SECONDARY EMISSION MAGNETRON INJECTION GUN FOR LINAC

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Abstract

The experimental research results for operation of the cold cathode magnetron injection gun in the linear traveling wave accelerator are described. The mechanism of the gun operation is connected with the current secondary electronic increase and the establishment of a self-supported secondary emission. The comparison of the beam passage conditions for a thermionic gun points on the fact, that the characteristics of the magnetron gun are acceptable for the purposes of injection in the rf accelerator.

1 INTRODUTION

The development of the accelerator engineering and of associated powerful rf sources put the new requirements to the appropriate sources of powerful electron beams. Thus it is more and more necessary to consider the alternatives to the traditional sources based on thermionic cathodes. One of such alternatives in the case of the necessity to achieve simultaneously a high current density and a long service life it can be the magnetron injection gun in the secondary emission mode [1]. The long service life of the cathode creates new opportunities in the accelerating engineering. For example, the manufacturing of the steamed off industrial accelerator modules instead of the existing vacuum pumped ones. Besides, the magnetron gun with the cold cathode, as will be shown below, is capable to form short (nanoseconds) current pulses with the help of the rather long voltage pulses on the gun. It has the essential practical importance for creation of the high current short pulse accelerators, as it facilitates formation of a high voltage to feed the gun. Moreover it is supposed, that the magnetron gun with cold cathode will be steady to back bombardment by the electrons reflected from the accelerating structure [2], and the last can limit the pulse recurrent frequency and the service term of the thermionic cathodes. The magnetron gun has a number of peculiarities, which can affect the gun operation in the rf linacs. First it is the cathode not magnetic screened and the tubular form of beam. To estimate the operation peculiarities of such a gun in the rf linacs was the purpose of the researches presented below.

2 EXPERIMENTAL EQUIPMENT

The Universal Injector Complex (UIC) of the accelerator, LA-300 MeV [3] was used for the experiments. UIC was intended for expansion of LA-300MeV opportunities to accelerate high current short pulse beams in a mode of rf energy accumulation. UIC consist of a threode thermionic gun; two cavity buncher placed in focusing solenoids; injector and two accelerating sections, which are supplied by a system of rf power recuperation. To carry out the experiments, described below, the thermionic gun was demounted and on its isolator a secondary emission magnetron injection gun (SEMIG) was mounted. The circuit of experiment is shown on Fig. 1. SEMIG consists of two cylindrical coaxial electrodes placed inside the solenoid of the buncher (SG). The internal electrode serving as a cathode (C) is a metal rod established on high-voltage isolator (I) in the transit channel, the walls of which are the anode (A). The cathode feeder of a short pulse voltage consists of the coaxial cable serving secondary winding of the high-voltage pulsed transformer (PT). The signal of the gun current is transferred through this cable from the high-voltage circuits to the oscillograph (IO).

3 THE GUN TESTING

After feeding the high voltage pulses on the cathode, and turning on the solenoid creating the magnetic field in the gun area the cathode current pulses with the amplitude up to 20 • were obtained. Their duration changed from 20 ns up to 0.5 microsec depending on the mode. For this gun the C-V characteristic, submitted on Fig. 2, is close to a square law. The use of a cathode material identical to the cathode material of the earlier investigated gun [4], allows to compare their parameters on the basis of the similarity theory [1]:

$$I = C\frac{U^2}{BD_c \ln^2\left(\dfrac{D_a}{D_c}\right)} \qquad (1)$$

Where I is the beam current emitted from SEMIG; Da, Dc are diameters of the cathode and anode accordingly; C is a constant depending on emission properties of the cathode; U is the gun voltage; B is the magnetic induction of the solenoid.

The comparison shows the increase of the current in our case. It is probably explained by stronger magnetic field. It agrees with dependence of the beam current on the magnetic field [5] measured later on.

3 HIGH CURRENT ACCELERATION MODE

After feeding the rf power to the accelerating sections and tuning the passage beam system, at the gun current about

12 A and the gun voltage about 45 kV, the current of the accelerated electrons about 0.5 A was obtained at the exit of UIC. The small value of the beam capture factor is probably caused by the low injection energy of electrons, determined by the low gun voltage. Comparison of the measured capture factors represented on the fig. 3 for the beams injected by both the traditional thermionic gun and SMIG shows that this capture factors represented on the fig. 3 are practically equal when the gun voltages are equal. The pulse duration of the relativistic electrons at the accelerator exit was about 20 ns. The duration of the current pulses and voltage on the gun was essentially more and was accordingly 50 ns and 1 microsec. The reduction of the beam duration observed at the Faraday's cylinder is determined mainly by two factors: by the small (down to 1 ns) time of the excitation of secondary emission in the gun at peak gun voltage and by the mode of accumulated energy when feeding the gun and the accelerating structures. The front of the beam pulse is formed due to fast excitation of secondary emission. The beam duration is increased with increasing the level of the accumulated energy and is decreased with increasing the gun current.

At testing SEMIG only the grouping and accelerating sections were turned on. The second section was without rf feeding and the focusing solenoid. Moreover, this section had the small effective shunt impedance [3], therefore at the current achieved in our case the influence of the induced fields to the movement of the beam particles can be neglected. Thus the second section played only the role of a long pipe collimator with known aperture.. In this case with the length, *L* and the diameter, *d* one can estimate the beam emittance [6] as

$$\varepsilon \le \frac{d^2}{\pi L} \qquad (2)$$

Substituting numerical meanings of the aperture d=3.0 cm and the length L=200 cm, we receive the estimation of the emittance not exceeding $\varepsilon \le 140$ mm mrad.

4 CYCLOTRON RESONANS MODE

During tests of SEMIG in the structure of UIC, we have detected that feeding the rf power to the buncher cavity influences the excitation of the gun current. The gun was located near to the buncher in a magnetic field as is represented in a fig. 1. Probably the fringing field region at the end of the buncher cavity achieved the area of the gun cathode. Originally it was detected the current from the cathode which was not seized in the mode of the acceleration. The current was during almost the whole gun voltage pulse (about 1 microsecond, 60 kV). The current from the cathode arisen in a narrow interval of the magnetic fields close to 136-140 mT and achieved of 1 A. By tuning of the buncher phase it was possible to receive 20 mA current of the accelerated electrons with energy over several MeV at the exit of UIC. The pulse duration of the current corresponded to the pulse duration of the gun voltage. The typical oscillograms of the current pulses are represented in the fig. 4. The rf pulse duration exceeded the pulse duration of voltage on the gun (about 2 ms), and the synchronization system was adjusted so that during the voltage pulse the rf power it would be a constant. Thus to obtain the accelerated beam it is necessary simultaneous feeding the voltage on the gun and feeding of the rf power for the certain magnitude of the magnetic field at the cathode and for the certain ratio of phases of the buncher and the accelerating sections. The typical oscillograms of the current pulses are represented in the fig. 4. The rf pulse duration exceeded the pulse duration of voltage on the gun (about 2 ms), and the synchronization system was adjusted so that during the voltage pulse the rf power it would be a constant. Thus to obtain the accelerated beam it is necessary simultaneous feeding the voltage on the gun and feeding of the rf power for the certain magnitude of the magnetic field at the cathode and for the certain ratio of phases of the buncher and the accelerating sections.

Because of above we may assume that the researched gun operates in the mode of the resonance cyclotron. Let us estimate the magnitude of the frequency of cyclotron oscillations. The transit time of an electron starting from the cathode and back we determine in the correspondence with [9]. Let's note the equation of radial motion of electron in the gun:

$$\frac{d^2 r}{dt^2} = -\frac{d\Pi}{dr} \qquad (3)$$

$$\Pi(r) = \frac{e}{m}\frac{U}{\ln\left(\frac{b}{a}\right)}\ln\frac{r}{a} + \frac{\Omega^2}{8}\left(r - \frac{a^2}{r}\right)^2 \qquad (2)$$

Where *r* is the radial coordinate of an electron; *e*, *m* are the charge and mass of the electron accordingly; *a*, *b* are the radiuses of the anode and cathode respectively. $\Omega = eB/m$ is the cyclotron frequency. This equation has the solution in quadratures:

$$\tau = \int_a^r \frac{dr}{\sqrt{-2\Pi(r)}} \qquad (4)$$

The period of motion was calculated as the double time of the motion up to the maximum radius. By inserting in the integral expression (4) the numerical meanings of the geometrical sizes of the gun: *a*=0.15 cm, *b*=1.5 cm and the experiment data: *B*=138 m•, the average meaning of the magnetic field taking from the interval in which there is the secondary emission excitation; *U*=30 kV, the gun voltage; we find the meaning of the cyclotron frequency, f_c=2.967 GHz. We see that the calculated frequency coincides with the sufficient accuracy with the meaning of the accelerator frequency, *f* =2.797 GHz. It point out on the fact that the gun works in the mode of the cyclotron resonance.

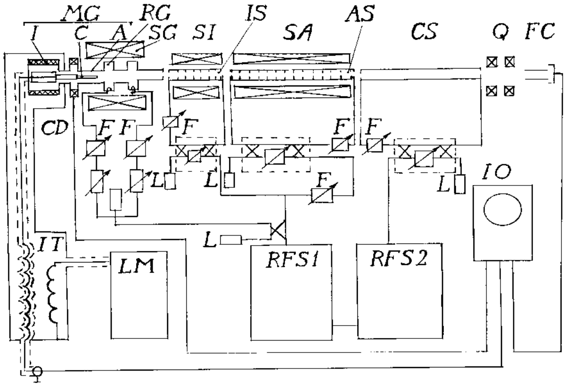

Fig.1 The experimental circuit of SEMIG in structure of Universal Injector Complex (UIC).

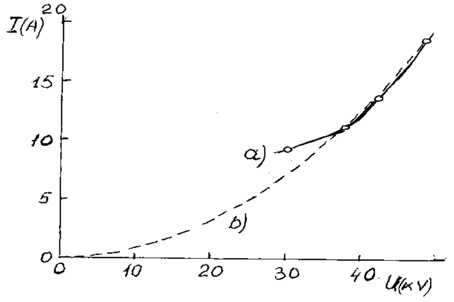

Fig.2 C-V characteristic of SEMIG.

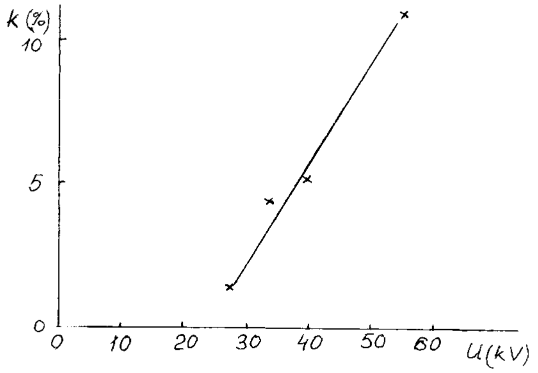

Fig.3 The capture factors v.s. the gun voltage. The markers corresponds to the beam injected by SEMIG; the line corresponds to the conventional thermionic gun.

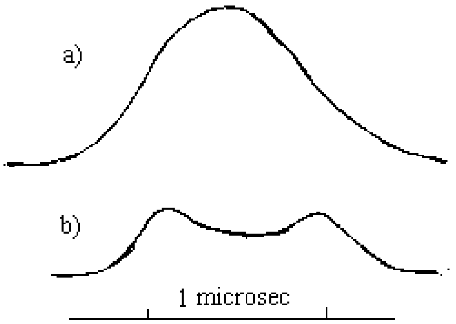

Fig.4 The typical oscillograms. The curves (a) and (b) correspond to the pulses of the gun voltage and the beam current respectively.

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