TIME PERFORMANCE CONTROL IN ELECTRON LINACS WITH THERMIONIC RF GUN

I.V. Khodak, V.A. Kushnir
National Science Centre 'Kharkov Institute of Physics & Technology'
1, Akademicheskaya St., NSC KIPT, 61108 Kharkov, Ukraine

Abstract

The method of the current pulse duration varying at thermionic RF gun output is proposed in the paper. The way of its realisation is described. The method permits also to control the time of a beam extraction from RF gun output and its injection into an accelerating waveguide of an electron linac. There was computed electric field distribution in the resonance system of the gun. Probable modes of RF gun operation were computer simulated. Frequency and time performances of the gun sample were researched experimentally.

1 INTRODUCTION

The energy spread of electrons at the linac output is defined besides all by the time of a beam injection into an accelerating waveguide. This is especially important when the transient time in an accelerating waveguide and in a bunching system of an injector is lower but comparable with a current pulse duration. The task of the optimal injection time setting is solved easy in linacs with injectors based on conventional DC guns and also with injectors with pulsed beam modulation (triode DC guns, photo RF guns) by setting definite time delays in the timing system of an accelerator. There is no such possibility for linacs with thermionic RF guns [1] where RF gun and accelerating waveguide are fed from one RF source. Electrons are injected into an accelerating waveguide in this case after the filling time of RF gun cavity. The beam at the accelerator output will have significant energy spread if an accelerating waveguide will not be RF power filled up to the injection time. Besides, there is no any possibility to vary the current pulse duration without external equipment. Therefore, the task of the beam time performance control at the thermionic RF gun output is important. The present paper is purposed to solve this task.

2 CONTROL METHOD CONCEPT

Beam performances including the capture factor at RF gun output are defined by axial electric RF field distribution [2]. The core of the proposed method consists in the fast (comparing with RF pulse duration) switching between electric field distributions in the cathode region where coaxial cavity is added for this purpose. One can change electric field distribution in the gun cavity and in the cathode region, in particular, by the varying of the fundamental frequency of the coaxial cavity using external pulse equipment. The ratio between fundamental frequencies of the cavities permits RF gun operation in few modes. Each mode is defined by its own electric RF field distribution. It is assumed that RF gun can operate in "no beam" mode or can produce the beam with improved performances comparatively to conventional RF gun operating mode.

3 RF GUN SIMULATION

RF gun operation was computer simulated using numerical methods to define the principal possibility to realise the proposed above method. Figure 1 illustrates the researched resonance system. Cylindric E_{010} cavity 1 of the gun is coupled directly with coaxial cavity 2 via a cathode-side axial hole. A cathode 3 is mounted in central axial rod of the coaxial cavity. The fundamental frequency of the coaxial cavity can be varied by special pulsed device 4. In particular, it can be tuned on the frequency equal to the fundamental frequency of the cylindric cavity f_0. The numerical value of the cylindric cavity length Z_{cav} corresponds to a single resonance cell of S-band RF gun.

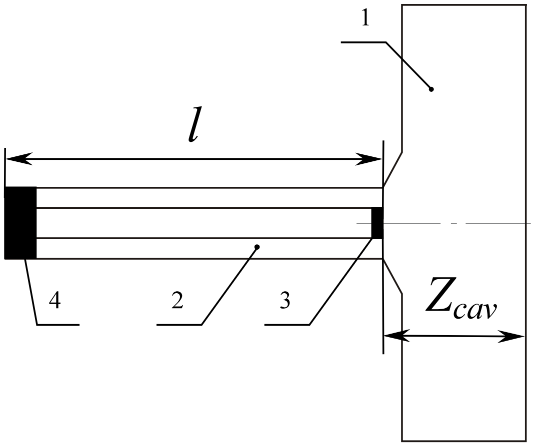

Fig. 1. Resonance Model Geometry

It is known [3] that to complete the equality of considered cavity frequencies the coaxial cavity length l should be equal to $\approx n\lambda_0/4$, where $n = 1,3,5,...$ and $\lambda_0 = c/f_0$. It's obviously that at high n values frequencies of side resonances will be closer to each other that can cause their undesirable intersection in real design conditions. Therefore, this value was accepted equal *3* for simulation.

There will be exited '*0*' и 'π' oscillation modes if frequencies both of cavities are equal to each other. The space between frequencies of these modes is defined by the coupling factor between cavities. The two-cavity system with equal resonance frequencies can be developed by the frequency varying in one of the cavities.

Axial electric field distribution was computed using SUPERFISH code [4] for cases when $l \le 3\lambda_0/4$, $l \ge 3\lambda_0/4$ and l is differed considerably from $3\lambda_0/4$. First two cases correspond to the exciting of '*0*' and 'π' oscillation modes respectively (Fig. 2). The third case corresponds to the total coaxial cavity detuning relatively f_0. Let us call this 'off-tune' state. In this case, electric field distribution in the system corresponds to the case of electric field distribution in simple single-cavity RF gun without any additional cavities (Fig. 2, curve 'off-tune').

'*0*' oscillation mode is featured by the electric field increasing in 3 times in the cathode region. Electric field is decreased in the cathode region for 'π' oscillation mode. This should be taken into account simulating particle dynamics in the model. Besides, both '*0*' and 'π' oscillation modes cause considerable RF power dissipation on the inner and outer cylindrical walls of the coaxial cavity that decreases the quality factor of the whole system. Calculations show that the quality factor is lower on 20% for '*0*' oscillation mode and on 60% for 'π' oscillation mode.

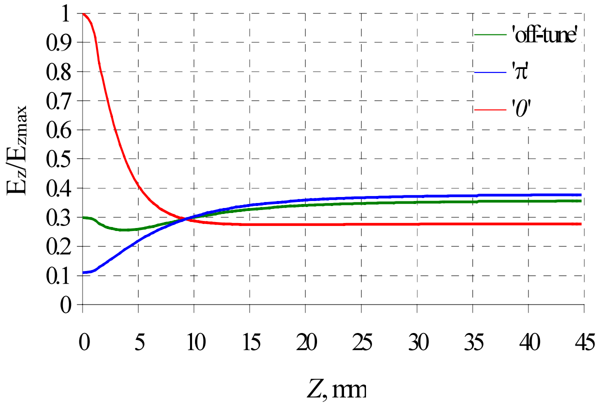

Fig. 2. Computed Electric Field Distributions

Particle dynamics simulation in the model using PARMELA code [5] for each of obtained electric field distributions permitted to define possible RF gun operating modes. It was assumed that particles are emitted during the whole accelerating half-period that is featured for thermionic cathodes. Simulation results for '*0*' and 'off-tune' states for feeding RF power of 1 MW are summarised in table below.

	'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
$\Delta\varphi$, °(70% of particles)	26	38
N/N_e	0.7	1

Particles don't reach the output of the gun cavity in 'π' oscillation mode. Beam parameters in 'off-tune' mode feature conventional single-cavity RF gun. Comparing results obtained for '*0*' and 'off-tune' states one can show that particle beam in '*0*' oscillation mode has more narrow energy spread and emittance value of one order less then in 'off-tune' state. This is agreed with electron dynamic calculation [2] for various maximum values of axial electric field and will permit also to produce electron beams of higher brightness.

Thus, it follows the next from the simulation results:

– 'π' oscillation mode switch RF gun in 'closed' state when there is no current at 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.

4 EXPERIMENTAL STUDY

To check the possibility of the development of proposed method there were measured RF performances of RF gun sample with the device for the pulse duration varying. There was used cylindrical E_{010} cavity with the fundamental frequency of 2804 MHz and with unloaded quality factor of 6800. The frequency of the coaxial cavity was varied by the switcher based on switching p-i-n diodes. The switching time is not higher then 100 ns. Electric length of the coaxial cavity was $\approx 9\lambda_0/4$. There were measured on-axis electric field distributions in cylindric cavity for each of three defined above cases and amplitude-frequency response of the system. Electric field distribution was measured using resonant perturbation technique. Figure 4 illustrates measured frequency band-pass performance. One can see that the frequency space between '*0*' and 'π' oscillation modes is more then 10 MHz. Oscillation amplitude of 'π' oscillation mode is lower because of low quality factor in this mode.

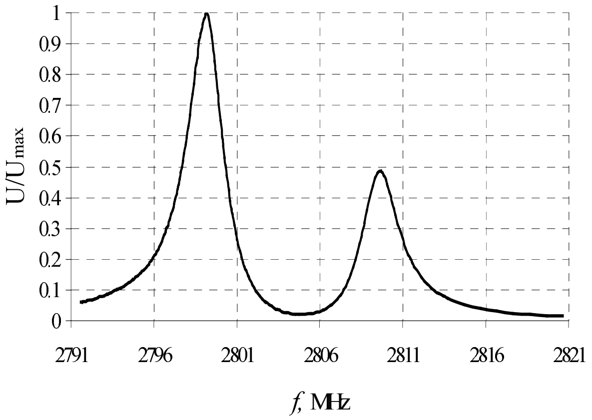

Fig. 3. Pass-band Performance

Measured dependences of the distribution of longitudinal electric field component are shown on Fig. 4. Comparing measured electric field distributions with calculated ones one could note that experimental curves have the same pattern as for calculated ones. The smaller spread in field amplitude values at the cathode plane (position Z=0 on Fig. 4) is explained by the increasing of the coaxial cavity length up to $9\lambda_0/4$ in experiments.

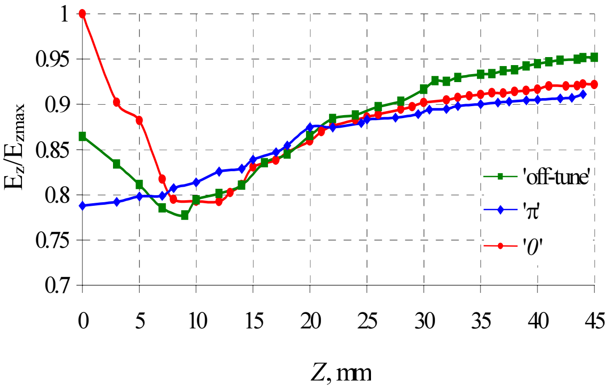

Fig. 4. Measured Electric Field Distributions

Oscillation modes '*0*' and 'π' were switched between each other by p-i-n – diode switcher. Figure 6 shows the signal from the detector that was installed in RF gun cavity in the switching moment.

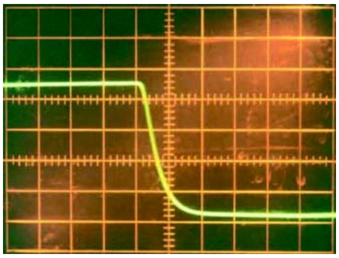

Fig. 6. Rise time of oscillations (1 μs/div.)

According to the pulse curve, the rise time of oscillations is ~ 1 μs that is confirmed by estimations made using equivalent circuit method. This points on the oscillation rise time in the system is defined mainly by the by the rise time of oscillations in the cavity with the most high quality factor value. In the given case this cavity is the cylindric cavity with $\tau = Q_1/\pi{\cdot}f_0$ where Q_1 is the loaded quality factor of the cavity. This time actually doesn't depend on the low quality factor value of the coaxial cavity and was equal to 0.9 μs in the experiment. It should be noted that the loaded quality factor is $(2\text{-}4)\cdot 10^3$ for most of thermionic S-band RF guns with pulse current of ≥1 A. Therefore, the switching time can be of (300-500) ns that is quite enough for the current pulse duration of 3-10 μs.

It should be noted that the resonance system being in '*0*' or 'π' oscillation mode has low quality factor value. This fact has no special sense for 'π' oscillation mode because of the gun is in the 'closed' state. However, it will require the gun should be fed by additional rf power in '*0*' oscillation mode in order to obtain qualitative electron beam at the gun output.

5 CONCLUSION

Thus, numerical simulation and experimental study have shown that time performances of the current can be controlled in RF gun. The control is implemented by the additional electrically tuned coaxial cavity. This permits to obtain few RF-gun operating modes, one of which corresponds to its 'closed' state. The developed system with pulse beam modulation is in actual fact triode RF gun. The proposed concept can be applied not only in thermionic RF guns. Its application will be very effective and for RF guns with metal-dielectric [6] and field emission cathodes where beam parameters depend strongly on the field strength in the cathode region.

It is assumed to carry out the full-scale experiment in prospect using single cavity RF gun with all real its operating conditions taken into account.

6 REFERENCES

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