SELF-MODULATION OF AN INTENSE ELECTRON BEAM IN AN INJECTOR OF A LINAC WITH A FEEDBACK

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Abstract

This paper reports the results of the analysis of the time structure of the beam versus the RF power supplied to the injector of the linac with a feedback. Using a nonstationary model of acceleration, we have performed a mathematical simulation of the dynamics of prebunched electron beam acceleration. The results of the mathematical simulation demonstrate that in the self-modulation acceleration regime of a linac with feedbacks there exists a possibility of adjusting the current pulse length, the pulse-to-pulse time being nearly the same.

Our previous studies of the dynamics of intense electron beams in linacs with feedbacks have demonstrated an important role of these latter in the dynamics of acceleration (1-3). Namely, at certain injection current and feedback valves, a self-modulated instability may develop in the injector, resulting in periodic time variations of both the accelerating field characteristics and beam parameters (current, energy). Considering that there is a great demand for accelerated electron beams with a complicated time structure, it is of interest to study the dependence of the time structure of the beam in the self-modulation mode on external conditions of a linac with a feedback.

This paper reports the results of the analysis of the time structure of the beam versus the RF power supplied to the injector of the linac with a feedback. Using a nonstationary model of acceleration (2,3), we have performed a mathematical simulation of the dynamics of prebunched electron beam aceleration in the structure with the following parameters: the interaction length $L = 80$ cm, the phase velocity of the wave at an operating frequency ($f_0 = 2797$ MHz) $V_{ph} = 0.96$ C, the shunt resistance $R_{sh} = 46.7$ MΩ/cm. The output and input of the system are connected via a phase shifter and a directional coupler with a variable coupling. The directional coupler is fed from an external RF source (4). A set of the parameters (RF source power, coupling coefficient of the directional coupler, phase shift in the feedback ring, phase difference between the RF signal and the first harmonic of the current, etc.) will be described by the characteristics of the corresponding stationary mode of acceleration, which is meant as a particular solution of the nonstationary model for a given set of the mentioned parameters, on the assumption of the time independence of all the quantities ($d/dt = 0$)*. This stationary solution for the assigned parameters of the infected beam is completely described by the field amplitude (A_{in}) and phase (ϕ_{in}) at the accelerating structure input. With a knowledge of these parametes, it is easy to calculate the acceleration characteristics, in particular, the output field amplitude (A_{out}) and phase (ϕ_{out}). Figure 1 shows A_{out} versus A_{in} (the amplitude is normalized to 100 kV/cm) for two ϕ_{in} values: $-\pi/2$ and $-\pi$. The initial beam energy W_0 is 100 keV, and the injection current is 1 A. It can be seen that this characteristic in the vicinity of the input amplitude value, at which the particles are captured into acceleration, had a fragment with a negative curvature. Its occurrence is due to an abrupt change in the nature of the bunch motion in the capture region.

* In real model, the feasibility of this regime is determined by its stability.

Let us consider the dynamics of acceleration for the case, where the stationary states of the system are described by curve 2 of Fig. 1 ($\phi_{in} = -\pi$). We assume an optimum tuning of the feedback ring for each mode of acceleration. The calculations show that the self-modulated instability arises at the external parameter values for which the steady-state input amplitude value lies in the range between 0.77 and 0.97 (the delay in the feedback ring T is 50 T_0), i.e., in the region adjacent to the amplitude, starting from which particles are captured into acceleration ($A_{in} = 0.92$). To know the time structure of the beam emerging from the injector, we have calculated the acceleration dynamics over a large time interval ($0 < t < 36$ K $T_0 \sim 13\mu s$, K = 1024, $T_0 = 1/f_0 \sim 0.33$ ns) with external parameters characterized by steady-state amplitudes $A_{in} = 0.95$, 0.925, 0.9, and 0.85. In all the cases considered, at $T = 50\ T_0$ the transition regime ($t \sim 2-3\ \mu s$) changes to a "steady-state" self-modulation regime, at which the electron beam parameters are modulated at two frequencies: the operating frequency f_0 and the self-modulation frequency f_m. Figure 2 shows energy (left column, MeV) and current (right column, A) as functions of time (μs) for the above-mentioned amplitude values (curves 1,2,3,4 correspond to $A_{in} = 0.95$, 0.925, 0.9, 0.85, respectively).

The analysis of the results obtained shows that in the $\phi_{in} = -\pi$ self-modulation mode, the current pulse length tends to diminish, as the input power decreases at practically the same beam modulation frequency. In the $A_{in} = 0.85$ mode, a sequence of macrobunches, each of the 15 ns duration, forms at the section output. Note that each macrobunch consists of two parts with different energies. Using an appropriate magnetic system to separate these parts, one can obtain macrobunches with a 5 ns duration. These characteristics confirm the physical mechanism of the self-modulated instability arising in the injector with a feedback (2).

In conclusion, the results of the mathematical simulation demonstrate that in the self-modulation acceleration regime of a linac with feedbacks there exists a possibility of adjusting the current pulse length, the pulse-to-pulse time being nearly the same.

References

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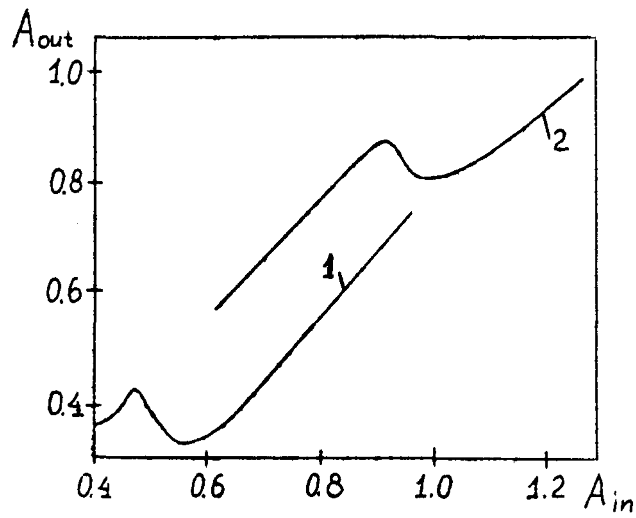

Figure 1

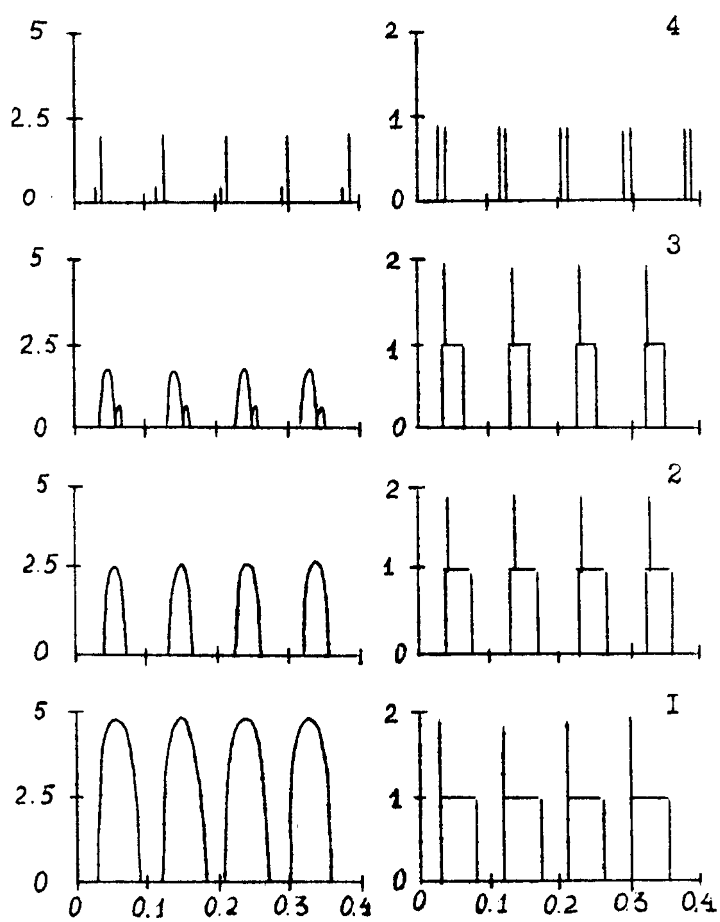

Figure 2