

# INTERBUNCH ENERGY EXCHANGE IN THE ACCELERATING SCHEME WITH UNIFORM CHARGE DISTRIBUTION\*

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## Abstract

The efficiency of energy transformation in multi bunch accelerating schema with uniform charge distribution is considered. The transmitted energy to accelerated bunch taking into account driving bunch exit of relativism and settling them on the walls of the waveguide is determined. It is shown that accounting losses charge of generator beam increases passed accelerated bunch energy by eliminating exhaust bunches.

## INTRODUCTION

The method of dielectric wakefield acceleration of electrons is one of perspective directions of creation high gradient structures of modern linear accelerators.

The basic element of a wakefield accelerator represents the cylindrical metal waveguide filled inside with a dielectric with the vacuum channel along an axis. The short electronic bunch with the big charge and concerning small energy of particles at flight on the vacuum channel generates a Cherenkov radiations TM<sub>01</sub> mode with longitudinal component of electric field up to 100 MV/m. Following for it with a delay selected from the requirement of the coordination with the accelerating phase of a wake field, the accelerated bunch with a small charge is accelerated by it wake field. The given principle of acceleration has been successfully experimentally shown in Argonne National laboratory of the USA (ANL) and now intensively develops in a number of laboratories [1, 2].

The size of a charge of a driving bunch which can be passed through a waveguide, is limited by technical possibilities of the photoinjector, a created by a bunch spatial charge a Coulomb field and the sizes of the vacuum channel of a waveguide. In this connection to increase in an accelerating field in a waveguide instead of a single bunch apply a chain of electronic bunches. The accelerating scheme with a flat profile of bunches sequence (flat bunch train – FBT) is used for coherent addition of fields of separate bunches and increase in a total accelerating field.

Increase of efficiency of the accelerator is connected with increase in a share of energy of a driving bunch which is transferred to particles of an accelerated bunch [3] – [6]. The factor of transformation of energy R is defined as the ratio of the maximum increment of energy electron in an accelerated bunch to the maximum decrease of energy of driving bunches

$$R = \Delta W^+ / (\max |\Delta W^-|).$$

For maximization of factor of transformation of energy R the accelerating scheme with a triangular profile of a chain Gaussian bunches with the sequence period  $d = m\lambda + \lambda/2$ , where  $\lambda$  – base frequency of accelerating structure (Ramped Bunch Train – RBT) is used. Charges in a chain a profiled so that the first bunch in sequence possesses the least charge, and last – the greatest. All driving bunches in a chain are affected identical on amplitude concerning the small braking field  $E_z^-$ , however the accelerating field behind a chain  $E_z^+$  – is considerable above. This factor provides high efficiency of transmission of energy from driving bunches sequence to an accelerated bunch that reflects numerically increase in factor of transformation which ideally one mode regime excitation of a waveguide, exact positioning of bunches and exact selection of charges can reach values  $R = 2N$  where  $N$  – the number of driving bunches in a chain. High efficiency of transmission of energy from a chain of driving bunches to a field in a RBT-method is reached by considerable range of flight on which there is a selection of energy from driving bunches.

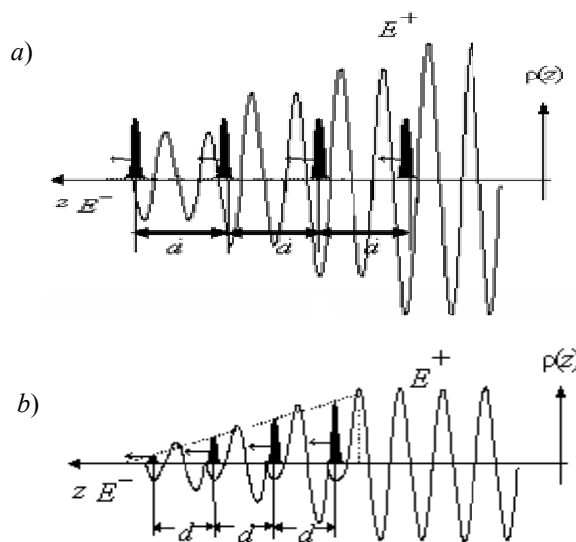


Figure 1: Multibunch acceleration schemes: (a) FBT, (b) RBT

## THE ANALYSES OF FBT

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## ACCELERATION SCHEME

Unlike RBT scheme, in FBT scheme the braking fields operating on driving bunches, located on distance  $d = m\lambda$  from each other, quickly increase with growth of bunch number in a chain, and, thus distance on which there is an energy extraction, much less, than in RBT scheme. The rate of acceleration reached in FBT scheme, exceeds rate of acceleration RBT scheme at equal maximum charges of driving bunches in  $2N-1$  time, and in  $N$  time at equal total charges of a chain, where  $N$  is quantity of driving bunches. At the same time FBT scheme shows much lower, than in RBT scheme, transformer ratio traditionally found as  $R \approx 1 + 1/(2N + 1)$ , [4-6].

The reason of low value of transformer ratio in FBT scheme is coherent summation of the fields operating not only on the accelerated bunch, but also on driving bunches, in particular on the last from them.

Taking into account of radial dynamics of a bunch allows achieving in FBT scheme fuller energy extraction from a chain of driving bunches  $\Delta W^- = \int eE^- dl$ , at increase energy transferred to an accelerated bunch  $\Delta W^+$ . The specified criterion demands some increase in range of flight  $L$  on which the bunch interacts with accelerating structure. This range however, appears much less, than in case of RBT.

The analysis of transverse dynamics high current bunches shows defining influence of a radial deviation of a bunch on restriction of range of flight  $L$  of bunches in a waveguide [2, 4-6]. Presence, along with longitudinal fields, transverse fields rejecting a bunch leads to a contact a bunch of walls of a waveguide, loss at first separate particles, and then and all bunch. Transverse instability limits longitudinal length of accelerating structure, and also defines distance on which transmission of energy from a driving bunch to an accelerated bunch is possible. At introduction of external focusing partially suppress transverse instability that leads to increase in range of flight.

At ultrarelativistic speed of particles of driving bunches influence of rejecting fields is expressed more weakly. In a case when longitudinal components of a field considerably exceed transverse fields, and also in the presence of external focusing, influence of rejecting field starts to be shown only near to an exit of bunches from a relativity, fig. 2a. Thus the greatest deviation undergoes last driving bunch of a chain, fig. 2b. As consequence, the particles which have left a relativity of the last driving bunch almost completely give the energy to an accelerated bunch and, as a result of action of rejecting fields, "sit down" on a waveguide wall.

$W$ , MeV

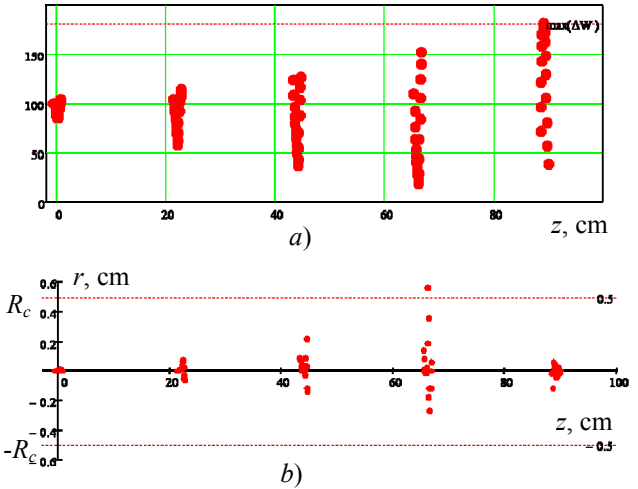


Figure 2: Energy (a) and displacement of bunches from a structure axis (b) at the moment of a contact of a waveguide wall

As a result after braking of last bunch we receive again FBT scheme, but already with  $N-1$  driving bunch. Process repeats, yet won't give the energy the very first driving bunch.

For simplification of estimations we will consider that initial energy of driving bunches  $W_0 \gg m_0c^2$ . Thus in the qualitative description of process of braking resulted more low we will neglect residual energy of bunches after their exit from a relativity.

In one mode regime of waveguide excitation intensity of a field, for Gaussian bunch in 2 times exceeds a field in a bunch, slowing down its movement. In FBT scheme the subsequent driving bunches are located on distance of an integer of lengths of waves of waveguide base frequency.

At the moment of an exit from a relativity of the last driving bunch, the energy transferred to an accelerated bunch makes  $W_{1,ac} = 2NW_0/(2N-1)$ . The distance passed by bunches makes

$$l_1 = \frac{W_0}{(2N-1)eE_1^-} = \frac{2W_0}{(2N-1)eE_1^-}, \text{ where } E_1^- = E_1/2 \text{ is a}$$

field, braking the first driving bunch,  $E_1$  is a field behind a single driving bunch,  $e$  – is an electron charge.

The remained energy in driving bunches of a chain at equal starting energy of bunches  $W_0$  forms sequence  $W_{1,i} = 2W_0(N-i)/(2N-1)$ , where  $i$  is a number of a driving bunch in a chain. Thus last driving bunch loses the energy  $W_0$  almost completely. The ratio of the energy transferred to the accelerated bunch  $W_{1,ac}$ , to the maximum loss of energy of particles of a driving bunch  $W_0$  makes traditionally counted for FBT schemes transformer ratio  $R_1 \approx 1 + 1/(2N + 1)$ , [4-6].

After loss of last driving bunch we receive again FBT scheme, but already with  $N-1$  driving bunch. Transmission of energy to an accelerated bunch proceeds further while the remained energy will be not given by a penultimate driving bunch of a chain. In this time bunches pass distance  $l_2 = \frac{W_{N-1}}{eE_{N-1}} = \frac{4W_0}{(2N-1)(2N-3)eE_1}$ . The energy of an accelerated bunch received on this step makes  $W_{2,ac} = (N-1)E_1 l_2 = \frac{4W_0(N-1)}{(2N-1)(2N-3)}$ . Remained in driving bunches of a chain energy forms sequence  $W_{2,i} = 2W_0(N-i-1)/(2N-3)$ .

The specified process repeats consistently with other driving bunches of a chain. After braking of last of driving bunches the accelerated bunch gets energy

$$W_{ac} = \frac{2NW_0}{2N-1} + 4W_0 \sum_{j=2}^N \frac{(N-j+1)}{(2(N-j)+3)(2(N-j)+1)}$$

The distance, demanded to a chain of bunches to full energy extraction, makes  $l = 2W_0/(eE_1)$  and it is equal to distance on which completely loses energy the very first driving bunch.

Thus, the factor of transformation of energy at the fullest extraction of energy in FBT to the scheme makes

$$R = \frac{W_{ac}}{W_0} = \frac{2N}{2N-1} + 4 \sum_{j=2}^N \frac{(N-j+1)}{(2(N-j)+3)(2(N-j)+1)}$$

In case of a chain of four bunches full transformer ratio makes  $R = 3.35$  that considerably exceeds calculated on a site of a way to an exit from relativity of last driving bunch  $R_1 = 1.14$ .

The rate of acceleration reached in FBT scheme with full extraction of energy of a chain of driving bunches, exceeds rate of acceleration RBT scheme at equal maximum charges of driving bunches in

$(2N-1)R/(2N)$  time that for a chain of 4 bunches makes 2.93 times, and in  $R/2$  time at equal total charges of a chain that for a chain of 4 bunches makes 1.676 times.

Thus, defined taking into account bunch dynamics the efficiency of FBT scheme appears considerably above, than by traditional consideration of movement till the contact moment a driving bunch of a wall of a waveguide.

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