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SYSTEM FOR CORRECTING THE LONGITUDINAL LENGTH OF ELECTRON BUNCHES FOR GENERATION A FREE ELECTRON LASER

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Abstract

The chicane is device for longitudinal compression of electron bunch for generation of coherent radiation in free electron laser. It is present a numerical simulation of beam dynamics passing through system which consist dielectric waveguide and four dipole magnets. The simulations made with use the modified Euler method based on Green-function knowledge for electromagnetic field. We researched influence of various physical parameters of the electron bunch, as well as the chicane parameters on the change in the longitudinal bunch length. The optimal parameters of the focusing system were proposed for a relativistic particle beam with given initial bunch parameters. Recommendations for the selection of chicane parameters are also presented.

INTRODUCTION

The beam compression is necessary for a variety of applications, such as, for example, the generation of short X-ray pulses [1]. To implement the compression of beams can, for example, using Laser Wake Field Accelerator (LWFA), which forms the necessary energy profile for the further use of this beam in a free electron laser (FEL) [2,3]. Also, for profiling of beam energy it is used Plasma Wake Field Accelerator (PWFA) [4]. The scientists of Argonne Wakefield Accelerator (AWA) employees are developing a compression system to generate a sequence of beams [5], which can then be used to produce THz radiation. The problem of generating a short beam in Stanford Linear Accelerator (SLAC) is solved using a periodic structure [6], where the wakefield creates a profile of the beam energy necessary to create the Linac Coherent Light Source (LCLS), which is part of FEL project. The purpose of this work is to obtain the recommended parameters of the chicane, based on bunch dimensions and the distribution of energy inside the bunch.

INITIAL PARAMETERS

A relativistic bunch of charged particles with a given linear distribution of energy and bunch length flies through chicane – a system consisting of four two-half magnets.

Simple scheme of chicane illustrated on Fig.1 and consists of four dipole magnets. The high-energy particles located in the "tail" of the bunch move along a short path and catch up with low-energy particles located in the "head" of the bunch, which move along a longer path, thus compressing the bunch.

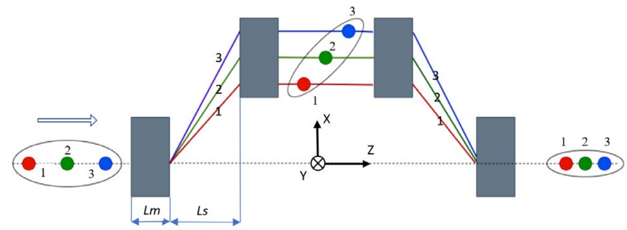

Figure 1: Schematic representation of a chicane consisting of four two-way magnets (1 – "tail" head of bunch and 3 – "head" of bunch).

It is necessary to determine the final length of the bunch, after the flight of the chicane, as well as to consider the influence of the bunch parameters and the parameters of the magnetic system on it. We use a qualitative characteristic of bunch, which is called a compression coefficient along the bunch length A. It is defined as:

$$A = \frac{l_0 - l_f}{l_0} 100\%,$$

where l_0 is initial bunch length, l_f is final bunch length.

It is also important to note that the height of the magnetic sections is infinite during chicane modeling. Therefore, we exclude in our numerical modeling the situation when particles do not fall into dipole magnets.

In this paper, to calculate the beam dynamics in chicane, two numerical based on macroparticle method [7] and the Euler method. According to macroparticle method the bunch is represented by number of interacting identical particles. This way allows significantly increase the speed of calculations. This method is quite simple to implement and less expensive compared to other methods of calculation. Also, we used modified Euler method was chosen to the simulation.

We choose initial data for numerical simulations: a magnetic system consisting of four dipole magnets arranged symmetrically with a magnetic field B = 1 T, length of magnetic section Lm = 2 cm, the distance between the magnetic sections Ls = 2 cm, the charge of the bunch Q = 0.16 fC, transverse dimensions (σ_x and σ_y) = 0.01 mm, longitudinal size of the bunch (standard deviation) σ_z = 0.1 mm, radial displacements along the axes X and Y (*offset_x*, *offset_y*) = 0 cm, bunch energy W = 1000 MeV, relative energy spread $\varkappa$ = 5 %.

It has been shown that the modified Euler method is stable with a sufficiently large number of particles, so it can be used for numerical modeling. Minimum number of *Nopt* lies in the range of 1000 or more particles. For present experiments, this number of particles will be used.

The first experiment is made to identify the dependence

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of coefficient A from the bunch energy with the fixed parameters of the bunch and chicane. It can be seen from calculation results (see Table 1) that energy growing causes a sharp decline of coefficient A.

Table 1: Dependence of the Compression Coefficient on the Energy of the Bunch

W, MeV	A, %
10	1.99025
100	0.082693
500	0.022229
1000	0.000216
10000	0.000002

This phenomenon is caused by the fact that if a bunch has a lot of energy, then the magnitude of the magnetic field B = 1 T is not enough to deflect the particles to the required trajectory and the electrons fly almost along their initial trajectory. It follows that small bunch energy causes strong influence of the magnetic field. In this case, the particles start to rotate inside magnetic section.

The next stage of the experiments was to determine the dependence coefficient A the bunch on the relative energy spread $\varkappa$, Fig. 2.

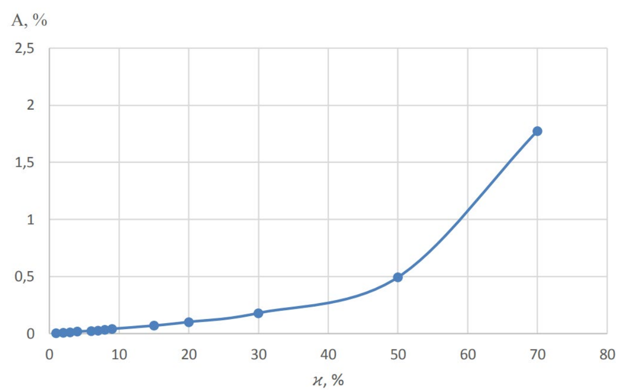

Figure 2: Dependence of the compression coefficient on the energy spread.

Based on this plot, it can be concluded that in the range of $\varkappa$ from 7% to 70%, there is an increase in the compression. This can be explained by the circumstance that large energy spread leads to growing of particles with high-energy. This fact increasing the probability of compression of the bunch.

Table 2: Dependence of the Compression Coefficient on the Longitudinal Length of the Bunch

σ_z, um	A, %
0.1	19.711600
1	1.784560
100	0.021851
1000	0.001933
1250	0.001190

The influence of bunch sizes on compression shows that the change in the transverse dimensions (σ_x, σ_y) does not affect A. Conversely, the increase of longitudinal bunch length (see Table 2) leads to sharp decline of compression coefficient A along the length. This is since at low values of σ_z, the distance between the electrons decreases, thereby reducing the time the flight of high-energy particles relative to low-energy particles. As a result of this process the "fast" particles catch up with the "slow" during the flight in chicane.

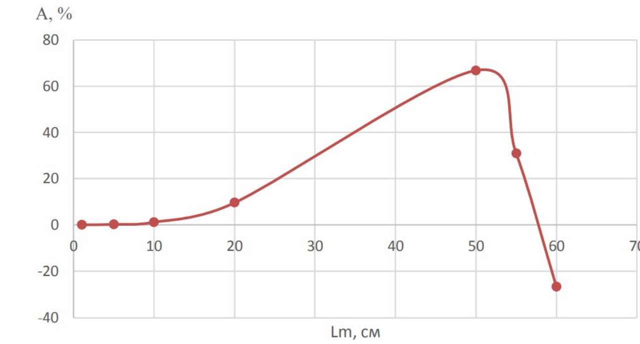

Figure 3: Dependence of the compression coefficient on the length of the magnetic section.

The dependency A (Lm), Fig. 3, explained by the fact that with an increase of magnetic section the bunch flight length also grows. It follows that high energy particles have time to catch up with low energy particles and the longitudinal length of the bunch becomes minimal. However, with large values of Lm, the "fast" particles begin to overtake the "slow" ones, which lead to stretch of bunch along the Z axis.

Analyzing the dependence of A (Ls), Fig.4, we can say that the increase in the value of A occurs for similar reasons as in the case of a change in the length of magnets Lm. That is, based on the same geometric considerations (increasing the length of the path of the particles), the bunch is pulled along the Y axis.

Because the phase volume should be conserved in time (Liouville's theorem on the conservation of the phase volume in space), it can be concluded that the projection of the bunch on the Z axis should decrease, which is what happens in this case.

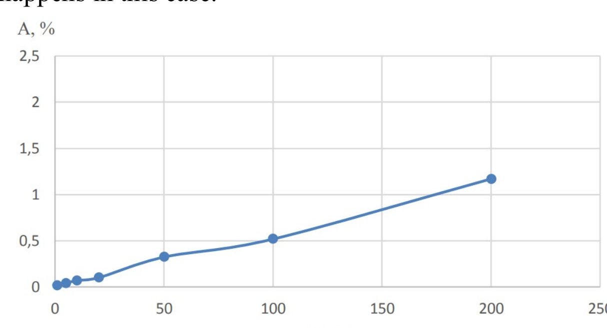

Figure 4: Dependence of the compression coefficient on the distance between the magnetic sections.

In the future, with a sufficiently large distance between the magnets, the value of A will drop sharply, because there will be a similar effect as when changing the length Lm. Given the above, it is necessary to select the distanc-

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es between the sections for certain lengths of magnets to achieve the optimal value of the compression coefficient A.

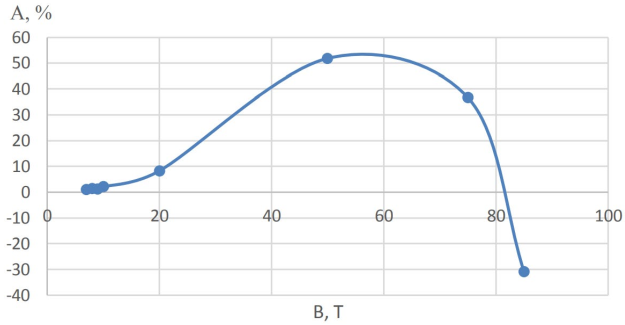

Figure 5: Dependence of the compression coefficient on the magnetic field value of the magnetic section.

When analyzing the dependence $A(B)$, Fig.4, it can be seen that at high values of magnetic induction, the compression coefficient A takes negative values. This is since some of the particles either fly away at a sufficiently large distance, or are reflected, thus, the magnetic section plays the role of a magnetic "wall". At low values of the magnitude of field B, the magnetic sections have practically no effect. As a result, the value of A takes on small values.

CONCLUSION

For a relativistic electron bunch with given initial physical parameters, the optimal parameters of the magnetic system were selected to achieve maximum compression of the longitudinal bunch length (see Table 3).

Table 3: Recommended Pattern Parameters for a Clump of Electrons with Specified Parameters

Parameter	Value	Parameter	Value
N	1000	σ_z, cm	100
Q, fC	16	Lm, cm	10
W, MeV	100	Ls, cm	10
$\varkappa$, %	5	B, T	6
σ_x, cm	10	A, %	97.5
σ_y, cm	10		

As a result of the analysis, it was revealed that the change in A is strongly influenced by such physical parameters of the beam as the energy of the bunch, the spread of energy in the electron bunch, the initial longitudinal length of the relativistic bunch, as well as the parameters of the stain. It is necessary to consider the fact that some values of the compression coefficient along the length at certain parameters of the bunch were achieved by modeling bulky magnetic systems with large magnetic field values, which in real life is quite impractical to use.

As a result of the analysis of the calculation results, it was revealed that the change in A is strongly influenced by such physical parameters of the beam as the bunch energy W, the relative spread of energy $\varkappa$, the initial longitudinal length, and the chicane parameters. It is necessary to consider the fact that some values of the compression ratio along the length at certain parameters of the bunch were achieved by simulating bulky magnetic systems with high magnetic field values, which in real life is rather inappropriate to use.

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