through the hole was added in the back plane of the cathode to evaluate the surface temperature of hollow cathode. External magnetic field was simulated by omitting the low energy component. The results are shown in Fig. 6.

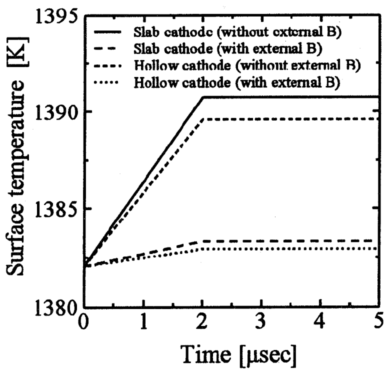

Figure 6: the time evolution of surface temperature of cathode

As shown in fig.6, magnetic field would reduce beam heating effectively. Thus, it was found that the low energy component made serious effect. On the other hand, high energy components tend to converge to the center of the cathode. Therefore, the reduction ratio of the heating power of the high energy component seems to be greater than that of the low energy component.

4. SUMMARY

We measured the surface temperature of the solid and hollow cathode during beam production. These temperatures were used to evaluate back-streaming electron beam power, and it was found that the average beam heating power was quite large and in case of long pulse operation or high duty operation, it was not negligible.

The time evolution of the surface temperature in the RF macro pulse was evaluated using a 1-D thermal conduction model and a 2-D particle simulation code. It was found that the low-energy back-streaming electrons, which tend to distribute widely on the whole cathode make serious influence to the beam quality. Although these low-energy back-streaming electrons can be swept out easily by applying external magnetic field, the high-energy back-streaming electrons hit the cathode even with the magnetic field. It was also found that the use of the hollow cathode would effective to reduce the back-bombardment effect for high-energy back-streaming electrons.

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