EXPERIMENTAL STUDY OF SECONDARY EMISSION MODE IN RF GUN WITH THERMIONIC CATHODE

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The paper deals with the problems concerning the influence of secondary emission on the operation of radio frequency (RF) gun with thermionic cathode. The characteristics of particles bombarding the cathode are investigated by the numerical simulation. The experiments on the study of secondary emission have been carried out on two-resonant thermionic RF gun, set as an injector of linac LIC. The results of measurements, their treatment and discussion are presented.

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1. INTRODUCTION

The using in linacs of RF gun-based injectors [1] allows the significant improvement of accelerated beam parameters. A RF gun is in general a RF cavity tuned on the operating linac frequency. On the cavity wall a cathode is installed. The emitted surface is placed in a high-strength RF field (more than 10^5V/m). Photoinjectors and thermionic RF guns are commonly used for generation of the high-quality electron beams. Besides, the RF guns based on other emission mechanisms are designed. Among them are, in particular, field emission RF gun, plasma RF gun [2] and secondary emission RF gun [3]. For future RF gun improvement it is of great interest the study of electron emission from the cathode exposed simultaneously to the action of a high strength RF field, optical and X-radiation, temperature and electron bombardment. The present work deals with the study of secondary emission processes which occur in the RF gun with a thermionic cathode.

2. THE BACK BOMBARDMENT EFFECT AND SECONDARY EMISSION IN THE THERMIONIC RF GUN

In thermionic RF guns the electron emission from the cathode takes place during the accelerating positive half-cycles of RF field. The part of electrons emitted from the cathode does not leave the cavity. When the field sign is changing electrons are accelerated in the back direction and bombard the cathode. This effect is named as "backbombardment effect". It leads to the following consequences.

1. The electrons bombarding the emitter pass their kinetic energy to the cathode. It leads to the change of the cathode temperature during the RF pulse. It is known that the emission current density in a thermionic RF gun is limited only by the emission possibility of the cathode but not the space charge (Chaild-Lengmur limitation). Therefore due to backbombardment the output current is changed during RF pulse too. If the cathode surface does not cool down to initial temperature during the time between pulses, the average temperature is increased. The bombardment in thermionic RF guns limits the range of the possible current pulse length (less than 10 μs) and pulse repetition-rate (less than 25 pps). This effect is studied well, and some methods to reduce the cathode heating up and to increase its influence on beam characteristics are developed. Thus, the use of a transverse dc magnetic field at the cathode allows one significantly decrease the bombardment. The number of back electrons and their average power are also reduced in the RF gun with optimal resonance system, containing some coupled cavities.

2. The incidence of electrons on the surface of the cathode causes the secondary electron emission. The number of secondary electrons is defined by the secondary electron yield δ and depends on the surface properties and impact electron energy. The destiny of secondary electrons depends on the impact time (we will neglect the time difference between the impact moment and the moment of secondary electron occurrence). Secondary electrons, as well as, thermoelectrons emitted during the accelerating positive half-cycles of RF field ($\pi>\varphi>0$) are accelerated, but some part of them can be accelerated in the opposite direction and again impact the cathode surface. Evidently the secondary emission will exert the influence on beam parameters at the thermionic RF gun exit, if $\delta \geq 1$ and the impact time (RF phase) is favorable.

We study the characteristics of bombarding electrons for the 1.5 cell 2797 MHz thermionic RF gun using PARMELA code. This RF gun is installed and operated in the linac LIC [4, 5]. The operating field on the cavity axes is of 35...40 MV/m. The dependence of the thermionic electron energy on the phase is shown in Fig.1. The sign plus corresponds to electrons leaving the cavity and the sign minus corresponds to surface electrons impacting the cathode.

One can see that electrons emitted in the phase ranges 85...95° and 160...180° can impact the cathode with a low energy that is preferable for secondary emission 180°. Analysis of the electron trajectory shows that electrons of the first phase range execute a complex motion during long time. The particles emitted in the phase range 160...180° come back on the cathode for time less than half-period. The number of back electrons increases and their energy decreases as the RF field in the cavity decreases.

The phase of electrons that corresponds to the moment of their coming back to the cathode versus the phase of their leaving is shown in Fig.2.

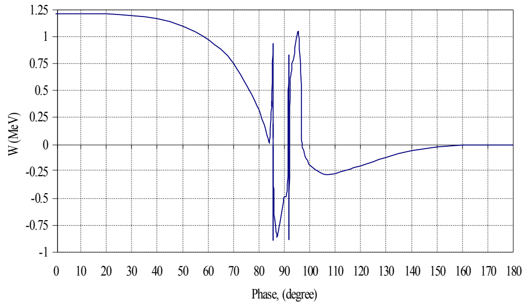

Fig.1. Thermionic electron energy versus RF phase

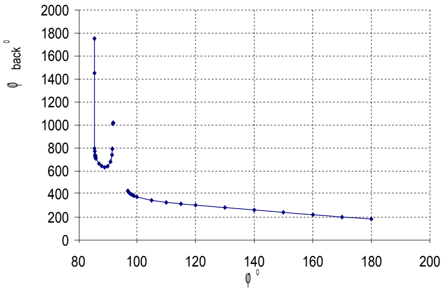

Fig.2. Phase of electrons corresponding to the moment of their coming back to the cathode versus the phase of their leaving

It follows from simulation results that the main source of secondary electrons is electrons emitted from the cathode in the phase range 80...100°. They come back to the cathode in the wide phase band and part of them has a low energy. It should be noted that due to the Shottky effect the number of thermionic electrons emitted in the field maximum (φ=90°, E ~10^5 V/m) can be on the order of magnitude greater than that of electrons emitted under φ=0°. The LaB_6 and dispenser cathodes are most frequently used in thermionic RF guns. The secondary electron yield δ_{max} of LaB_6 does not exceed 1, but for dispenser cathodes δ_{max} it can be significant. For instance, for the oxide-nickel pressed cathode [6], that we use, the secondary electron yield δ_{max} is more than 4 under some conditions.

3. EXPERIMENTAL RESULTS

The experimental study of the secondary emission in a thermionic RF gun was carried out in the linac LIC [5], that contains the universal 1.5 cell RF gun [4] as an electron injector. During the experiments the gun operated in a thermionic mode with the oxide-nickel thermionic cathode [6]. The typical oscillograms are shown in Fig. 3. The growth of the output current during the pulse is a feature of thermionic RF guns and it can be explained by the existence of backbombardment effect and the temperature increase.

It is possible to observe the secondary emission in the RF gun being studied, when the thermionic emission is suppressed by the cathode temperature decrease or by the increase of the work function. It is known that the secondary emission yield is weakly dependent on these parameters. This approach has been used in our experiments.

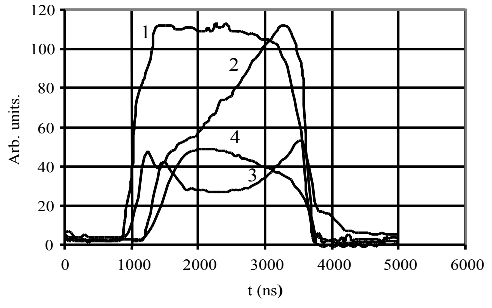

Fig.3. 1 - the envelope of RF pulse at the entrance of cavity, 2 –output current, 3 – the envelope of RF pulse reflected from the cavity, 4 –RF field in the cavity

The change in the beam pulse current with the heater current change is shown in Fig.4. The corresponding temperature change of the cathode surface is of (Δ T ≈ 150°...200°). This temperature variation leads to the significant decrease of the thermionic current density.

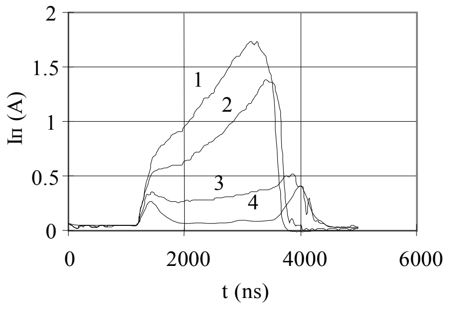

Fig.4. The output current versus the cathode heater current: 1 – I=4.5 A, 2 – I=4.1 A, 3 – I=3.8 A, 4 – I=3.5 A

The growth of the output current occurs at the moments of the leading edge and the trailing edge of the RF pulse. Under subsequent temperature decrease the thermionic current disappears, but the current on the pulse edges is does not disappear. If the field strength in a cavity decreases in such a temperature regime, the current pulse of rectangular form is observed at the exit of the gun. The current amplitude in this case is of 100...150 mA and the electron energy does not exceed 300 keV. It is evidently that the current observed is not caused by the thermionic or field emission of electrons. We suppose that the secondary electrons are the source of this current. The electrons of thermionic or field emission and secondary "back" electrons also can play the role of the primary electrons.

Secondary emission mode has been observed, when some samples of oxide-nickel cathodes with anomalous properties were investigated. The ordinary dependences of a thermionic current on the temperature and the field strength have not been obtained for these cathodes. Apparently these cathodes have anomalous high work function. Probably, the cause of significant growth of the secondary emission yield was creation in these cathodes of a non-conducting film on their nickel substrate. In this case the pulse current does not practically depend on the temperature of the cathode surface under its change by 200...300°. As a result, the increase of the current amplitude during the pulse typical for thermionic RF gun was not observed. The oscillograms for this operation mode are presented in Fig.5.

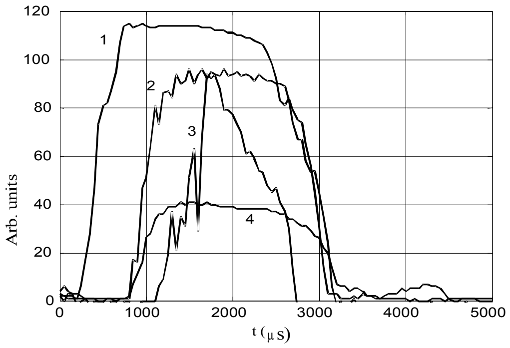

Fig.5. 1 – the envelope of RF pulse at the entrance of cavity, 2 – output current (I=1.4 A), 3 - current at the linac exit (I=0.75 A), 4 – RF field in the cavity

The described mode has been observed at a field of 30 MV/m. The electron energy exceeded 300 keV with a current up to 1.4 A at the exit of the gun. Instability of the leading current pulse edge was observed at the exit of the accelerating section (see Fig.5.) This instability can be caused by the significant phase- or energy instability in the initial part of the current pulse injected into the section. The pulse current at the exit of the gun decreases in the range of 20...30% with the decrease of the field strength up to ≈ 20 MV/m. However, a further decrease of the field to some limit value resulted in disappearance of the current at the exit, in decrease of the field in the cavity up to zero and the cavity detuning. We suppose that such a behavior corresponds to the appearance of a multipactor discharge.

CONCLUSION

Thus, we can make the following conclusions:

1. It has been shown, that there are all the necessary conditions in the thermionic RF gun for appearance of the current caused by the secondary emission. The mode with the intensive secondary emission in the RF gun with oxide-impregnated or pressed cathode is the most probable.
2. The anomalous operation modes of the thermionic RF gun have been observed during experiment. These modes can be explained by only secondary emission processes on the oxide cathode surface.
3. The results of preliminary measurements give the possibility for the background of further experimental investigation to study in detail the secondary emission in RF guns. Of great interest is the study of the following problems such as: stability; conditions of appearance of single-wall multipactor discharge and the mechanism of its saturation; dependences of bunch parameters on secondary emission properties of the surface and so on.

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REFERENCES

1. V.A. Kushnir. RF guns for resonance linacs // *Zarubezhay radioelektronika. Uspekhi sovremennoy radioelectroniki.* 2001, №12, p.19-34 (in Russian).
2. M.I. Ayzatsky, V.A. Kushnir, V.V. Mitrochenko et al. The metallic-dielectric cathode in the RF gun // *Pisma v Zh. Tekh. Fiz.* 1998, v.24, №19, p.36-39 (in Russian).
3. L.K. Len, Frederic M. Mako. *Self-bunching electron guns.* Proc. of the 1999 PAC, New York, 1999, p.70-74.
4. N.I.Aizatsky, E.Z.Biller, A.N.Dovbnya et al. *Two-cell RF gun for a high-brightness linac.* Proc. of the 1996 EPAC, 1996, v.2, p.1553-1555.
5. M.I. Ayzatsky, E.Z. Biller, A.N.Dovbnya et al. *Operating performances and current status of the Laser Injector Complex facility (LIC).* Proc. of the 1996 EPAC, 1996, v.1, p.795-797.
6. Yu.V. Alekseev, N.R. Kanicheva, V.V. Korablyov et al. *The investigation of oxide-nickel thermo cathode surface:* Preprint NIIEFA. П-б-0753, L., 1987, p.19.

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ВТОРИЧНО-ЭМИССИОННОГО РЕЖИМА РАБОТЫ ВЧ-ПУШКИ С ТЕРМОЭМИССИОННЫМ КАТОДОМ

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Рассмотрены вопросы, связанные с влиянием вторичной эмиссии на работу высокочастотной электронной пушки с термокатодом. Методом численного моделирования исследованы характеристики частиц, бомбардирующих поверхность катода. Эксперименты по изучению вторичной эмиссии проведены на двухрезонаторной термоэмиссионной ВЧ-пушке. Приведены результаты измерений и их обсуждение.

ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ВТОРИННО-ЕМІСІЙНОГО РЕЖИМУ РАБОТИ ВЧ-ГАРМАТИ З ТЕРМОЕМИССІЙНИМ КАТОДОМ

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Розглянуті питання пов’язані з впливом вторинної емісії на роботу високочастотної електронної гармати з термокатодом. Методом чисельного моделювання досліджено характеристики часток, що бомбардують поверхню катода. Експерименти по дослідженню вторинної емісії проведено на дворезонаторної термоемісійної гарматі. Наведено результати вимірювань та їх обговорення.