MEASURES TO ALLEVIATE THE BACK BOMBARDMENT EFFECT OF THERMIONIC RF ELECTRON GUN

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Abstract

Thermionic rf electron gun finds application as a high brightness electron source for rf linacs. However, cathode heating from back-boombardment effect causes a ramp in the macro-pulse beam current and limit the usable pulse width. Three methods: ring cathode, magnetic deflection and laser assisted heating are studied in theory and in experiment. The results of these studies are reported.

I. Introduction

In the thermionic rf electron gun, the microwave in the cavity causes a part of the electrons emitted from the cathode change their direction of motion and hit and heat-up the cathode. This phenomena is called back bombardment.

In this way, the cathode will be heated from the heater power and the back bombardment power. The cathode temperature will accordingly vary in operation as shown in Fig.1. The back bombardment heating

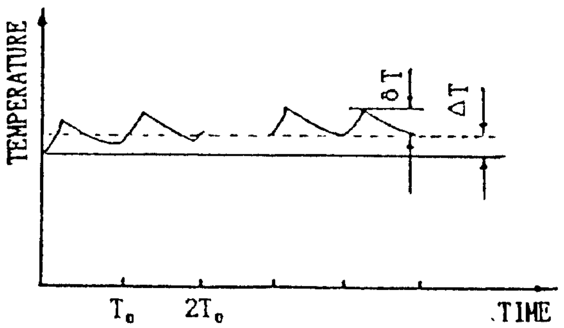

Figure 1: Conceptive variation of cathode temperature during operation.

affects the cathode temperature in two aspects, one is average growth ΔT and another is pulse growth δT during macropulse. The average growth is not harmful, we could reduce the filament current to maintain the cathode working temperature. The pulse temperature growth would induce emitted current growth during the macropulse. Fig.2 is the current in a macropulse measured by beam current transformer for a circular cathode[1]. According to heat conduction and the analysis of experiment results, the growth rate is about $10^{o}K/\mu s$.

As a result of beam loading, the field strength in the cavity would decrease with increasing current and hence produce beam energy and emittance variation in the macropulse. Therefore, for long pulse operation of linac based FEL etc., measures have to be taken to alleviate the bombardment effect in order to maintain the beam quality.

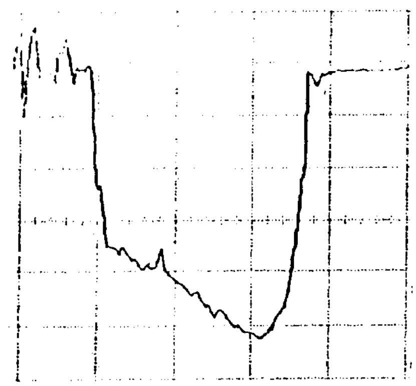

Figure 2: Current pulse for circular cathode $\Phi 3(0)$, $2\mu s$/div, 250 mA/div.

Obviously, there are two kinds of methods to reduce the back bombardment effect. One is to reduce the number of back electrons which hit on the cathode surface, such as using ring cathode or transverse deflecting magnetic field[2]. Another is to compensate the temperature growth by reducing the cathode temperature very quickly, such as heating cathode by laser assisted heating. This paper will describe these three measures and related experiments.

II. Ring Cathode

According to the simulation results[1] it was found that there are part of back electrons, especially those with high energies, concentrating on the centre region of the cathode surface. This suggests the idea of using ring cathode, ie. drilling a hole on the centre of the cathode to reduce the effective back beam power. Table I gives the ratio of the power hitting the cathode to the total power of back electrons. It can be seen that the effective back bombardment power for ring cathode is 75 percent of that for a circular cathode with the cost of emittance increase by a factor of two, because the central electrons with good emittance are thrown away.

Table I. The ratio of heating power to total back power and the effective emittance of different cathodes

cathode	power ratio	ϵ_{nx} $(\pi mm - mrad)$
$\phi 3(0)$	98.7%	2.20
$\phi 4(0)$	98.5%	3.12
$\phi 4(2)$	73.5%	6.24

Fig.3 is the beam current waveform of $6\mu s$ width for ring cathode. It is seen that the current of ring cathode is much flatter than that of circular cathode. However, the improvement in performance can hardly be explained by 25 percent reduction of back bombardment power alone. There might be some other processes that were not considered.

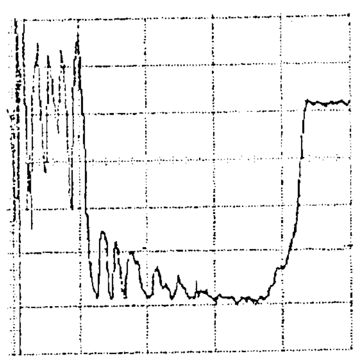

Figure 3: Current pulse for ring cathode, $2\mu s$/div, 250 mA/div.

III. Deflecting Magnet System

It is obvious that by placing a deflector magnet near the cavity can reduce the number of back electrons, through it will also deflect the forward electrons. Theoretically, the back electrons can be deflected out of the cathode completely by increasing the field strength, however, in practice the strength would be limitted by the output beam emittance growth andthe exit aperture of the cavity. The deflector causes effective emittance growth in the direction perpendicular to the magnetic field, so the field vector should be in vertical plane because the emittance growth in horizontal plane has less effect on the FEL performance.

The ideal magnetic field distribution for our case is looked like that shown in Fig.4, where some typical forward and backward electron trajectories are also shown. B_1 is responsible for deflecting the backward electrons, B_2 compnsates the bending of the forward electrons caused by B_1, B_3 and B_4 move the beam centre back to the axis. The purpose of B_2 , B_3 and B_4 is to minimize the effective emittance growth of the forward electrons. Since the forward beam has a finite energy spread and the electrons are accelerated time dependently, the emittance growth cannot be wholly eliminated. It is easy to understand that the ideal field should be:

1) high field strength for sufficient deflection.
2) short period for quick correction.

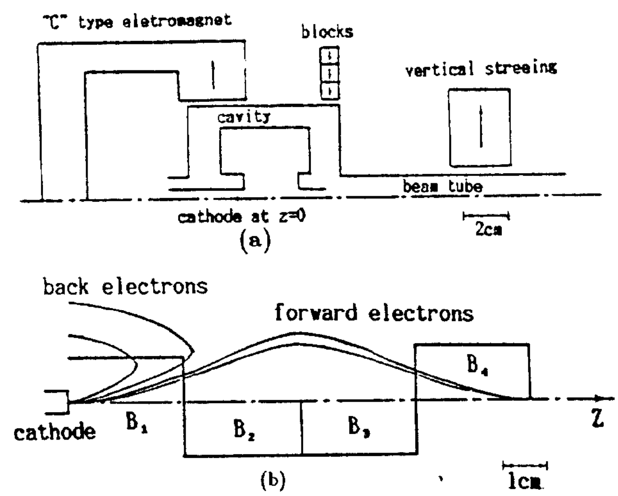

Figure 4: (a) Physical deflector system, (b) Ideal deflector field distribution and typical electron trajectories.

It is not easy to make a physical magnectic field distribution nearly the same as that shown in Fig.4. The physical deflector system used composes of a "C" type electromagnet, several N_dF_eB permanent magnectic blocks and a steering magnet. The field pattern can be modified by moving the positions of each component and changing the field strengths. In the experiment, it was found that for circular cathode without the deflecing

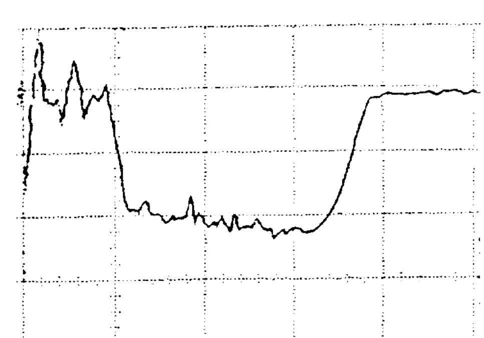

Figure 5: Current pulse under deflector field, 2 μs/div, 250 mA/div.

magnet, the macropulse length for the rf gun is limited to 2.5 μs because of back bombardment heating. With the placement of the magnets the macropulse can be extended to 6 μs without significant emittance growth (Fig.5). It is not clear what is the longest usable macropulse length because of the klystron modulator pulse width limitation.

IV. Laser Assisted Heating

Supposing there is another physical process existing on the cathode surface that makes the cathode temperature drop at the same rate as the temperature rise during macropulse due to back bombardment. The net result will be a constant cathode temperature. This scheme can be carried out by introducing laser pulse to assist the heating of the cathode.

The temperature rise of solids generated by irradiation of different laser pulse structures has been studied [3] in general. The variation of the surface temperature of L_aB_6 was simulated similarly and Fig.6 (a) shows the calculated surface temperaturepulse started from 0° as a function of time started at laser pulse arrival, the temperature is normalized to the maximum value. The laser pulse is also plotted in the figure, it comes from a $N_d : YAG$ laser driver laser of 1.06 μm, typically with 0.5 joule/pulse, and we use the right triangle pulse with bottom width of 40μs to approximate the actual pulse.

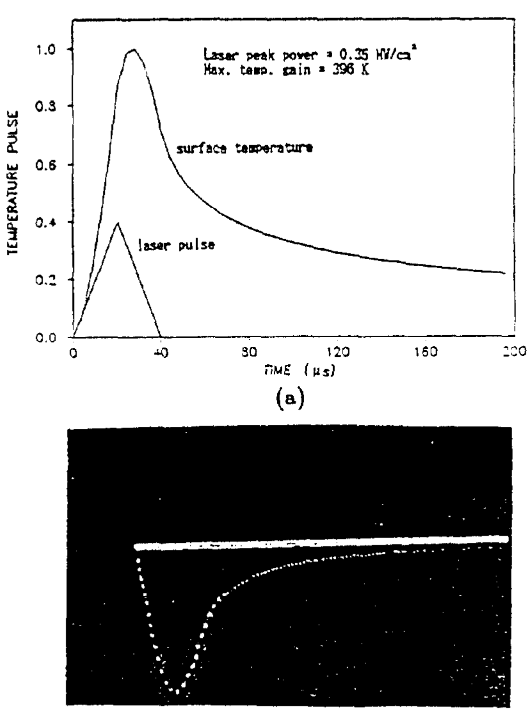

Figure 6: (a) Normalized surface temperature pulse induced by laser pulse, calculated by HEAT. (b)Measured cathode temperature pulse induced by laser.

Fig.6 (b) shows the measured cathode surface temperature rise induced by the laser. We find the temperature pulse peaks somewhat after the peak of the laser pulse and falls off more slowly. For a given irradiate energy, the narrower the laser pulse, the higher the temperature gain and the more quickly the temperature rises and falls. For our purpose we are more interested in the falling rate of the temperature rather than the peak temperature gain, beause the initial temperature can be controlled by the filament power.

It is expected that by varying the pulse width and the energy of the laser irradiance one could produce a suitable falling gradient about $10^oK/\mu s$ at some time after irradiation, and the maximum temperature is below the melting point of L_aB_6, which is about 2200^oC. In Fig.6, it was found a suitable operating point is just after the peak of temperature pulse.

The lauoyt of the experiment of setup for laser assisted heating is shown in Fig.7. The laser pulses are delivered to the cathode via an optical transport line which consists of a lens and a steering mirror which directed the laser pulse through a vacuum window and onto a stationary final pointing mirror. The final pointing mirror, locates inside the vacuum enclosure of the gun cavity, directs the laser pulse onto the L_aB_6 cathode.

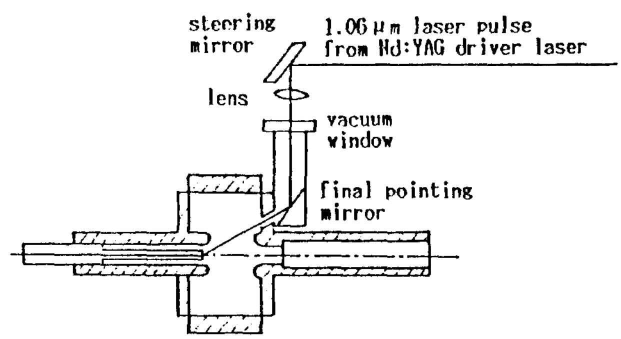

Figure 7: Illustration of the final pointing mirror and the rf gun.

Experimental results of this scheme has not been obtained because the rf electron gun is in use to produce electron beam for the FEL experiments. Once the gun is available, measurement will be carried out and the result reported.

Reference

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3. J.T. Lin and T.F. Gearge, JAP 54 (1983) 382.