VLEPP: LONGITUDINAL BEAM DYNAMICS

V.E.Balakin and A.V.Novokhatsky

Institute of Nuclear Physics, Novosibirsk, USSR

The effective acceleration of a single bunch in the accelerating structure is possible in the case when the bunch carries a way, during one flight, a considerable fraction of the stored RF energy at the minimum energy spread.

The total field in the accelerating structure is a superposition of the accelerating field of an outer generator, the 'own' field of the bunch and the radiation field.

Let us consider the dynamics of radiation fields when the bunch flies through the hole in a diaphragm placed in a waveguide. Fig. 1 illustrates the picture of the force lines of an electric field of the bunch at various moments: the bunch before the diaphragm and behind the diaphragm. When coming nearer to the diaphragm, the bunch 'carries' its 'own' field which is a transverse one in the relativistic case. Some part of the 'own' field is cut off by the diaphragm and is reflected back to the waveguide. Behind the diaphragm, the bunch forms again its 'own' field, giving off a fraction of its kinetic energy. It is worth noting that in the case of an infinitely thin diaphragm, the field behind the diaphragm can be represented as a sum of the 'own' and 'cut-off' fields, the latter being the same as to the left of the diaphragm but mirror-reflected. As seen from this figure, it is the energy of the 'cut-off' field which determines the backward-emitted energy. Of interest is to compare Figures 1 and 2 where the electric field distribution on the diaphragm surface is shown at different instants upon passage of the bunch through the hole in the diaphragm.

With such a conception of the emission process one can obtain the estimates for some cases. So, the energy, emitted by the point-like bunch during its flight through a hole of radius a in the infinite screen, amounts to

$$W \approx 0.1 \frac{Q^2}{\varepsilon_0 a} \gamma$$

where Q is the charge of the bunch, γ is the relativistic factor, and ε_0 is the dielectric constant. It is necessary to emphasize a linear increase of the radiation energy with increasing the particle energy in the bunch. If the bunch is not a point-like one but has the finite longitudinal size l under assumption $l < a$, $\gamma l > 2a$, the energy

$$W \approx \frac{Q^2}{\pi \varepsilon_0 l} \left(\ln \frac{\gamma l}{2a} + \frac{3\pi}{16} \right)$$

grows logarithmically with γ, as a consequence of the fact that the 'own' field at the transverse distance $r \leq \frac{\gamma l}{2}$ decreases inversely proportionally to r^2.

In the ultrarelativistic case, the emitted energy of the finite bunch in the waveguide tends to a limiting value as $\gamma \to \infty$. For example, let the bunch cross, while moving in the waveguide, the region of a sharp change of the transverse cross section. Note that if the bunch arrives from the waveguide of larger size b at the waveguide of smaller size a, then the energy, emitted back to the waveguide, is equal to

$$W \approx \frac{Q^2}{2\pi\varepsilon_0} \cdot \frac{1}{l} \ln \frac{b}{a} \tag{1}$$

and the kinetic energy of the particles in the bunch remains nearly the same under the condition that $l \ll b$. For the inverse problem (i.e. the bunch flies from the smaller-in-size waveguide to a larger one) the above relation determines a fraction of the kinetic energy which is given off by the bunch for the formation of the 'own' field in the larger waveguide.

In the case of a waveguide with diaphragm, under the condition that the distance between the diaphragms equals $D \gg \frac{a^2+l^2}{2l}$, the relation (1) will determine the energy, emitted upon passage by each of them, and the amplitude of the averaged field, which has influence on the particle in the bunch, will be equal to

$$\bar{E}_z \approx \frac{1}{2\pi\varepsilon_0} \frac{Q}{lD} \ln \frac{b}{a}$$

Let us present the quantitative estimates. If $N = 10^{12}$, $l = 1$ cm, $D = 2.2$ cm and $\frac{b}{a} = 4$, then $\bar{E}_z = 180$ kW/cm.

Aiming at a detailed study of the relation field. we have used the numerical methods [1]. Fig. 3 shows the distribution of the longitudinal force of radiation fields over the bunch upon its passage through the accelerating structure. The full field, which influence the bunch particles against the sinus-shaped accelerating field, is depicted in Fig. 4. As is seen, it is possible to obtain approximately the same acceleration for all the particles in the bunch with a correct choice of the longitudinal size of the bunch, the number of particles in it and of the phase relative to the accelerating field. Depending upon the permissible energy spread, the energy, which is carried over from the accelerating structure by the bunch, can achieve 50%. With a 1% energy spread, the fraction of the carried-over energy constitutes about 30% for VLEPP parameters.

References

1. Balakin V.E., Koop I.A., Novokhatsky A.V., Skrinsky A.N. and Smirnov V.P. Dynamics of the VLEPP beam. Proc. of the 6th National Conference on Charged Particle Accelerators. Dubna, 1979, p. 143.

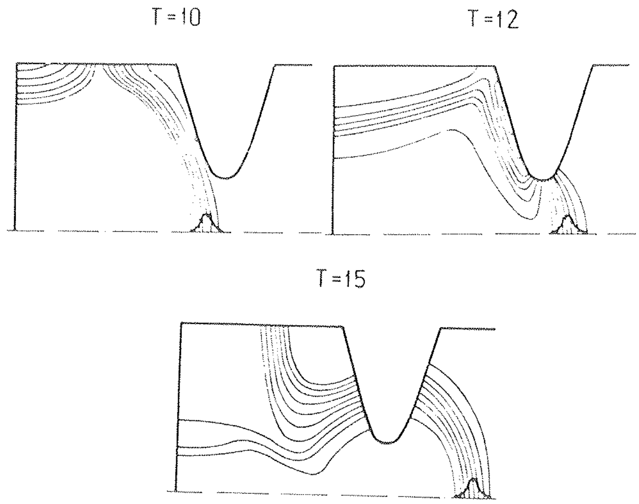


Fig.1. The time picture of the force lines of the electric field of a charge passing by the diaphragm.

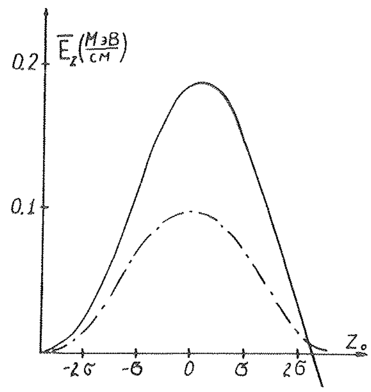
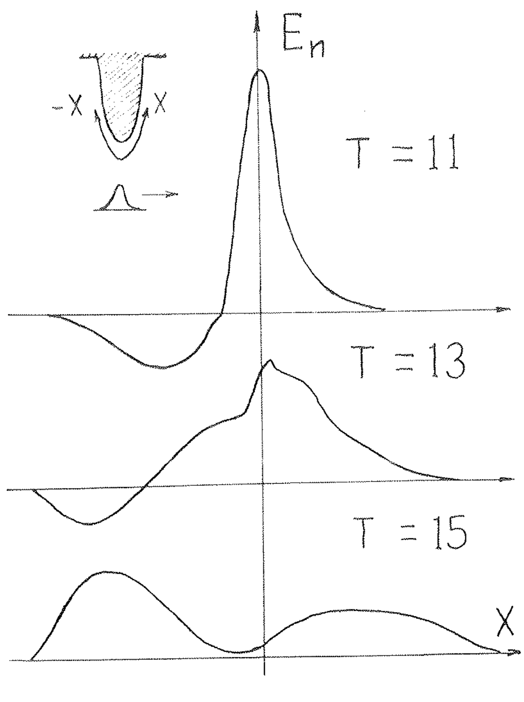


Fig.3. Distribution, over the bunch, of the longitudinal force of radiation field which acts on the particles of the bunch upon its passage through the diaphragmed waveguide.



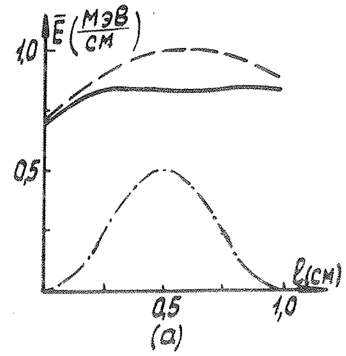


Fig.4. The total field having an influence of the particles of a bunch in comparison with the sinusoid-shaped accelerating field.

Fig.2. The time representation of an electric field on the diaphragms' surface in passing a charged bunch through a hole in the diaphragm.