THE CONSTANT PHASE VELOCITY ELECTRON INJECTOR ACCELERATOR

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1. INTRODUCTION

The characteristics of high energy linear accelerators are to a large degree determined by the parameters of the accelerated beam coming from the injector part of the accelerator. The injector accelerator is designed to supply a relativistic beam of electrons (energies between 5--6 MeV) of diameter 4--6 mm, and a spread not larger than 10^{-3} radians. The energy spread of the accelerated electrons should not exceed 10 percent, while the phase width of the bunch should be within 20^{o}. The number of electrons reaching the target per second should be of the order of 10^{13}.

Starting from the above specifications one usually proceeds to design electron injector accelerators or, as they are sometimes called, wave guide bunchers. This last name is most often applied to injector accelerators with a variable phase velocity of the wave since it reflects the strict phase focusing requirements in linear electron accelerators.

The present paper studies the accelerator injector with constant phase velocity close to the speed of light. The accelerating system of such an injector can be constructed from the same elements as the basic accelerating sections and the small changes in the phase velocity can be easily achieved by varying the temperature of the diaphragmed wave guide. If in a constant phase velocity accelerator injector one is able to fulfill the above-mentioned specifications, then it is clear that such a device has marked advantages as compared with bunchers operating with a variable phase velocity. In addition to the simplicity of the design and construction, constant phase velocity injector accelerators are less sensitive to the changes in low current loads because of their constant dispersion, can be tuned over the frequency range of several megacycles, have very stable characteristics, and do not require high mechanical precision in their construction. The particle dynamics within a constant phase velocity injector accelerator can be calculated with comparative ease.

During the study of electron injector accelerators with constant phase velocity we discovered that to achieve a satisfactory optimum electron capture into the accelerating condition, one must remove the parasitic electron modulations by the hf field at the input matching transition. This last mentioned effect is due to a sharp difference of the phase velocities at the transition section and that within the regular diaphragmed wave guide. Experimental and theoretical study of the processes of parasitic modulation supplied the quantitative characteristics and criteria for the choice of such transfer parameters which for all practical purposes remove the parasitic modulation. At the same time, we were able to achieve fully satisfactory phase-energy and current characteristics of the accelerated beams.

2. THE ELECTRON INJECTOR ACCELERATOR DESIGN

The given injector represents, from the constructive viewpoint, a complete accelerator and may be used as an independent device. All elements of the injector accelerator are mounted on a rigid base and may be easily transported without dismantling.

The accelerating wave guide consists of a section from a "standard" accelerating system section 83 cm long. At 37°C the phase velocity is constant over the entire accelerator while the group velocity represents 1/25 of the speed of light. A system of temperature control keeps the temperature of the accelerating wave guide within a 1°C limit. In addition, changes in the absolute value of the diaphragmed wave guide temperature by means of the temperature control system enables one to decrease the wave velocity down to a magnitude equal approximately to 0.96 of the speed of light.

A two-electrode electron gun serves as the source of electrons. A tantalum strip serves as emitter and is heated by electron bombardment. At an anode voltage of 80 kV the current within a 1.5 μsec time interval reaches 1 A.

A longitudinal magnetic field prevents diversion of the beam into the region between the electron gun and the input matching section, and also fixes the focusing along the entire length of the accelerating wave guide.

The injector accelerator is evacuated by means of two titanium sorption-ionic pumps having 50 ℓ/sec capacity each. The operating pressure within the system does not exceed $3 \cdot 10^{-6}$ torr.

3. ACCELERATOR TESTING

Frequency Characteristic. Because of the difference in the velocity of the wave and the particle within an electron injector accelerator with constant phase velocity there occurs a continuous displacement of the accelerating electron with respect to the phase of the accelerating field. Depending on the magnitude of the initial electron velocity, the wave velocity, and the strength of the accelerating hf field, the displacements with respect to the phase of the wave of various electrons over the length of the accelerator are necessarily different. It is clear that all other things being equal a significant increase or decrease of phase velocity of the wave worsens the parameters of the accelerated field, and, consequently, there must exist a certain optimum magnitude of the phase velocity for which the parameters of the accelerated beam turn out to be the best.

Since within the design under investigation the dispersion remains constant over the length of the accelerator, the change in frequency leads to an inversely proportional variation in the magnitude of the phase velocity of the wave. Figure 1 shows the dependence of the current corresponding to the optimum energy of the particles on the frequency of the hf generator for two values of the accelerating field strength: 78 and 86 kV/cm. The figures show also the value of this optimum energy of the particles and the magnitude of its energy spread. It is of interest to study the basic characteristics of the injector accelerator for the case of optimum frequency (frequency corresponding to the maximum capture of electrons).

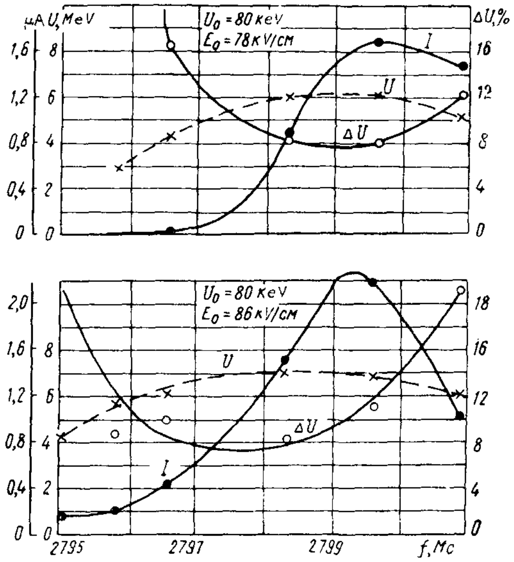

Figure 1. Frequency characteristics of the injector accelerator for two values of the accelerating field strength E_0 and equal injection energy U_0.

Influence of the Initial Electron Energy. Because of the high phase stability, accelerators with variable phase velocity need not impose any special requirements on the stability of the anode voltage of the electron sources. In accelerators with constant phase velocity, in view of the absence of synchronization between the wave and the particle, the system does not generate any phase oscillations. Consequently, changes in the initial electron energy lead to a change in the character of the phase motion of the particles and this, in turn, may affect the parameters of the accelerated beam. Figure 2 shows the dependence of the magnitude of the accelerator current corresponding to the maximum of the energy spectrum (optimum energy and half-width of the energy spectrum) on the initial energy of the particles for the case of the optimum frequency. It is clear that in the case of optimum frequency this dependence is slight. The utilization of a preliminary buncher during an accelerator operation near the optimum frequency is sufficient for the improvement of the parameters of the accelerated beam.

Influence of the Accelerating Field Strength. By investigating, as in the previous case, the dependence of the output beam parameters on the magnitude of the accelerating electric field strength, or on the magnitude of the supplied hf power for the case of optimum frequency, one can show that in the region of the usual operating values of the accelerating fields (70--80 kV/cm) such a dependence is extremely slight. At lower field strengths (50--60 kV/cm) the parameters of the accelerating beam become poor abruptly.

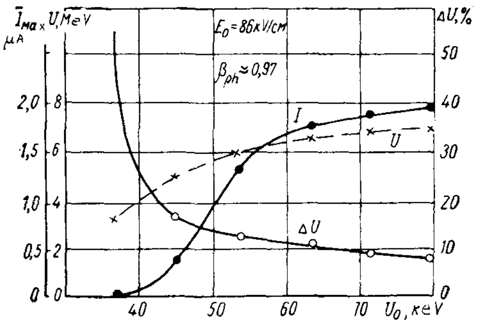

Figure 2. The dependence of the output parameters of the injector accelerator on the initial energy of the beam.

Influence of the Beam Load. We studied the influence of the beam load on the parameters of the accelerating beam. We changed the magnitude of the injected current while keeping the dimensions of the beam at the entrance to the accelerator constant by means of a collimating slit. Figure 3 shows the dependence of the optimum energy of the accelerated beam, the magnitude of the energy spread, and the magnitude of the exit hf power of the accelerator as

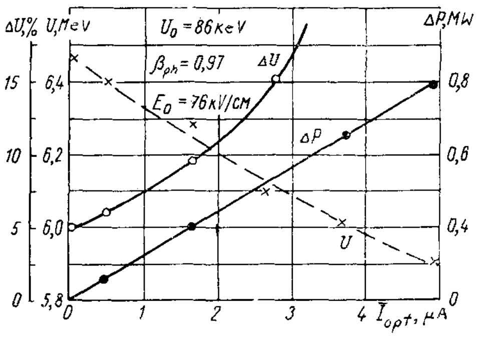

Figure 3. Dependence of energy, energy spread, and the magnitude of the output hf power on the beam load.

function of the current load. The magnitude of the mean current corresponding to the optimum energy of the accelerated particles is plotted on the abscissa. The values for the accelerated current shown on the graph do not represent the limiting value of such a current.

4. THE DIMENSIONS OF THE ACCELERATED BEAM

By means of fluorescent screens and television setups we observed the shape of the beam at the exit of the injector accelerator and the divergence of the beam was measured at the distance of 6.5 m from the exit. During operation at the optimum frequency, the beam showed sharp edges without halos and did not become washed out with changes in the input parameters but showed only a change in size. Figure 4 presents the radius of the accelerated beam as function of the changes of the initial energy and strength of the accelerating field. It can be seen from the

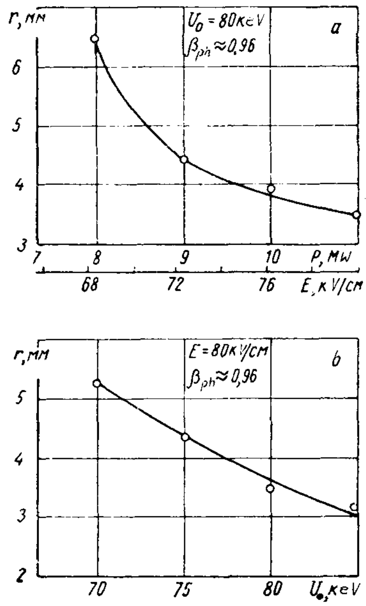

Figure 4. Radius of the accelerating beam as a function:

a -- Of the introduced hf power, P; b -- of the initial energy U_0.

graph that an increase in initial energy reduces the dimensions of the beam. Measurements of the electron beam spread at the exit of the accelerator showed that in case of the optimum frequency the beam spread is equal to 10^{-3} radians.

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It follows from the above diagrams that a constant phase velocity injector accelerator operating at an optimum frequency can develop the necessary parameters of the accelerated beam:

Average current....................	10 μA (120 mA/p)
Particle energy....................	6.5 MeV
Energy spread......................	8 percent
Beam radius........................	3 mm
Beam spread........................	10^{-3} radians

Electron injector accelerators with constant phase velocity are fully competitive with wave guide bunchers utilizing variable phase velocity of the waves.