BEAM LOADING IN THE STANDING WAVE INJECTOR ON THE BASE OF EVANESCENT WAVE

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Abstract

Standing wave injectors on the base of evanescent waves are considered. The injectors consist of the fragments of the cylindrical disc loaded waveguide (*CDW*) and biperiodic *CDW*. The parameters of the systems are selected in such a way, that at the working frequency the resonant oscillation in the injector corresponds to the evanescent wave of the boundless periodic structure. It gives possibility to create in the injector the increasing amplitude distribution, which improves the bunching process at the initial stage of acceleration. The simulation of the beam dynamics is carried out with taking into account the beam loading.

1 INTRODUCTION

It is known, that for improvement of the beam bunching at the initial stage of acceleration it is necessary to create an increasing field distribution [1]. It was shown [2-4], that there is the eigen oscillation in the resonant periodic (biperiodic) structure corresponding to only one (increasing or decreasing) boundless structure evanescent oscillation. We proposed the simple of periodic (biperiodic) electron buncher with the increasing distribution of the field amplitude [2-4], which is based on the resonant system with evanescent wave.

Taking into account the beam loading in the resonant system is of great importance when the intensive electron beam is bunched. The aim of our study is to take into account the influence of the beam loading on the bunching of the intensive electron beam in the resonant system with evanescent oscillation.

2 BEAM LOADING MODEL

The bunchers based on the segments of cylindrical disk-loaded periodic and biperiodic waveguides are considered. To describe such structures we use the oscillation equations of the weakly coupled cavities. The field excited by the external source and electron beam can be determined from the general theory of waveguide excitation [5].

All the calculations are carried out under the assumption that the particle motion is one-dimensional. We consider the stationary state[1] of bunching and acceleration, which established after the transition process has been completed.

The amplitude distribution of the field excited by the external source and electron beam in the buncher consisting of N cavities is determined by the following set of equations:

$$A_1\left(\omega_*^2-\omega_1^2(1+\varepsilon(1))+\frac{i\omega_*\omega_1}{Q_1}\right)+\omega_1^2\tilde{\varepsilon}(1)A_2=\frac{i\omega_* I_0\lambda}{N_1}\int_0^1 d\tau_0\int_0^\delta e^{i\tau_L 2\pi}d\xi, \quad \textbf{(1)}$$

$$A_n\left(\omega_*^2-\omega_0^2(1+\varepsilon(n))+\frac{i\omega_*\omega_0}{Q_n}\right)+\omega_0^2\tilde{\varepsilon}(n-1)A_{n-1}+\omega_0^2\tilde{\varepsilon}(n+1)A_{n+1}=$$
$$\frac{i\omega_* I_0\lambda}{N_n}\int_0^1 d\tau_0\int_0^\delta e^{i\tau_L 2\pi}d\xi \qquad n\neq 1,N \quad \textbf{, (2)}$$

$$A_N\left(\omega_*^2-\omega_N^2(1+\varepsilon(N))+\frac{i\omega_*\omega_N}{Q_N}\right)+\omega_N^2\tilde{\varepsilon}(N-1)A_{N-1}=$$
$$-\frac{i2\omega_*\omega_N\beta U_0}{Q_N\theta_N}+\frac{i\omega_* I_0\lambda}{N_N}\int_0^1 d\tau_0\int_0^\delta e^{i\tau_L 2\pi}d\xi \quad \textbf{, (3)}$$

where A_n is the complex amplitude of the E_{010}-oscillation in the n-cavity; n=1,2,…N, $\chi=\frac{2}{3\pi J_1^2(\lambda_{01})}$; λ_{01} is the first root of the zero order Bessel function; $\varepsilon(n)=\chi\frac{a^3(n)+a^3(n+1)}{b^2(n)d}$; $\tilde{\varepsilon}(n)=\chi\frac{a^3(n)}{b(n)b(n+1)d}$;

$i\omega_* I_0\lambda\int_0^1 d\tau_0\int_0^\delta e^{i\tau_L(\tau_0,z)2\pi}d\xi=\frac{d}{dt}\int_V \vec{j}_e\vec{E}_n dV$ is the integral that takes into account the influence of the electron beam on the field amplitude in the self-consistent problem. The integration is carried out over the initial phases and the structure period, $\tau_L(\tau_0,z)$ is the Lagrange coordinates, $\omega_* t_0=\tau_0 2\pi$, $\omega_* t_L=\tau_L 2\pi$.; I_0 is total electron current; ω_0 is the resonant frequency of the E_{010}-oscillation in the n-cavity, $n\neq 1,N$; ω_1 is the resonant frequency of the E_{010}-oscillation in the 1-cavity; ω_N is the resonant frequency of the E_{010}-oscillation in the N-cavity; Q is corresponding quality factor; β is coupling coefficient of coaxial line with buncher; a(n) (for n=2…N) are the iris radii. For convenience we introduce a(1)=0, a(N+1)=0.; b(n)=b (for n=2…N) are the cavity radii of the regular part of the buncher, at that b(1) and b(N) are the radii of boundary cavities; d is the cavity length; λ is the wavelength of the external RF source; Z is the wave resistance of the coaxial line; ξ=z/λ, δ=d/λ is the dimensionless coordinate; $N(n)=\varepsilon_0 d\, b^2(n) J_1^2(\lambda_{01})$; $\theta_N=\omega_N\beta Z N_N/Q_N$.

The motion of the electron beam in the buncher can be described by the equations:

[1] Suppose that such state exists.

$$\frac{d\tau_L}{d\xi}=\frac{\gamma}{\sqrt{\gamma^2-1}} \qquad \textbf{(4)}$$

$$\frac{d\gamma}{d\xi}=\frac{\lambda}{mc^2}2Re\left[eA_n e^{-i2\pi\tau_L}\right] \qquad \textbf{(5)}$$

3 BUNCHING SYSTEM BASED ON THE EVANESCENT OSCILLATIONS

3.1 Buncher on the base of CDW

The geometry of the buncher is shown in fig.1.

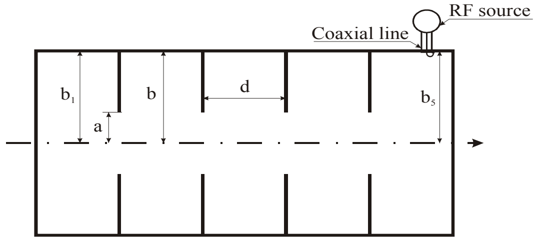

Figure 1

It is known that there is the infinite number of stopbands in *CDW* is well known. We choose the first stopband of the symmetric mode as operating[2]. For the realization of the increasing field amplitude distribution it is necessary to select the resonant frequency of the bounded structure (the buncher) to be above ω_π frequency (π oscillation) of the boundless structure:

$$\omega_* = \alpha\omega_\pi,\ \alpha>1 \qquad \textbf{(6)}$$

The phase shift per cell equals π in the first stopband. The dimensions of the cavities of the regular part of the buncher are selected in accordance with the condition (6). At that, the operating frequency ω_* equals 2797.15 MHz. To obtain the increasing field amplitude distribution in the buncher the radii of the boundary cavities have to be selected in a proper way [3] with taking into account (6).

3.2 Buncher on the base of biperiodic cdw

The geometry of the biperiodic buncher is shown in fig.2.

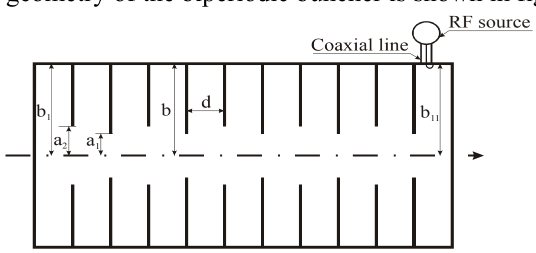

Figure 2

For the realisation of the increasing field in the biperiodic buncher it is necessary to select the cavity dimensions in a proper way. There are two passbands separated by the stopband in the biperiodic structure, as distinct from the periodic one. So, it is possible to select the operating frequency inside the inner stopband. At that, the compensation should not take place [4]. For the improvement of the stability the operating frequency has to be equal to the middle frequency of the inner stopband.

4 SIMULATION RESULTS

4.1 Buncher on the base of CDW

Proceeding from the above presented theory, we determine the dimensions of the buncher cavities. The simulation of the continuous electron beam bunching and acceleration is carried out with taking into account the beam loading. The simulation was held under the electron beam initial energy 25 KeV, working electron beam current I_0=1 A and the time-transit angle 0.3π (for relativistic particle). The power forwarded from the RF source to the bunchers is 570 kW. The field amplitude and the phase shift are plotted versus the cavity number in fig.3 for I_0=0 A (o) and I_0=1 A (*).

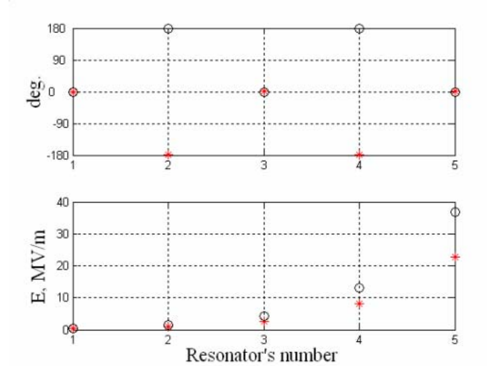

Figure 3

Simulation of particle dynamics in the system has shown that the maximum energy of the electron beam is 0.6 MeV, average energy is 0.54 MeV, capture is 84% and energy spectrum is <25%.

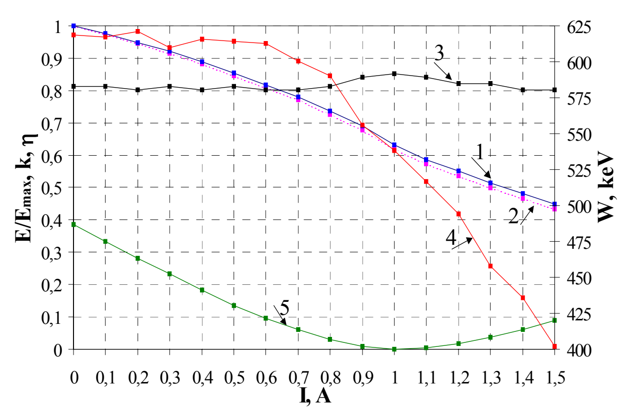

Figure 4: 1, 2 – is the normalised field amplitude E/E_{max} in the 1st and 5th cavities; 3 – is the average energy W_{avr}; 4 – is the capture k; 5 – is the is the reflection coefficient η.

[2] There is the stopband $0<\omega<\omega_0$ disposed bellow the first passband in the *CDW*. This stopband, which exists even in the regular waveguides, we call zero or basic.

The beam characteristics at the exit of the injector were calculated depending on the injected electron current: $0<I_0<1{,}5$ A. The results are shown in fig.4.

In fig. 4 the curves of the normalised field amplitude depending on the injecting electron current in the 1-st and 5-th cavities coincide. Such situation takes place for the other cavities, too (the curves for the rest cavities are not shown in the fig. 4, for they coincide as well). So, we can conclude, that the beam loading is uniform along the injector for different currents of the electron beam.

4.2 Biperiodic buncher on the base of CDW

Simulation of the electron bunching in the biperiodic buncher on the base of resonant system with evanescent wave is carried out. We consider the biperiodic waveguide with all the corresponding dimensions are to be equal, except the iris radii. The transit angle for the relativistic particle is 0.3π per period. The phase shift per period is π. The required on-axis field distribution was obtained by periodical variations of iris radii and by boundary cells tuning. The field amplitude and the phase shift are plotted versus the cavity number in fig.5 for $I_0=0$ A (o) and $I_0=1$ A (*).

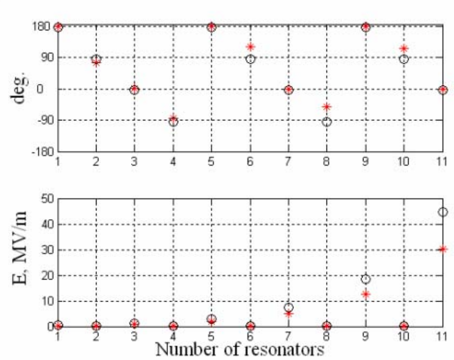

Figure 5

Simulation of particle dynamics in the system has shown that the maximum energy of the electron beam is 0.52 MeV, average energy is 0.45 MeV, capture is 88% and energy spectrum is <25%.

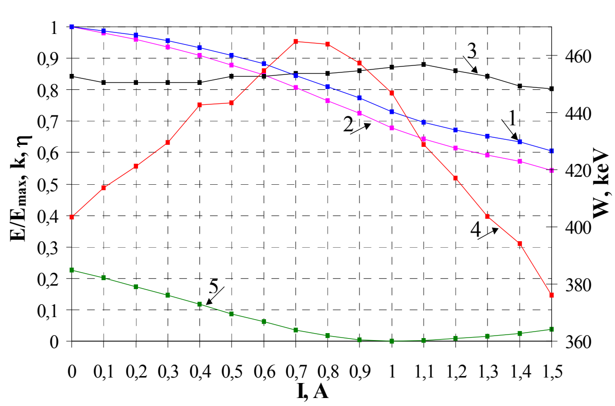

Figure 6: 1, 2 – is the normalised field amplitude E/E_{max} in the 1[st] and 11[th] cavities; 3 – is the average energy W_{avr}; 4 – is the capture k; 5 – is the reflection coefficient η.

As in the previous case (periodic injector), the beam characteristics at the exit of the biperiodic injector are calculated depending on the entrance electron current: $0<I_0<1{,}5$ A. The results are shown in fig.6.

The analysis of the field amplitude dependence on the electrons current in the buncher resonators shows that in the cavities with large amplitude the uniform beam loading takes place.

5 CONCLUSION

Our simulations show the possibility of intensive electron beam bunching in the bunchers on the base of segments of simple systems – *CDW* and biperiodic *CDW*. The field distribution in such bunchers when $I_0=0$ A corresponds to one evanescent wave of the periodic and biperiodic structure. It is shown, that in the case the uniform sections of the periodic structure are used as the buncher, the beam accumulates more energy then for the case of biperiodical structure at the same input of RF power. At that time, the average beam energy changes with the increasing of the beam current considerably weaker in the biperiodic buncher, than in the periodic one. Since for both bunchers the uniform beam loading along the entire resonance system takes place, simulation of the stationary state of bunching on the base of the PARMELA code can be used [6]. The results obtained allow to conclude about the possibility of the construction of simple injector for bunching and accelerating of the intensive electron beams with satisfactory characteristics.

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6 REFERENCES

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