# LINOTRON - A PROPOSED SYSTEM OF PARTICLE ACCELERATION

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High-energy electrons can be obtained by means of cyclic accelerators (synchrotrons) or linear accelerators (LA).

From various points of view it would not be amiss to look for variants of accelerator systems in which particles acquire in a given LA an energy several times greater than its nominal energy.

Only one type of LA multiacceleration system has been discussed up to now, namely, one in which particles traverse the LA each time in the same direction. In this case, the particle trajectory is a spiral-shaped curve with two straight sections per turn. One section, common to all turns is the LA itself and the second, parallel to the first, is separated from it by a distance that increases with particle energy[1].

Such a system, however, may be inconvenient because of the large space (radial aperture) required in the direction perpendicular to the LA. Moreover, such a system may be impractical for an existing LA since it may be very difficult or impossible to expand the working region in the lateral direction.

We wish to draw attention to the fact that other variants of multiacceleration in a LA, which can be called for brevity "linotrons", are possible[2]. Their action is based on the peculiarities of particle dynamics in a LA. In the case of relativistic particles, the resonant accelerating wave is propagated in the waveguide at a constant velocity that is equal to the velocity of light, and the structure of the LA may be practically constant over the entire length[x)]. This leads to two important results: first, it is possible to accelerate simultaneously particles having greatly differing relativistic energies (LA achromatism); second, it is possible to accelerate the particles in both directions, alternately as well as simultaneously (LA symmetry). For the simultaneous (symmetrical) mode, it is necessary to excite a standing wave consisting of the sum of two waves travelling in opposite directions. In order to have alternate acceleration, one must excite the travelling waves alternately in the forward and reverse directions (with a certain time overlap). In principle, one can use also a wave travelling in one direction. In this case, each even passage of the LA (in the direction opposite to the wave)is "idle", i.e. will occur practically without energy change while each odd passage will be accompanied by an energy gain equal to the nominal energy of the LA.

In order to realize the linotron regime, special magnetic "reflectors" must be installed at the ends of the LA. They should consist in general of turning-focusing magnets, with fields constant in time, and 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 $\lambda$ - the wavelength of the generator feeding the LA. In the general case, particle bunches with multiple energies $E_1$, $E_2$, ... will move in the LA in both directions. Particles with maximum energy $E_M = k_M E_L$, where $E_L$ is the nominal energy of the LA, after experiencing the last acceleration in the LA, will pass all the channels and emerge from the accelerator. Assume, for example that we have a standing-wave LA rated at $E_L$ = 350 MeV and we wish to obtain $E_M$ = 1 GeV, i.e., triple the electron energy. In this case, it is necessary to add two ring magnets with radii $R_1 \simeq 1$ m and $R_2 \simeq 2$ m, respectively, assuming a moderate magnetic field intensity H = 10 kOe. These magnets are small compared with the LA itself, whose length is L = 70 m, and are of the same scale as equipment used for experimental work with the LA (spectrometers, analyzers, etc.).

It should be noted that certain advantages can also accrue in a "mixed" variant, in which the reverse path of the particles is not situated in the linac, but rather external to it. However, in contrast to the situation in the usual variant discussed, there should be only one external straight section, which can be achieved by suitablly shaping the magnetic field in the "reflectors".

From the point of view of particle motion, a linotron with several accelerations is an accelerator with changing harmonic number (multiplicity) q. After each passage through the LA, the value of q experiencies a jump, which must be

x) We neglect for simplicity the small variations in the waveguide structure which are often introduced to achieve a uniform axial electric field.

equal to integer $\Delta q = h$. Therefore, the acceleration regime in a linotron is a more general case of the microtron regime[3]. For certain simplifying assumptions, the phase-stability condition can be written in the form

$$0 < tg\varphi_s < tg(\varphi_s)_{lim} = \frac{2}{\pi h_k} \; ; \; h_k = \frac{2(\pi + g)\mathcal{E} L \cos\varphi_s}{\lambda H_k} \geq 1,$$

where $\varphi_s$ is the equilibrium phase, $(\varphi_s)_{lim}$ – its limiting value, $\mathcal{E}$ – the amplitude of the electric field of the wave in the LA, $g$ – a value of the order of unity. It should be noted that in an ordinary microtron $h_k = 1$. In the given case $h_k$ can be of the order of a score or two, or even several hundred. This can lead to some difficulties because the phase stability region decreases with h.

In order to reduce h and make the acceleration conditions less critical one should maintain the length of successive orbits approximately constant. This means that one should try to make the average magnetic field at these separated orbits rise approximately proportional to energy.

It is clear that for a given energy the length and size of the power supply system can be greatly reduced in a linotron as compared with a LA designed for the same energy. It will be especially important in the case of an expensive superconducting cryogenic LA with continuous operation. At the same time, the linotron may retain the advantage of the LA as regards intensity and simplicity of injection and extraction of particles. It is also inportant that synchrotron radiation of electrons in a 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 a LA is large. For the same reason, one can use strong magnetic fields and thereby reduce the dimensions of the channels.

In order for the acceleration regime under consideration to be possible, the rf pulse must be long enough. The duration of this pulse must exceed the time necessary for an electron to pass through the LA the required number of times. For instance, in the above case of a 350-MeV LA the pulse must exceed 1 $\mu$sec. A regime is also possible (for a long LA) in which rf pulses in a given klystron follow one another at time intervals varying from zero (at the end of the LA) to the value required for passing the double LA length (at the beginning of the LA).

The general principle of the linac is that energy gain is proportional to the square root of the radiofrequency power and the accelerator length.

So having a given complement of klystrons in a given LA and using the linotron scheme, one can obtain, in principle, a considerable gain in particle energy. For example, in order to double the particle energy in a given ordinary linac one must have a quadrupled number of klystrons. Let as assume one can use the linotron principle and during each passage of the beam through the LA, consecutively switch on each of four sets of klystrons alternately in the forward and reverse directions. Then the energy would be, in principle, quadrupled rather than doubled.

In view of the above it would seem, that linotron scheme opens, at least on paper, some new possibilities in the accelerator field.

## LITERATURE


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DISCUSSION (condensed and reworded)

M.C. Crowley-Milling (Daresbury): Have you considered in detail the magnetic systems necessary in this scheme? It would appear that any system which keeps the phase correct results in a defocussing which is difficult to overcome.

A.A. Kolomensky: I agree that this poses a similar problem to an accelerator with long straight sections, but one needs only a small number of traversals through the linear accelerator to benefit from this scheme, and in this case I think the problems can be overcome.

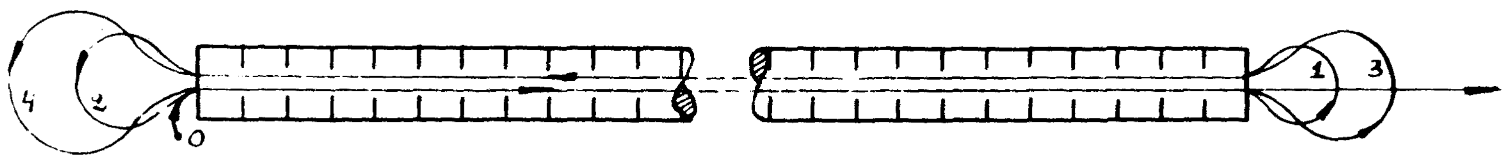


Fig.I,a.

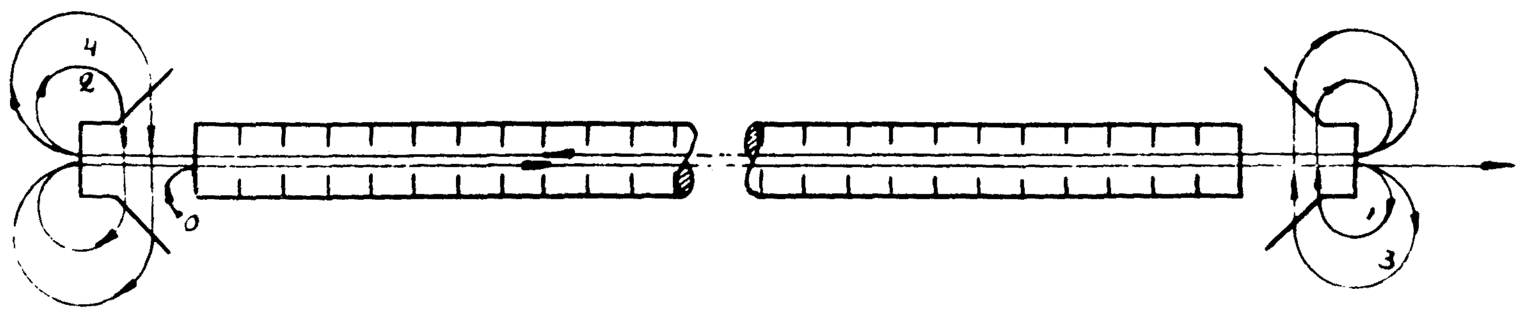


Fig.I,б.

Fig.1. Principal schemes of linotron; 1, 2, 3, 4 - particle orbits in magnetic reflectors.