THE OPTIMIZATION OF THE ELECTRON INJECTOR RESONANT SYSTEM BASED ON THE EVANESCENT OSCILLATIONS

M.I. Ayzatsky, K.Yu. Kramarenko, V.A. Kushnir, V.V. Mytrochenko, S.A. Perezhogin#, V.Ph. Zhiglo, NSC KIPT, Kharkov, 61108, Ukraine

Abstract

The methods and results of the bunching system optimization in the compact S – band electron injector are presented in the report. The injector consists of the low-voltage diode electron gun and bunching system based on the resonant system with the evanescent oscillations. In the bunching system such field distribution along the axis is realized, that its amplitude increases from the point of injection of electrons to the exit. The optimized resonance system allows to obtain the electron bunches with the phase length less than 10° (for 70 % particles) at the injector exit.

INTRODUCTION

An increase of the electric field along the axis of a resonant system of an injector allows to improve the short bunches formation at comparatively small energy spread [1,2,3]. Such principle is realized in the injectors, described in [4, 5, 6]. In the injector [6] the section of periodic disc-loaded waveguide excited in the stop-band is adopted for this purpose. The injector consists of five E_{010} coupled cylindrical cavities (see Fig. 1). The coupling has been realized through the central apertures for the beam pass, the RF-power is supplied to the fifth cavity. The eigen frequency of that cavity is close to the operating frequency of the accelerator and is above of the π mode frequency of the pass-band of the homogeneous infinite disc-loaded waveguide consisting of cavities which sizes coincide with the sizes of the second, third, and forth cavities of the injector. Therefore, our working frequency will lay in the first stop-band*. In this stop-band the phase shift per cell equals π. In such system there are five longitudinal mode. The axial field amplitude in the centers of the cavities of the operating longitudinal mode sharply decreases from the fifth cavity to the first one (in the injector designed by a factor of 150). The field in the adjacent cavities is phase-reversal. The field distributions of another four longitudinal modes are such that their amplitudes in the fifth cavity are small. The choice of such resonant system has been caused by the easiness of its tuning for obtaining the increasing field distribution. The injector is now used in the two-section linear electron accelerator at the energy up to 100 MeV [7]. The more detailed particles dynamic analysis has shown that the choice of identical cavity lengths in the middle part of the resonant system is not optimal for the bunching process. So, a research was conducted with the aim to find the optimal parameters of the resonant system geometry for getting minimum phase length of bunches at the acceptable values of energy spread and transversal emittance.

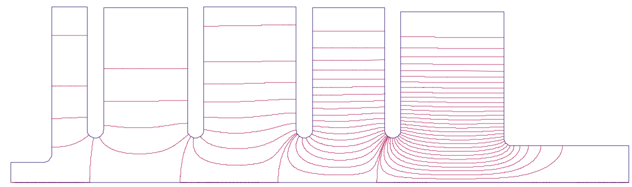

Figure 1: Resonant system geometry and space field distribution.

OPTIMIZATION METHODS

To calculate the electrodynamics characteristics of the resonant system the SUPERFISH group of codes has been used [8]. Simulation of particle dynamics in the diode gun and in the bunching resonant system has been carried out with the use of the EGUN code [9] and the PARMELA code [10] respectively. The simulation has been carried out for the electron beam with the initial energy 25 keV and current 245 mA, with taking into account the space charge force. To take space charge forces correctly, the input beam was represented by bunch with length of $5\beta\lambda$, where β is initial relative speed of particles, λ is operating wavelength. The resonant system of the injector [6] (see Fig. 1) has been chosen as the object of optimization.

The main point of the optimization was to select the field distribution on the system axis that provides minimal phase length of bunches. This procedure consisted of two stages. At the first stage, the initial resonant system has been broken with the plains, passing the points on the axis where the field changes the sign, into five independent artificial cavities. Field distributions of the cavities have been input into PARMELA. The specially designed control program was able to run PARMELA with different cavity field amplitude multipliers and analyze the beam parameters at the injector exit. Calculations of changes of field amplitude multipliers were carried out according to the optimization algorithm. The Nelder-Mead simplex search [11] was used for this purpose. The optimization criterion (criterion function) was the bunches phase length minimization at the energy spread <5% (for 70% particles) and normalized root-mean-square emittance <20 π·mm·mrad.

The second stage included the resonant system synthesis with applying the SUPERFISH for obtaining the field distribution on the axis, close to the one obtained after the optimization carrying out. It is concerned with the fact that in the described above method the resulting field distribution has the "smooth" dependence only at the

psa@kipt.kharkov.ua

* There is the stopband $0<\omega<\omega_0$ disposed bellow the first passband in the disc-loaded waveguide. This stopband, which exists even in the regular waveguides, we call zero or basic.

system axis, meanwhile at the periphery the field experiences disturbance, if the field amplitudes in the artificial cavities differ from the initial ones. It is necessary to note that to obtain the best fit of the field distribution, the cavity lengths should be changed.

SIMULATION RESULTS

Based upon the described above optimization methods the bunching system simulation has been carried out. The results obtained at different stages of the optimization are described bellow. Fig. 2 shows on-axis field distribution before optimization (curve 1 (black)). The curve 2 (blue) in Fig. 2 represents the on-axis field distribution after the first stage of the optimization. The curve 3 (red) in Fig. 2 corresponds to the on-axis field distribution of the synthesized resonant system. One can see the good fit of the final on-axis field distribution to the obtained one after the first stage. Curried out optimization caused the change of the field amplitudes in each cavity. In order to synthesize the required distributing of the field, it was necessary to change the lengths of the cavities and their radii. Relative change of the maximal values of field amplitude within each cavity $\Delta E/E$ and their lengths $\Delta d/d$ are presented in Table 1.

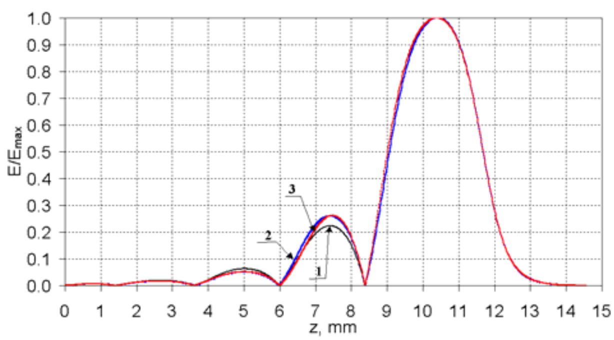

Figure 2: Distribution of on-axis field for different stages of optimization.

Table 1. Changes of field within the cavities and their lengths

Cavity	1	2	3	4	5
$\Delta E/E$, %	8.66	-9.03	-18.32	17.15	0
$\Delta d/d$, %	-8.7	2.1	10.5	-12.8	3.5

It is seen the tendency of decreasing the field change along the initial part of the resonant system (cavity numbers one through three) to obtain minimal phase length of bunches.

To demonstrate how the optimization influences particle dynamics, several plots of particle distribution in longitudinal phase space at the injector exit are represented here. Fig. 3 shows the distribution before the optimization while that after the firs stage of optimization is shown in Fig. 4. Phase-energy distribution of a bunch after the final tuning of the resonant system is presented in Fig. 5.

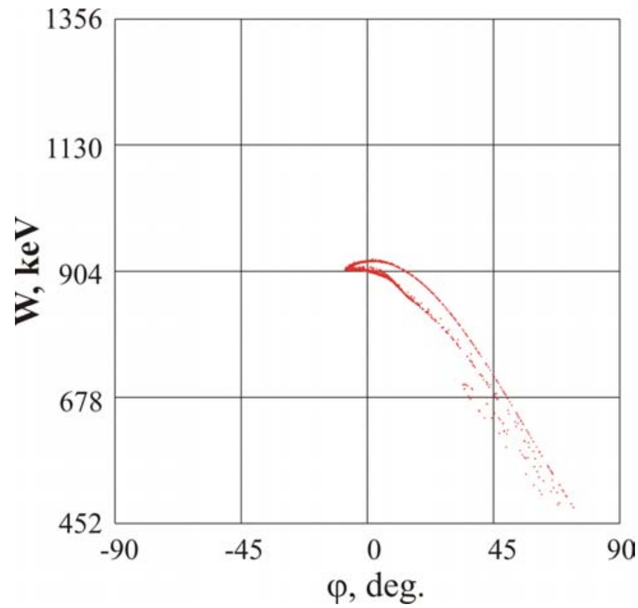

Figure 3: Phase-energy distribution of a bunch before optimization.

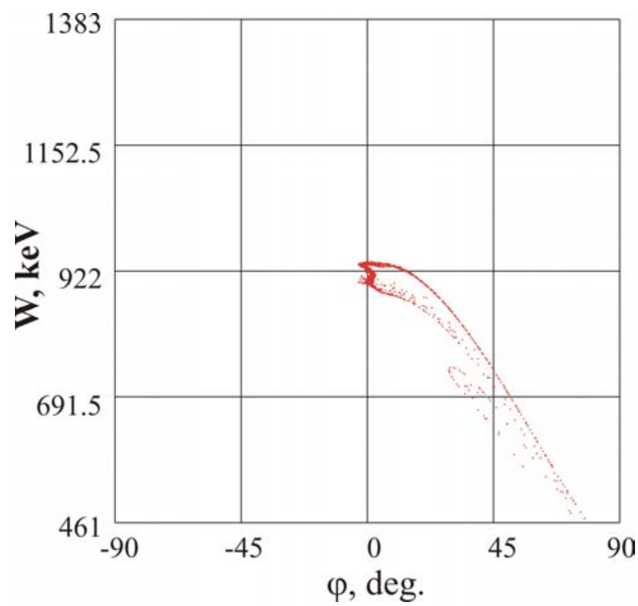

Figure 4: Phase-energy distribution of a bunch after the first stage of optimization.

As it is seen in the figures, optimization leads to more complicated phase motion of particles and most of them are concentrated in the head of a bunch. Phase-energy distribution of particles accelerated in the synthesized resonant system is almost the same as that after the first stage of optimization.

The beam characteristics at the injector exit for different stage of optimization are presented in Table 2. One can see substantial decreasing of bunch phase length after curried out optimization. Transversal characteristics of the beam remain almost unchanged, so the beam brightness was increased.

0-7803-8859-3/05/$20.00 ©2005 IEEE

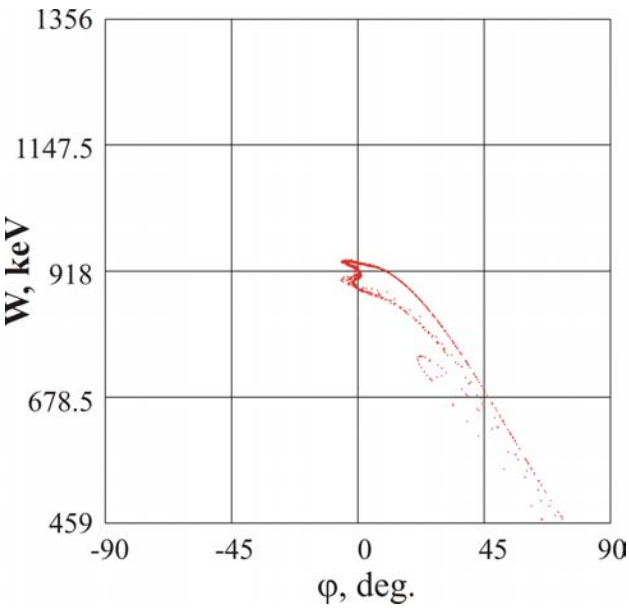

Figure 5: Phase-energy distribution of a bunch after the final tuning of the resonant system.

Table 2. Beam characteristics at the injector exit before and after optimization.

Name	Initial values	Optimization	
		Stage 1	Stage 2
Normalized emittance, $\varepsilon_{rms\ x,y}$ π·mm·mrad	11.58	14.4	9.79
Beam size $4\sigma_{x,y}$, mm	3.07	3.37	2.62
Bunch phase length $\Delta\varphi$ (for 70% of particles), °	19	8.57	7.89
$\Delta W/W$, (for 70% of particles), %	4.9	3.93	4.89
Maximal energy W_{max}, keV	925	940	940
Average energy W_{avr}, keV	834	860	860
Energy in the maximum of the energy spectrum, keV	908	931	932
Widths of the vertical and horizontal beam profiles for 70% of particles, mm	1.34	1.37	1
Capture coefficient k_3, , %	91.7	88.4	88.7

CONCLUSION

The method of resonant system optimization was developed and applied to enhance beam characteristics of the compact S – band electron injector. Optimized resonant system of the injector allows to form bunches with phase length of 7.9° at energy spread of 4.9% and normalized emittance 10 π·mm·mrad. Energy of particles is suitable to inject bunches in accelerating sections with phase velocity that is equal to velocity of the light. It should be noted that the tuning of such resonant system will be more complicated because of each cavity's independent tuning. At the moment the methods of bunching system tuning with the optimized field distribution are being developed.

REFERENCES

[1] A.N. Lebedev, A.V. Shalnov Base physics and techniques of accelerators. M.: Energoatomizdat, 1991 (In Russian).

[2] N.M. Bogomolov, DAN USSR 208 (1973) 113 (In Russian).

[3] M.S. Avilov, A.V. Novochatsky, "Single bunch compression in exponent field," Proc. of the XIV Workshop on charged particle accelerators, Protvino, October 1994, Vol. 3, p. 181 (In Russian).

[4] B.V. Zverev, V.F. Timofeev, V.K. Shilov "Simulation and design of small-sized electron accelerator RELAC-3," in Coll. Accelerators, M.: Energoatomizdat, 1981, p.19 (In Russian).

[5] Yu.P. Vakhrushin, A.V. Rjabtsov, V.L. Smirnov et. al. Accelerating structure with optimized many cavity buncher. Proc. of the XIII Workshop on charged particle accelerators, Dubna, October 1992, v. 1, p. 249 (In Russian).

[6] M.I. Ayzatsky, E.Z. Biller, V.A. Kushnir et. al. Problems of atomic science and technology Ser. "Nuclear Physics Investigations" 1 (2004) 60.

[7] K.I. Antipov, M.I. Ayzatsky, Yu.I. Akchurin, et al. Problems of atomic science and technology, Ser. "Nuclear Physics Investigation" 5 (2004) 135.

[8] J.H. Billen and L.M. Young "POISSON /SUPERFISH on PC compatibles," PAC 1993, Washington, May 1993, p. 790.

[9] W.B. Herrmannsfeldt, "EGUN: Electron Optics Program," SLAC-PUB-6729, Stanford Linear Accelerator Center, 1994.

[10] L.M. Young, "PARMELA", LA-UR-96-1835, Los Alamos, 1996.

[11] J. A. Nelder, and R. Mead, Computer Journal, 7 (1965) 308.

0-7803-8859-3/05/$20.00 ©2005 IEEE