INJECTOR OF INTENSE ELECTRON BEAM

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Abstract

The results of beam dynamic simulation in a S-band injector that can be used for creation of the powerful electron linac are presented in the report. The injector consists of a diode electron gun with beam current of up to 2 A at energy of electrons of 25 keV, the klystron type prebuncher and the three cavity buncher. In the buncher, due to the special choice of eigen frequencies of resonators, maximal amplitude of the field on the axis of resonators exponentially increases from the first (downstream of the beam) resonator to the last resonator. It allows to realize an effective bunching the intensive electron beam and accelerating it to relativistic velocities. For achievement a low transversal beam emittance the injector is placed into the external magnetic field. The injector provides more than 1 A of beam current with particle energies of about 1 MeV. Attention is paid to research of transients and stability of injector work.

INTRODUCTION

Often it is necessary to provide ampere range beam at an exit of the pulsed electron S-band linacs with high beam power because a duty factor of pulsed klystron amplifiers is about 0.1%. Use of relatively low voltage electron guns (several tens of kilovolts) in a linac injector facilitates obtaining high reliability of the linac at compact linac dimensions. Bunching system based on evanescent waves (see for example [1]) is very suitable to generate electron bunches from continuous beam emitted from a cathode of such low voltage gun as well as to accelerate particles to relativistic velocities. The above mentioned bunching system comprised of five cells has exponential rise of on-axis field from the entrance of the electron beam into the buncher to the it exit. This rise is provided by correspondent choice of cell dimensions. To provide flexibility of the system at bunching and accelerating of the ampere range electron beam it was decided to change the first two cells of the buncher with a klystron type prebuncher and drift space. To prevent degradation of transversal beam emittance the prebuncher and buncher are placed into solenoidal magnetic field. This paper is devoted to brief description of simulation algorithms of beam dynamics in a system comprised of the prebuncher and the three cell buncher as well as to review of simulation results.

SIMULATION ALGORITHMS

The POISSON/SUPERFISH [2] group of codes was used to calculate characteristics of resonance and magnetic systems of the injector. Simulation of electron motion in the injector was performed using the PARMELA [3] code. Beam parameters of the ampere range diode gun [4] was calculated with EGUN [4] code. Study of unsteady self consistent beam dynamics in the injector were performed both with technique [6] and with developed by us program COUPLRES. Technique [6] solves self-consistent equations of field excitation in axially symmetrical cavities both by an electron beam and by an external RF generator. The PARMELA code is used in this technique to simulate particle motion in evaluated field to get needed data at each temporal step of the equation solution. This technique takes into account only one mode of a cavity field.

COUPLRES (COUPLing RESonators) allows to describe unsteady processes arising at interaction of electron beam with electromagnetic systems that can be represented as a chain of coupled cavities. This code is elaborated on a base of mathematical model that is development of the coupled cavity model by correct taking into account self-consistent beam dynamics in fields excited both by external sources and by particles itself. At the moment the model takes into account only fields that are symmetrical relatively the main direction of beam propagation. The base of the model is decomposition of a considered electromagnetic system into closed volumes and representation of fields inside of the volumes as an expansion into a series of eigen functions (solenoidal and potential) of closed cavities. Particles are injected into a simulated system at certain moments of time. A set of equations to be analyzed consists of particle motion equations and equations for expansion amplitudes (differential equations for basic oscillations and algebraic ones for non-resonant modes).

A developed variant of the code is applicable to describe systems that can be decomposed into cylindrical volumes. In this case there are analytical expressions for the eigen functions. The Runge-Kutta method is used to solve both equations of motion and equations for amplitudes of basic oscillations. At solution of the last equations values of current and charge integrals are kept constant over RF period of the fundamental frequency. Quasi-coulomb fields are represented as expansion into series of solenoidal and potential functions and are evaluated at frequencies $\omega \approx 0$ and $\omega \approx \omega_0$, where ω_0 is frequency of a RF source.

The merit of the code is a possibility to take into account influence of all eigen modes at simulation of time beam dynamics. This feature allows to make an analysis of injector operation stability at bunching and accelerating of intense electron beams.

SIMULATION RESULTS

Simulations were carried out to attain two aims. On the one hand in was necessary to find configurations both the resonance and magnetic system of the injector that provide effective bunching of the ampere range electron beam at minimal degradation of the transversal emittance. On the other hand stability of the each considered configurations against excitation of parasitic oscillation in the buncher was checked. As a result of preliminary researches we chose injector structure that provides on-axis field distributions shoved in Fig. 1 and Fig. 2.

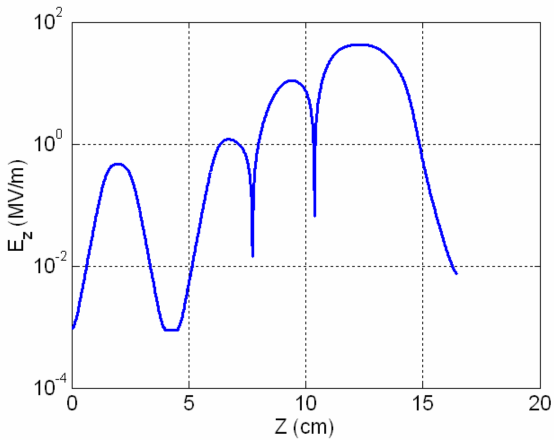

Figure 1: On-axis distribution of the electromagnetic field.

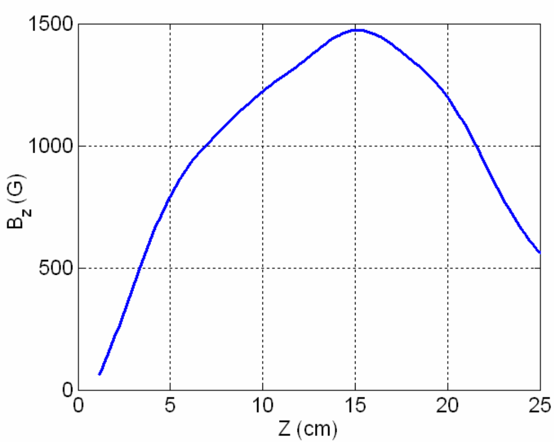

Figure 2: On-axis distribution of the static magnetic field.

Injector parameters and data obtained in self-consistent beam dynamic simulation with technique [6] are listed in Table 1. Beam parameters are given taking into account transients. The COUPLEREZ code gives similar results. It can be seen from Table 1 that the injector provides enough short bunch length at formation of an ampere range beam. High energy of particles allows injection directly into acceleration section with phase velocity that is equal to velocity of the light. We are going to optimize field distribution in the buncher with technique [7] to get shorter bunch in near future.

Some simulated signal waveforms that characterize injector operation are shown in Fig. 3 through Fig. 5.

Analysis of simulation results has shown that some part of electrons uncaptured into process of acceleration in the buncher goes backward through the prebuncher cavity. Current of such electrons can reach 0.15 A at average energy of 0.1 MeV. Interaction of these electrons with prebuncher field sets a feedback loop by beam. For the described injector configuration the feedback does not notably change beam parameters at the exit of the injector, but transient times in cavities are high compare with the case when we do not take back motion into account.

Table 1: Injector Specification

Gun current, A	1.5
Output beam current, A	1.34
Bunch repetition rate, MHz	2797.15
RF power supply of prebuncher, W	570
RF power supply of the buncher, MW	1.8
RF pulse length, μs	2.9
Current pulse length, μs	2.4
Normalized root mean square (RMS) emittance $\varepsilon_{rms\ x,y}$, π·mm·mrad, (1 σ)	12
RMS beam size ($4\sigma_{x,y}$), mm	2.8
Bunch phase length (for 70% of particles), °	18
Energy spread width (for 70% particles), %	5.4
Energy of particles, keV	948

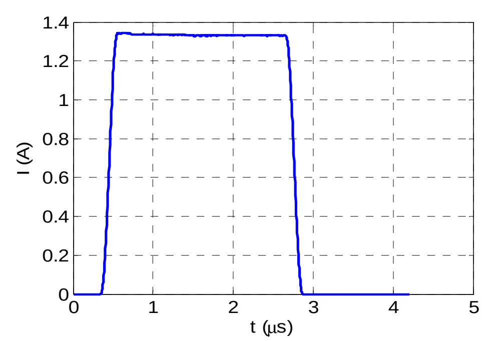

Figure 3: Output current pulse.

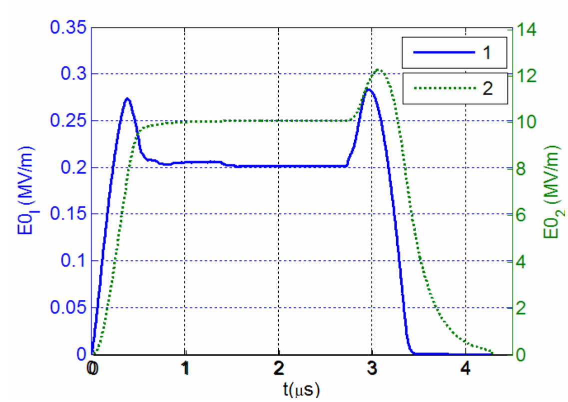

Figure 4: Waveforms of average on-axis field in the prebuncher (1) and in the buncher (2).

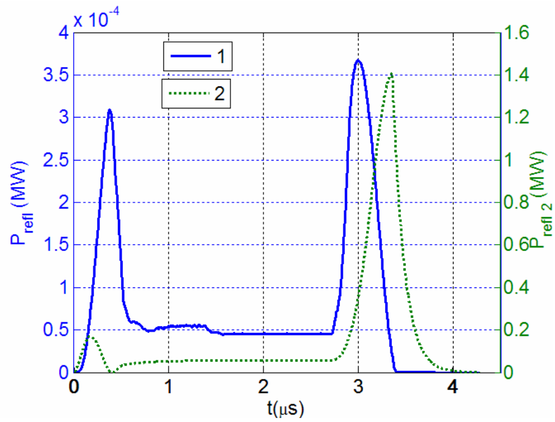

Figure 5: Waveforms of reflected waves from the prebuncher (1) and the buncher (2).

Increase of transient time due to the beam induced feedback can be seen in Fig. 4 and Fig. 5 at temporal interval from 0.5 to 1.5 μs. If we do not include backward propagated electron into consideration, above mentioned features will disappear.

At interaction of intense electron beam with multicavity system there is possibility of field excitation on adjacent modes that can cause unstable operation of the injector. The COUPLRES code was used to analyze stability of considered injector operation at bunching and accelerating electron beam with current up to 2.5 A. It is necessary to note that on-axis field distribution for nearest adjacent modes in the buncher has inverse dependence compare with shown in Fig. 1. That is field amplitude in the first cell has about the maximal level while that in the last cell has very small level. Therefore excitation of the adjacent modes will influence mostly field amplitude in the first cell of the buncher. Fig. 6 shows time dependence of a value that is proportional to field amplitude of E_{010} oscillation in the first cell of the buncher at no beam load and at acceleration of 1.5 A beam (current pulse length was 4.5 μs in this case). It can be seen decreasing field amplitude at beam injection but after transient is over the steady state regime is established. Therefore a process of bunching and acceleration is stable at such beam current.

SUMMARY

As a result of carried out simulation we determined configurations of both the resonance and magnetic system of the injector that provide effective bunching of the ampere range electron beam at minimal degradation of the transversal emittance. The injector with the chosen configuration is stable against excitation of parasitic oscillation in the buncher at input currents up to 1.5 A. It was shown that backward propagated electrons interact with the prebuncher and increase transient time.

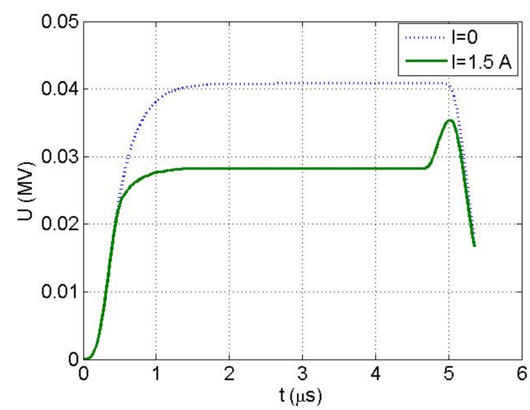

Figure 6: Voltage over the gap of the first buncher cell.

The injector can provide more than 1 A of output current at particle energies about 1 MeV and normalized RMS (1 σ) transverse emittance of 12 π·mm·mrad.

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