THE BUNCHING SYSTEM BASED ON THE EVANESCENT OSCILLATIONS

M.I. Ayzatsky, E.Z. Biller, N.G. Golovko, K.Y. Kramarenko, V.A. Kushnir, V.V. Mitrochenko, S.A. Perezhogin[#], V.F. Zhiglo, NSC KIPT, Kharkov, Ukraine

Abstract

The report presents design and simulated performances of the S-band electron bunching system based on coupled cavity chain in which the on-axis field amplitude changing substantially from the cell to the cell. For realization of such field distribution the operating frequency of the bunching system, which is close to the eigen frequency of the last cell, is higher than frequency of the "π" mode of the rest part of the bunching system. Cell lengths are chosen in the way to get the effective bunching and accelerating of the beam from the initial energy of 25 keV to the energy about 1 MeV with the current of 300 mA. The bunching system can be used in electron linacs both for fundamental researches and for radiation technologies.

INTRODUCTION

An injector substantially defines beam characteristics on a linac exit. It is known, that the increasing of amplitude of an accelerating field on the initial stage of acceleration when phase motion of particles is not frozen allows receiving small phase length of bunches at low energy spread [1]. Bunchers, which use such principle, are described, for example, in [2-4]. Resonant systems of the first and the second of them are a section of non-uniform biperiodic waveguide with magnetic coupling and the third one uses the section of non-uniform dick loaded waveguide (DLW) with the large attenuation of a counter-propagating wave. In [5,6] it was offered to use for this purpose a section of homogeneous DLW exited on the frequency that lies beyond the pass-band of corresponding infinite waveguide. Simulations of longitudinal motion of particles with the self-consisted model of the weakly coupled cavities [5,6] has shown that such system consisting of five cells is able to group low-voltage (25 keV) beam and to accelerate it up to energy, sufficient for injection in accelerating section with constant phase velocity. Besides, it was shown, that in such buncher at beam loading up to 1.5 A the field distribution does not change substantially. Therefore to simulate particle dynamics in the steady state mode it is possible to run the PARMELA program [7] using field distribution obtained with a SUPERFISH group of codes [8]. Intensive study of beam dynamics in the bunching system showed that longitudinal and transversal motion of particles is complicated. In particular, at the large change of energy of particles (from 25 keV to 1 MeV) the efficiency of homogeneous structure decreases. Besides, on the initial stage of bunching particles undergo defocusing action of a RF field that imposes requirements on the transverse characteristics of an input beam. Development of a buncher on the basis of a section of inhomogeneous DLW excited in a stop-band was the result of carried out researches. Design of the buncher, simulated performances of an output beam as well as measured on-axis field distribution of a buncher prototype for "cold" tests are presented below.

DESIGN AND CHARACTERISTICS OF THE BUNCHER

The buncher consists of a chain of five coupled cavities. The coupling of cavities implemented through central holes for beam passing. The sizes of the holes were selected equal each other. For realization of required on-axis field distribution, the operation frequency of a buncher, which was close to the eigen frequency of the last cell, was selected higher than the frequency of the "π" mode of oscillations of a remaining part of the buncher. In this case the phase advance of a field on a cell remained equal π.

The preliminary calculations of the bunching system were made on the basis of self-consistent model of weakly coupled cavities. Further simulation of the system was carried out with SUPERFISH and PARMELA programs. To do so the configuration of a resonant system obtained as a result of preliminary calculations, was some changed in view of finite width of disks and fringing fields on an entrance and an exit of the buncher that were not taken into account in the preliminary calculations.

As the buncher is intended for bunching and accelerating of a unmodulated beam, 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 calculations were conducted for an electron beam with initial energy of 25 keV and current about 300 mA.

The purpose of calculations and simulations was the definition of lengths of the first and the last cells providing the required characteristic of a beam. The period of cells located between the first one and the last one were chosen equal to $0.22\,\lambda$ according to the preliminary calculations. Such choice was stipulated by rather simple adjustment of a resonant system in this case.

To reduce influence of a space charge on a transversal emittance, the electron gun should be placed close to the bunching system as much as possible. Therefore in the developed buncher the inlet opening for injection of a beam is an anode of the gun. Estimations with approximation of a laminar flow on the base of a technique [9] without taking into account action of a RF

[#]psa@kipt.kharkov.ua

field on particle motion have shown that the transporting of a beam on necessary distance can be carried out without application of magnetic lenses. However, for the implementation of calculated parameters of a beam it would be required to increase diameter of a focusing electrode of a gun excessively. Besides, as simulations of particle dynamics in a buncher showed, small radius of a beam in a waist in this case increases value of phase width of bunches because of influence of space charge forces. It has forced us to refuse optimum conditions of transportation and to accept the conciliatory solution taking into account features of longitudinal motion of electrons in the buncher and technical feasibilities of gun manufacturing. The final solution was found by successive running the EGUN [10] and the PARMELA codes. The computational parameters of the gun and characteristic of a beam without taking into account influence of a RF field are listed in Table 1.

Table 1: Computational parameters of a gun and characteristic of a beam

Parameter	Value	Units
Cathode voltage	-25	kV
Cathode radius	2.5	mm
Normalize beam emittance (1 σ)	4.1	π·mm·mrad
Distance from the front cut of the anode aperture to the beam waist	40	mm
The beam radius in the waist	1.2	mm
Beam current	0.3	A

As a result of the carried out researches of particle dynamics in the buncher the optimum distribution of an on-axis field for a case when three middle cells have the identical sizes was determined. This distribution is shown in Fig. 1 by continuous line. Fig. 2 shows the simplified view of the buncher designed on the base of simulations. Buncher characteristics and characteristics of a beam on it exit are listed in Table 2. Fig. 3 shows phase and energy spectra, emittance and transversal profile of a beam. It can be seen, that the designed buncher can be utilized in linacs both for fundamental researches and for radiating technologies.

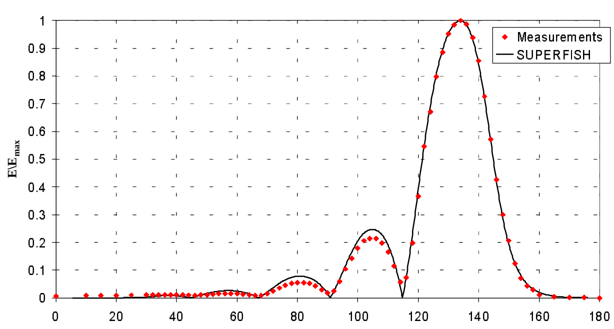

Figure 1: Distribution of on-axis field amplitude: calculated and measured.

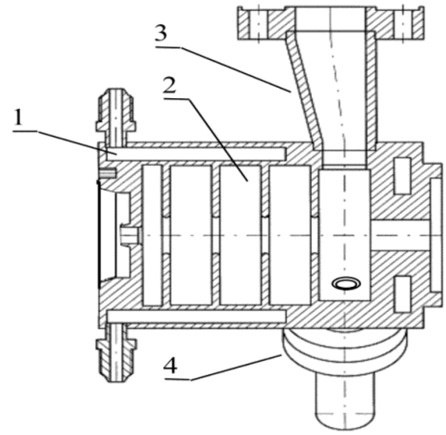

Figure 2: Simplified view of the buncher (1 – cooling ducts; 2 – resonant system; 3 - waveguide; 4 - tuning unit).

Table 2: Characteristics of the buncher

Parameter	Value	Units
Operating frequency	2797.15	MHz
Quality factor	12300	
Power losses in walls	480	kW
Maximum field on the axis	36	MV/m
Current at the injector output	0.28	A
Normalize emittance (1 σ)	18	π·mm·mrad
Δφ (for 70 % of particles)	20	deg
ΔW/W (for 70 % of particles)	7	%
Capture coefficient $k_з$	93	%
Average energy	767	keV
Maximum energy	863	keV
Beam ∅ (for 70 % of particles)	3	mm
$4\sigma_{x,y}$	3.9	mm

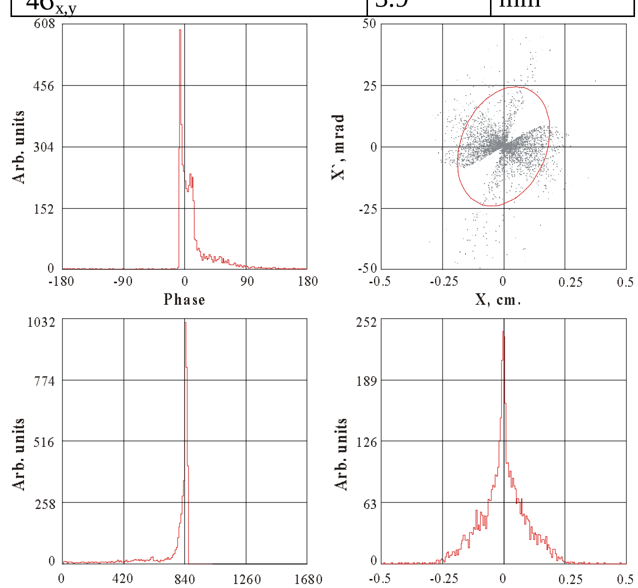

Figure 3: Beam characteristic on an exit of the buncher.

One of the important stages of a buncher creation was the development of a technique of adjusting of a resonant system for obtaining necessary distribution of the on-axis field on an operating frequency. With this purpose the prototype of a resonant system for "cold" measurements was manufactured and adjusted. The technique of the adjusting consists in following. At first the frequency of the "π" mode of a homogeneous segment of the system (cells number two, three and four) was found by the SUPERFISH. Then the stack of three identical cavities, restricted with cavities of half length, was adjusted to obtain the "π" mode on this frequency taking into account frequency shifts due to brazing, evacuating and difference between the operating temperature and temperature, at which the adjusting is carried out. The cavities were adjusted by lathe boring of their diameter at several steps. After each step the distribution of the on-axis field was checked up by a bead pull method. If it was necessary amplitudes of field in cavities were matching by the additional boring of the cavity with larger amplitude. Then the first half-length cavity of the stack was changed on the first cavity of a buncher and its diameter was adjusted to restore the frequency of the "π" mode of the stack. After that the last half-length cavity was swapped with the fifth cavity of the buncher. By changing its eigen frequency the stack was adjusted on the operating frequency of 2797.15 MHz taking into account the above-mentioned frequency corrections. In such way the required on-axis field distribution on operating frequency was obtained. It is necessary to note, that the measurement of a field distribution in such system has some distinctive because of the amplitude in the fifth cavity exceeds more than 100 times its value in the first one, so the bead should be enough big. The metal cylinder with diameter of 4 mm and length of 6 mm was used. For measurements the technique [11] was used, which allows determining the change of a resonance frequency with a relative mean square error of $6\cdot10^{-8}$ at a loaded quality of a cavity about 10000. Simulation of process of measurement with the SUPERFISH showed that errors of the method are –13% for the maximum field in the first cavity and –2,7% for that in the last one. The above-mentioned errors are the best trade between ability of apparatus and influence of the bead on the field distribution. The measured on-axis distribution of the field amplitude of the prototype is shown in Fig. 1 by points.

Encouraged with good performances of the developed buncher we studied possibility of further improvement of beam characteristics by some complicating a resonator system of the buncher. For optimization of electron dynamics in the buncher it is necessary to change length and eigen frequency of each cavity separately, that, however, will not cause essential change of the design of the buncher. Simulations showed that it is possible to get bunches with phase length of 9° and relative energy spread of 5% (for 70% of particles in bunch). Transversal normalized root mean square emittance of a beam is 16 $\pi\cdot$mm$\cdot$mrad in this case. In our opinion, the injector on the basis of such buncher can be used even in infrared free electron lasers. However it is necessary to mark, that the adjustment of the resonant system will be more complicating because of necessity of independent adjustment of each cavity. Now a technique of adjusting of a buncher with the optimized field distribution is under development.

CONCLUSION

Being based on results of research of electron dynamics in bunching systems on evanescent oscillations with self-consistent model of weakly coupled cavities as well as with the SUPERFISH, PARMELA and EGUN codes the design of a S-band buncher and technique of its adjusting were developed. The buncher effectively forms of electron bunches and accelerates them from initial energy of 25 keV to energy about 1 MeV at a current of 300 mA. The buncher can be used in electron linacs both for fundamental researches and for radiation technologies.

REFERENCES

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

[2] A.A. Zavadtsev, B.V. Zverev, V.E. Kaluzhny, “Manufacturing and adjusting of a buncher of a 5 MeV resonant linac,” Uskoriteli, M., Atomizdat, Vol. 17, 1979, p. 93 – 98. (In Russian).

[3] Yu.P. Vakhrushin, A.V. Rjabtsov, V.L. Smirnov, V.V. Terentjev, “Acceleratin structure with optimized many cavity buncher,” Proceedings of the conference on charge particle accelerators, Dubna, 1993, Vol. 1, p. 249-251 (In Russian).

[4] M.S. Avilov, A.V. Novochatsky, “Single bunch compression in exponent field,” XIV Workshop on charged particle accelerators, Protvino, 1994, Vol. 3, p. 181 – 183. (In Russian).

[5] S.A. Perezhogin, N.I. Ayzatsky, K.Yu. Kramarenko, “Evanescent oscillations in bunching systems,” PAC`2001, Chicago, June 2001, p. 2281.

[6] S.A. Perezhogin, N.I. Ayzatsky, K.Yu. Kramarenko, Problems of atomic science and technology, 2001, No. 3, p. 83-85.

[7] L.M. Young, “PARMELA,” Los Alamos National Laboratory, LA-UR-96-1835, 1996.

[8] J.H. Billen and L.M. Young, “POISSON/SUPERFISH on PC compatibles,” PAC`93, Washington, 1993, p. 790–792

[9] J.R. Pierce, “Theory and design of electron beams,” Second edition D.Van Nostrand company, inc. Toronto New York London, 1954.

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

[11] V.A. Kushir, V.V. Mitrochenko, Instruments and Experimental Techniques, Vol. 41, No. 2, 1998, p. 206 – 209.