THE METHOD OF COHERENT ELECTRON ACCELERATION WITH A MAXIMALLY HIGH GRADIENT BY A PROTON BEAM

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The collective methods of proton acceleration with the help of electron bunches are currently well known. However, the maximum energy of the proton beams produced by the conventional method in todays's accelerators substantially exceeds the achieved energy of electron beams. Therefore, the use of proton beams for electron acceleration becomes quite natural.

In the present report the method is considered of coherent acceleration of electrons with the highest gradient, up to an energy of the order of several hundreds of GeV and higher, by means of intense ultrarelativistic proton beams produced at big accelerators. This method has been published in 1979 for the first time /1/.

The method works as follows. The accelerated proton beam is grouped into a single compact bunch. The electrons, the total number of which constitutes some part of the number of protons, are injected into it so that the total charge decreases by 10-30% as compared to the charge of the proton bunch. After that, this proton-electron bunch is directed to a special non-excited resonant structure similar to the diaphragmed waveguide of a linear accelerator. Upon motion of the bunch in the structure, the electromagnetic field is excited because of the scattering of its self-electromagnetic field on the structure's diaphragms. This process of radiation is demonstrated in Fig. 1 in which the time picture of the force lines of electric field of the charged bunch flying by the diaphragm in the waveguide is shown. The distribution of electric force lines has been obtained by means of computer simulation/2/. The radiated field effects, in turn, the proton-electron bunch (the reaction of radiation fields) such that at the same time the protons are decelerated and the electrons are accelerated. In such a way the energy of protons is converted into the energy of electrons; of course, some fraction of the radiated energy remains in the structure.

An analysis of the radiation fields shows that an amplitude of the radiated field increases with decreasing both the diameter of a flight hole and the distance between the diaphragms but is limited by the size of the bunch. In terms of Fourier harmonics this means that the higher harmonics, up to the wavelengths comparable with the bunch size, are radiated. Hence, a choice of the sizes of the structure is due to those of the bunch. It is necessary to emphasize that the amplitude of the radiated field, i.e. the total amplitude of all radiated harmonics, can be by 10 and more times larger as compared to the fundamental harmonic. In contrast to the method suggested by E.A.Perevedentsev and A.N.Skrinsky/3/, the use of a single bunch by the method under consideration makes it possible to create the accelerating fields which are much higher than those excited by a sequence of bunches with the same total number of particles.

The distribution of the longitudinal force (which is a decelerating one for protons and an accelerating one for electrons) averaged over the structure period is given in Fig. 2 as a function of the coordinate in the bunch. The density distribution of a charge in the bunch is also shown in this Figure. As is seen, the bunch with 10^{13} protons and of about 0.5 cm in size creates an accelerating field for electrons of about 1 GeV/m. The required monochromaticity can be achieved by an appropriate arrangement of electrons inside the proton bunch. It is noteworthy that this method of electron acceleration is free from rigid requirements for geometrical sizes of the accelerating structure so important in conventional linear accelerators.

An intense compact bunch creates a strong electric field not only on the structure axis but also on the metallic surface of diaphragms, that leads to the autoelectronic amission and electric breakdown in the vacuum. The autoelectronic emission on the surface of diaphragms will be so significant at large values of electric field that the picture of fields will vary in considerable extent. This limits the range of applicability for our calculations but not, as we hope, for the suggested acceleration method. In order that to avoid the destruction the fail of electrodes at vacuum breakdown occuring after the passage of the bunch by the emitted energy, this energy should freely propagate in the environment and be absorbed already in a large volume Fig. 3). This way enables one to achieve a maximally short time for the existence of fields on the diaphragms' surface.

In practice, the realization of the suggested method is possible with the use of proton beams produced by accelerators already operating being projected. So, the proton beam with $3 \cdot 10^{13}$ particles (Batavia, Geneva), compressed to 0.5 cm, can provide a rate of acceleration of about 3 GeV/m. The use of the proton beam with $6 \cdot 10^{14}$ particles formed as a bunch of 1 cm in size will make it possible to attain a rate of acceleration of about 30 GeV/m.

References

1. V.E.Balakin, A.V.Novokhatsky, The Method of Accelerating the Electrons with a Maximum High Gradient by a Proton Beam. Preprint INP 79-86, Novosibirsk, 1979.
2. V.E.Balakin, I.A.Koop, A.V.Novokhatsky, A.N.Skrinsky, and V.P.Smirnov. Proc. of the 6th National Meeting on Charged Particle Accelerators. Dubna, 143 (1979).
3. E.A.Perevedentsev, A.N.Skrinsky, ibid., p. 272.

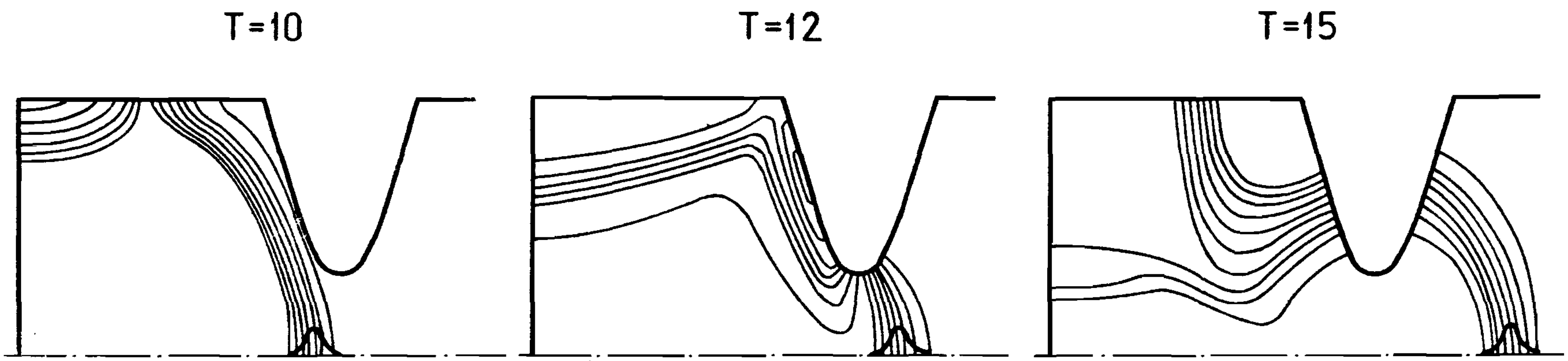

Fig. 1. The time picture of the force lines of electric field of a charge drifting by a diaphragm.

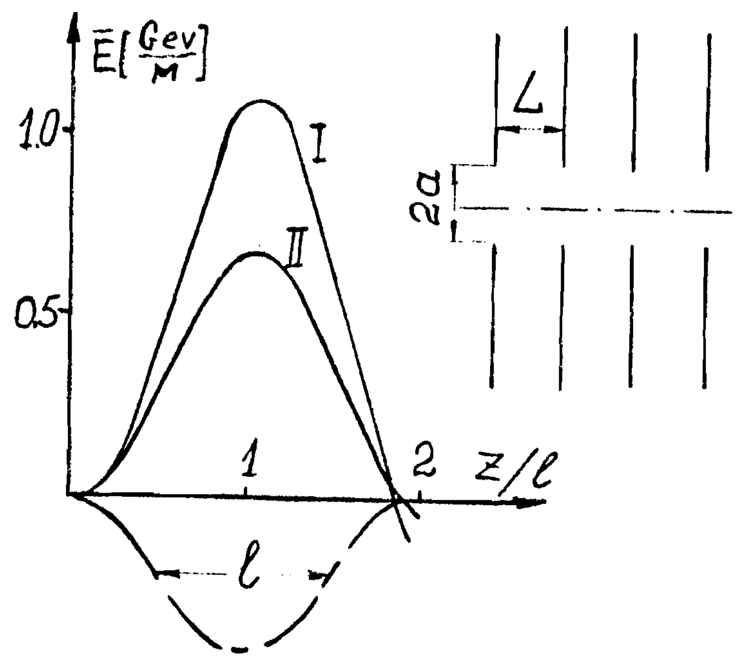

Fig. 2. Distribution of the accelerating (for electrons) field along the bunch; the number of particles $N = 10^{13}$, the longitudinal size of the bunch $l = 0.5$ cm, $a/\ell = 0.5$, (I) $L/\ell = 1$, (II) $L/\ell = 2.5$

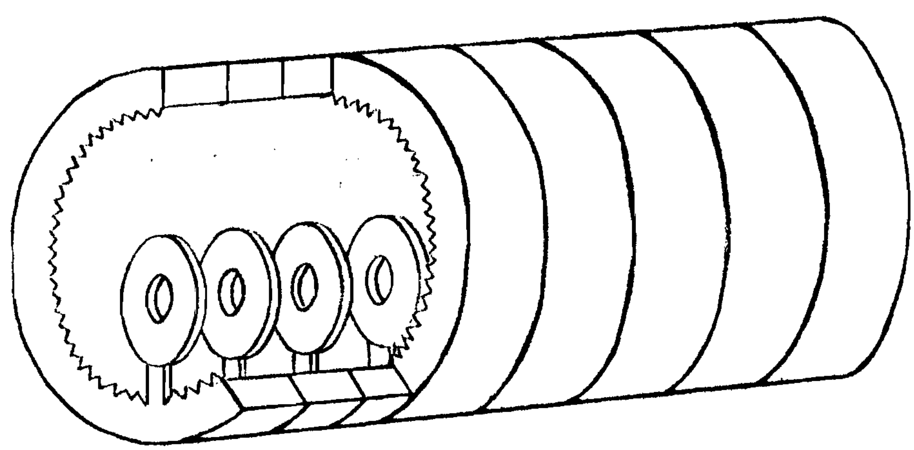

Fig. 3. The layout of the accelerator

DISCUSSION

Reiser. If the electrons in the bunch are accelerated and the protons decelerated they separate.

Balakin. If you take a TeV proton it doesn't matter, because the velocity is close to that of light.

Reiser. Certainly not at the beginning, but since the idea is to lose the proton energy to the electrons it might matter towards the end where it is most important.

Balakin. You can decelerate protons to an energy of say 0.7 TeV initially. In this case the proton at the end of the accelerator still has high velocity.

Zotter. Do you realise that the number of protons in your bunch is three hundred larger than the biggest one used for pp in the SPS? (3×10^{13} compared with 10^{11}).

Balakin. I think it is possible to have the total number of particles in the large accelerator in a single bunch.

Morton. What about wake fields associated with the bunch? Are you not concerned about aiming this bunch accurately down the middle?

Balakin. We have a solution for the transverse stability of such a bunch.