

METHOD OF ELECTRON EMISSION CONTROL IN RF GUNS

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The electron emission control method for a RF gun is considered. According to the main idea of the method, the additional resonance system is created in a cathode region where the RF field strength could be varied using the external pulse equipment. The additional resonance system is composed of a coaxial cavity coupled with a RF gun cylindrical cavity via an axial hole. Computed results of radiofrequency and electrodynamic performances of such a two-cavity system and results of the RF gun model pilot study are presented in. Results of particle dynamics simulation are described.

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1 INTRODUCTION

It is known that radiofrequency electron sources (RF guns) are efficient tools to obtain bunched electron beams of a high intensity and high brightness. The emission current duration at the RF gun output is determined by the RF power pulse duration. The problem of emission control is appeared in cases when a current pulse has to be differed considerably from the gun RF power pulse. This problem is solved, for instance, in laser driven RF guns [1]. The current pulse duration in these guns is in synchronism with the laser pulse duration and can be both of picosecond duration range [2] and nanosecond duration range [3]. There is also one more type of RF guns where the current pulse duration is in a nanosecond range - RF gun with metal-dielectric cathode [4].

At the same time, the problem of emission control is not solved for wide-used thermionic RF guns. The cathode is fixed directly in the RF field of a high strength in these guns. The current pulse duration at the output of such guns is actually in synchronism with the RF power pulse. Due to the transient that takes place, application of such a RF gun in a single-section electron linac with one RF source sometimes causes the degradation of output beam parameters.

In the paper the method of emission control in RF guns and the way of its implementation are proposed. In the course of the problem realization, the on-axis electric field was calculated numerically for the gun resonance model, gun operating modes were determined using computer simulation. Frequency and time characteristics of the gun resonance model were researched experimentally.

2 PROBLEM CONCEPT

Beam parameters at the RF gun output including the particle capture factor are determined by on-axis electric RF field distribution [5]. The core of the method we have proposed consists in the fast (comparing with RF pulse duration) varying of electric field distribution in the cathode region where the additional coaxial resonance system is created for this purpose. Changing the fundamental frequency of the coaxial cavity with the use of an external pulsed equipment one can change

electric field distribution in the gun cavity on the whole and in particular, in the cathode region. Having tuned the coaxial cavity on the fundamental resonance frequency of the cylindrical cavity f_0 , we receive two oscillation modes that can exist in the system. In case of fundamental studies frequencies of cavities are differed considerably, the coaxial cavity presence has no influence on the frequency and electric field distribution in the main cylindrical cavity. Each of these three states is featured by their own electric field distribution.

It is supposed to design the coaxial cavity tuning using p-i-n diode based RF switchers that vary length of the coaxial cavity. The given concept was put in basis for the calculation, computer simulation and experimental research of the gun resonance model.

3 CALCULATION AND NUMERICAL SIMULATION

We investigated the S band two-cavity resonance model (Fig. 1) where the coaxial cavity is directly coupled with a gun cylindrical E_{010} cavity via a cathode-side axial hole and can be tuned on the resonance frequency of the cylindrical cavity f_0 . The cylindrical cavity length in the model Z_{cav} was chosen closer to real RF guns. An axial conductor of the coaxial cavity can be used as a cathode placeholder.

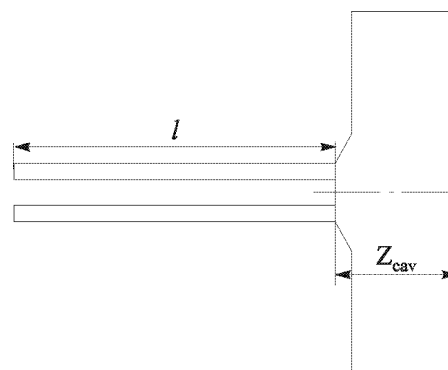


Fig. 1. Resonance model geometry.

It is known [6] that for the fulfilling of the frequency equality, the coaxial cavity length l should be equal to $\approx n\lambda_0/4$, where $n = 1, 3, 5, \dots$. The value $l = 3\lambda_0/4$ was chosen taking into account real conditions of the experi-

ment. Besides, fundamental resonance frequencies for higher n values will be closer to each other that can cause their undesirable intersection under real design conditions.

Calculation of on-axis electric field distribution held using a SUPERFISH code [7] has shown that the resonance model frequency is lower of $f_0 \cong 2.8$ GHz for $l < 3\lambda_0/4$ and electric field distribution corresponds to 'zero' oscillation mode (Fig. 2, curve '0'). The resonance model frequency is higher of f_0 for $l > 3\lambda_0/4$ and electric field distribution corresponds to the ' π ' oscillation mode (Fig. 2, curve ' π '). The increasing of the field absolute value in the cathode plane (position $Z=0$ in Fig. 2) features both oscillation modes. According to the calculation, the RF power in both cases is dissipated considerably on the inner and outer cylindrical walls of the coaxial cavity that decreases the quality factor of the whole system. The quality factor value is decreased in 4 times in both cases.

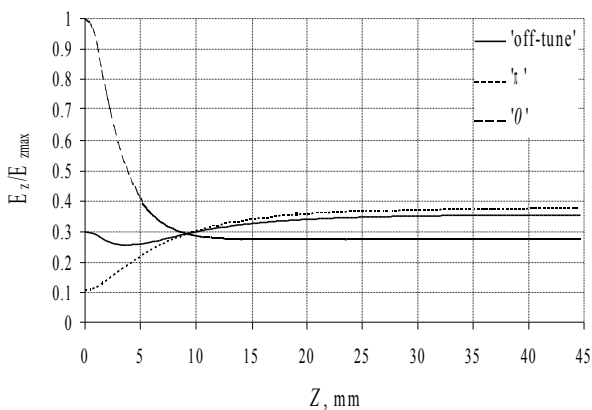


Fig. 2. Calculated electric field distributions.

Values of l that differ considerably from $n3\lambda_0/4$ correspond to the total coaxial cavity detuning relatively to f_0 . Let us call this as 'off-tune' state. In this case, the electric field distribution in the system corresponds to the case of electric field distribution in a simple single-cavity RF gun without any additional cavities (Fig. 2, 'off-tune' curve).

It should be noted that the frequency difference between '0' and ' π ' oscillation modes is small (~ 9 MHz) that corresponds to the coaxial cavity length variation in few tenth of millimeter. This fact should be taken into account when designing the coaxial cavity tuning system.

To define possible RF gun operating modes particle beam dynamics in the model was simulated for each of obtained electric field distributions using PARMELA code [8]. It was supposed that particles are emitted during the whole half-period of an accelerating field. The model geometry was changed a little to determine correct simulation results. The output hole of 25 mm in diameter, which does not modify the electric field distribution in the cathode region, was added in the cylindrical cavity on the wall that is opposite from the coaxial cavity. Simulation results are summarized in Table 1.

Simulation shows the absence of accelerating particles at the exit of such a resonance system when performing the ' π ' oscillation mode. Particle beam parameters in 'off-tune' mode are incident to a single-cavity RF gun. Comparing results obtained for 'zero' and 'off-tune' states one can show that the particle beam in '0' oscillation mode has a more narrow energy spread and emittance value of one order less than in the 'off-tune' state.

Table 1

	'Off-tune'	'0' - mode
W_{max} , MeV	0.64	0.88
ϵ_n , mm-mrad	3.8	0.17
$\Delta W/W$, % (70% of particles)	51	32
$\Delta \phi_{\Delta}$, °	26	38
N/N_e	0.7	1

This is agreed with the electron dynamic calculation [5] for various axial electric field amplitudes and will permit also to obtain electron beams of higher brightness.

Thus, the summary that can be made on basis of simulation results is as follows. The ' π ' oscillation mode switches the RF gun in the 'closed' state when a current is absent at the RF gun output. The preferred mode is the switching between '0' and ' π ' oscillation modes that corresponds to 'open' and 'closed' RF gun states respectively. Such operating mode can be recommended for wide-used thermionic RF guns.

4 RF MEASUREMENTS

To define the possibility of switching between oscillation modes is feasible, there were measured amplitude-frequency and pulse performances of the resonance model. All measurements were held according to the block diagram shown in Fig. 3.

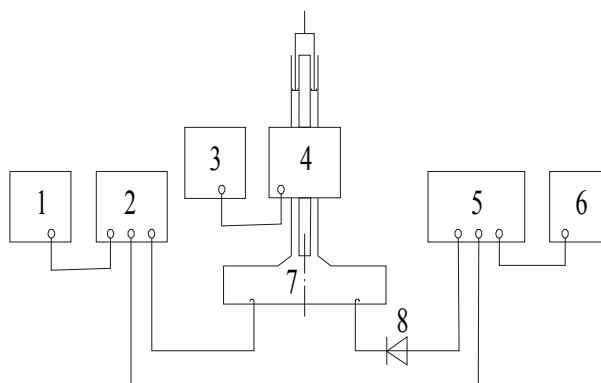


Fig. 3. Measuring layout (1-frequency meter, 2-RF generator, 3-pulser, 4- RF switcher, 5-automatic system of resonator frequency measurement, 6-oscilloscope, 7-cavity, 8-detector).

The automatic system of resonator frequency measurement [9] was used in the measuring setup (Fig. 3, pos. 5). On-axis electric field distributions in cylindrical cavity were measured for each of the three above-defined cases and amplitude-frequency response of the system. The electric field was measured using the resonant perturbation technique. Measured dependences are

shown in Fig. 4 and Fig. 5.

The amplitude-frequency response was measured in the state when the coaxial cavity length was equal to $3\lambda/4$ within accuracy of ± 0.05 mm.

Comparing measured electric field distributions with calculated ones one could note that these experimental curves have the same pattern as for calculated ones. A small spread in the field amplitude values in the cathode plane (position $Z=0$ in Fig. 5) explains the coaxial cavity length increasing up to $9\lambda/4$ caused by the RF switcher.

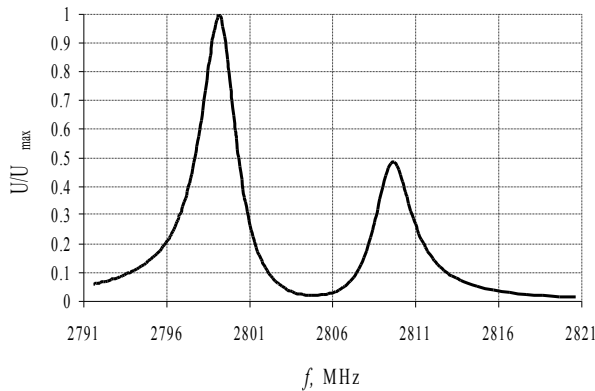


Fig. 4. Amplitude-frequency response.

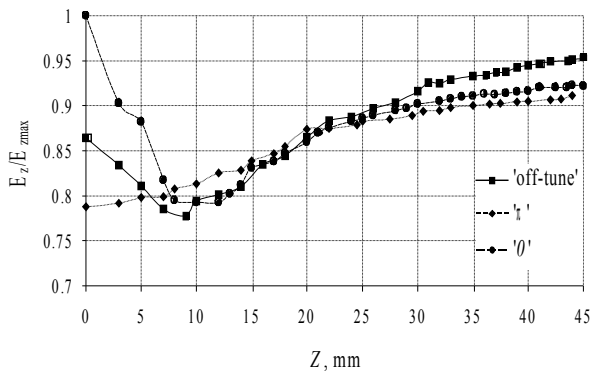


Fig. 5. Measured electric field distributions.

There was used RF switcher based on KA520 p-i-n diodes. Initially the system was tuned on ' π ' oscillation mode that corresponds to the 'closed' state of a gun. Position of the p-i-n diode switcher was choosing so that state of the system was changed to 'off-tune' state after applying bias voltage. Then diode was fed by pulse voltage. The obtained pulse from detector (Fig. 6) permitted to confirm experimentally the fact of oscillation mode control in the two-cavity resonance system.

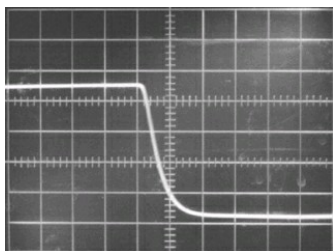


Fig. 6. Rise time of oscillations ($t = 1\mu\text{s/div}$).

The rise time of oscillations was defined for such a two-cavity model. According to the pulse curve, the rise time is $\sim 1\mu\text{s}$ that is confirmed by estimations made using the equivalent circuit method. This points to the oscillation rise time in the system are determined mainly by the high-quality factor value of the cylindrical cavity and actually does not depend on the low-quality factor value of the coaxial cavity.

It should be noted that the resonance system being in ' θ ' or ' π ' oscillation mode has a low-quality factor value. This fact has no special sense for the ' π ' oscillation mode because the gun is in the 'closed' state. However, it will require that the gun should be fed by additional RF power in ' θ ' oscillation mode in order to obtain a qualitative electron beam at the gun output. Besides, the low-quality factor value causes the pass-band broadening of the resonance system. This should be taken into account when defining the range of adjustment of p-i-n diode switchers.

5 CONCLUSION

Investigations have shown that switching between electric field distributions in the RF gun can be made using an additional electrically tuned coaxial cavity. This permits to obtain few RF-gun operating modes, one of which corresponds to its 'closed' state. Hence, the beam at RF gun output can be pulse modulated that corresponds to diode- to- triode RF gun conversion.

It is supposed to carry out the full-scale experiment with an electron beam using one of existing in our institute RF guns.

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