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THE LINOTRON - A SHORT LINEAR ACCELERATOR

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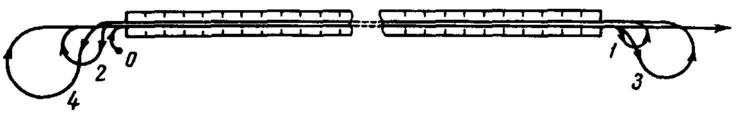
High-energy electrons are obtained either with cyclic accelerators (synchrotrons) or linear accelerators (LA). These installations are very large: the length of a LA reaches several kilometers, and the diameter of a synchrotron several hundred meters. The variability of the magnetic field causes the average beam intensity in the synchrotron to be at least two orders of magnitude smaller than in the LA. This difference becomes even sharper when cryogenic continuously operating LA are used, but the loss per unit length of cryogenic LA is much higher than that of ordinary LA. The diameter of the synchrotron is made larger to reduce the loss to synchrotron radiation and to reduce the power of the high-frequency system.

We wish to point out in this article the possibility of producing accelerating systems in which a given LA can yield energy several times larger than that for which it is nominally designed. The possible realization of such systems, which can be called for brevity linotrons, is based on the peculiarities of the particle dynamics in a LA constituting a iris-loaded waveguide. In the case of relativistic particles, the resonant accelerating wave propagates in the waveguide at constant velocity equal to the velocity of light, and the structure of the LA remains constant over the entire length. This leads to two important properties of the relativistic LA, to which due attention has not been paid so far: first, it is possible to accelerate simultaneously particles having greatly differing relativistic energies (the achromatism of LA); second, it is possible to accelerate the particles in both directions, both alternately and simultaneously (the symmetry of LA). For the symmetrical mode it is necessary to accelerate a standing wave constituting a sum of two waves traveling in opposite directions.



Schematic diagram of reciprocal linotron. 0 - injection channel, 1,2,3,4 - magnetic channels.

The achromatism and symmetry properties make it possible to extend the possible use of LA in different variants, of which we shall consider here only one - the reciprocal linotron. Assume that the end points of an LA are provided with a certain number of magnetic channels, which in general should consist of turning-focusing magnets with fields that are constant in time, and of magnetic lenses. After the k-th passage through the LA, the bunch of particles with energy E_K is turned in the next magnetic channel and again enters the LA in the opposite direction (see the figure). The path length s_K in the channel should be a multiple of λ, the wavelength of the generator feeding the LA, i.e., $s_K = q_K\lambda$ (q_K is an integer). Particle bunches with multiple energies E_1, E_2, ... , will move in the LA in both directions. The particles with maximum energy $E_M = k_M E_L$, where E_L is the nominal energy of the LA, will move, after experiencing the last acceleration in the LA, past all the channels and will be extracted to the outside. Assume, for example, that we have a standing-wave LA rated $E_L = 350$ MeV, and we wish to obtain $E_M = 1$ GeV, i.e., to triple the electron energy. In this case it is necessary to add to the available LA two ring magnets with radii $R_1 = 1$ m and $R_2 = 2$ m, respectively, assuming a moderate magnetic field intensity H = 10 kOe. These magnets are small compared with the LA itself, whose length is $L \simeq 50$ m, and are of the same scale as the equipment used for experimental work with the LA (spectrometers, analyzers, etc.).

It is clear that given a specified energy the length and scale of the power supply system can be greatly reduced in a linotron compared with an LA designed for the same energy. The linotron retains here the decisive advantage of the LA in the sense of intensity and simplicity of injection and extraction of particles. It is also important that the synchrotron radiation of the electrons in the linotron will not play as important a role as in synchrotrons, since the number of passages through the magnetic field is limited, and the energy gain in the LA is large. For the same reason, one can use strong magnetic fields and by the same token reduce the dimensions of the channels.

Following each passage through the LA, the multiplicity q_K experiences an appreciable jump, so that it is more appropriate to describe the phase motion in the linotron by using finite differences. This makes the linotron closer in some respects to the microtron and makes applicable the results of a theory developed by the author earlier [1]. Under certain simplifying assumptions, the phase-stability condition can be written in the form

$$0 < \tan\phi_s < \tan(\phi_s)_{\mathrm{limit}} = \frac{2}{\pi h_K}, \quad h_K = \frac{2(\pi + 1)\, E \cos\phi_s\, L}{\lambda H_K} \gtrsim 1, \tag{1}$$

where φ_s is the equilibrium phase and E is the amplitude of the electric field of the wave in the LA.

The condition for the stability of the vertical betatron oscillations has in the simplest case the form

$$-2 < \left(1 + \frac{1}{\eta_K}\right) \cos 2\pi\nu_K - 2\pi L \frac{\nu_K}{s_K} \left(\frac{\ln \eta_K}{\eta_K - 1}\right) \sin 2\pi\nu_K < 2, \tag{2}$$

where $\nu_{k/2}$ is the number of oscillations in the given channel and $\eta_k = E_k/E_{k-1}$. An approximate idea of the stability of the radial betatron oscillations can be obtained from a condition, similar to (2), but in general these oscillations must be analyzed simultaneously with the phase oscillations [1]. Conditions (1) and (2) provide an estimate of the tolerances, which depend strongly on the number of accelerations k_M and the requirements imposed on the monochromaticity of the beam. The general requirements which follow from the linotron principle and from the stability requirements are good time stabilization of the parameters and bunching of the beam during injection.

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