SELF-ACCELERATION OF RELATIVISTIC MODULATED BEAMS

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Abstract

Unlike the case of self-acceleration of continuous beams, the self-acceleration of relativistic modulated beams requires the energy redistribution between the particles not at the period of excited oscillations but rather between the bunches. This may occur only in the case when the electron beam creates a multifrequency "equilibrium state" in the passive structure. In this case, there is a possibility for some bunches to be captured in the accelerating phase of the field without any external action. We have analyzed this possibility both theoretically and experimentally.

The methods of self-accelerating high-current electron beams through their interaction with passive cavity structures (1–6) have not gained ground in the acceleration technology, though, being proposed in the early seventies, they were the subject of many theoretical and experimental investigations. The studies undertaken were however of use, since they extended our knowledge of the collective phenomena arising in electron fluxes and gave a stimulus to the development of some new trends in the accelerator physics. One of them is the postacceleration of relativistic electron beams produced at the output of a linac (7,8). The main aim of this method, similarly to the self-acceleration of high-current electron beams, is the energy redistribution between the beam particles. In self-acceleration, this redistribution occurs automatically, because in the interaction of continuous beams with a time-evolving field there are always the particles that are captured in the accelerating phase, thereby increasing the energy. In the post-acceleration method, the energy is to be redistributed among the particles of the beam which represents a sequence of well formed bunches following one after the other at intervals equal to the accelerating field wavelength in the linac. As a consequence, the beam so modulated and injected into a passive structure, would inevitably excite there oscillations at its modulation frequency. Note that appreciable electromagnetic field strengths (about several hundred kV/cm) are observed at currents of about several amperes, i.e., several orders of magnitude lower than it is necessary to attain a noticeable self-acceleration of continuous L ams. However, this advantage is greatly reduced, because all bunches, owing to their time structure, get involved in the decelerating phase, and the post-acceleration can occur on condition that at a certain instant the external devices change the phase of particle arrival in the passive structure (7,8).

Unlike the case of self-acceleration of continuous beams, the self-acceleration of relativistic modulated beams requires the energy redistribution between the particles not at the period of excited oscillations but rather between the bunches. This may occur only in the case when the electron beam creates a multifrequency "equilibrium state" in the passive structure. In other words, a multifrequency mode of generation should be attained in the self-oscillator, i.e., the resonant structure through which the relativistic modulated beam passes. In this case, there is a possibility for some bunches to be captured in the accelerating phase of the field without any external action.

We have analyzed this possibility both theoretically and experimentally. It has been necessary, first of all, to find the conditions favorable from the onset of the multifrequency mode (9), and then to study its characteristics. The analysis shows that this regime can occur with the injection of moderate energy beams (< 10 MeV). To verify this, measurements were performed using the universal injector complex (UIC) of the 300 MeV electron linac (10). Figure 1 shows the calculation and measured data for the dynamics of the interaction of the modulated beam ($W_0 \sim 4.5$ MeV, $I = 0.7$ A) with the traveling-wave cavity. As a cavity, we have used the second UIC section, the coupling coefficient of the directional coupler being zero in this case. In the time dependences of Fig. 1 (the horizontal scale division is 0.5 μs), the phase shift in the feedback ring is $\Delta\phi = -1, -0.5, -0.25, 0, 0.35, 0.7$ (from bottom upwards). It may be seen that both calculations and measurements indicate a possible development of instabilities in the system under consideration. Their characteristics depend on the phase shift adjustable by a phase shifter. A mathematical simulation shows that the "steady-state" self-modulation is achieved within 3–5 μs. This presents difficulties for testing the possibility of self-acceleration under our conditions, because the current pulse length was shorter than the above-mentioned interval ($\Delta\tau \sim 2\ \mu$s).

The computer simulation results for the "steady-state" multifrequency modes are given in Fig. 2. Output field amplitudes (100 kV/cm; 1,2,3) and energies (MeV; $1'$, $2'$, $3'$) are shown versus time (μs) ($\Delta\phi = 0, -0.25, -0.5$, respectively, $I = 1$ A, $W_0 = 4.5$ MeV). It follows from the results that in the multifrequency mode a portion of bunches is accelerated, and with the optimum adjustment the energy is nearly doubled.

So, the present results show that under certain conditions, the self-acceleration can be accomplished through the interaction of relativistic modulated electron beams with passive structures. These regimes may be used to create a specific beam structure (11). However, the self-modulation may have a negative effect, e.g., in energy recovery systems (12).

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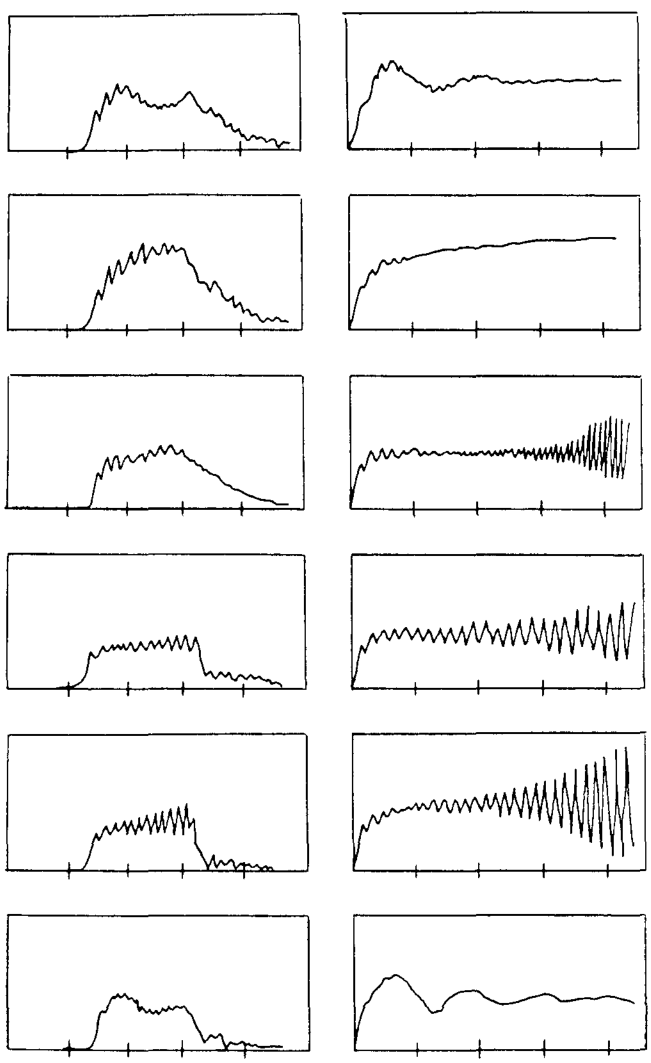

Figure 1

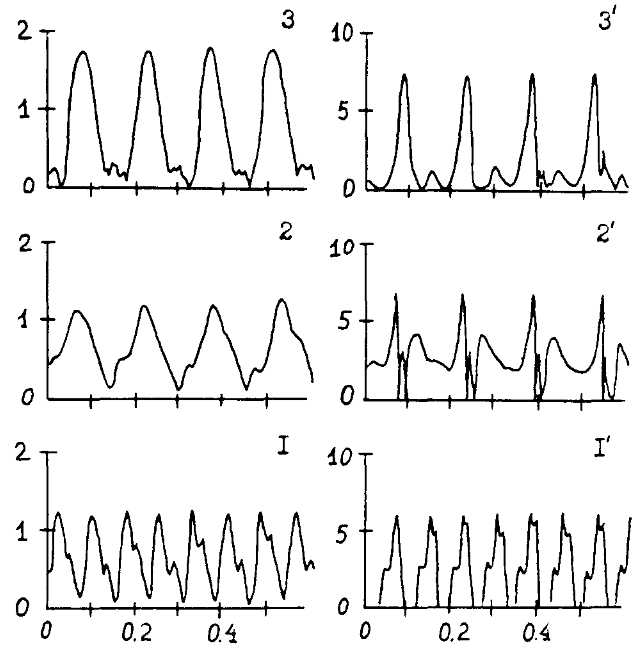

Figure 2