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SELECTION OF A SYSTEM FOR CORRECTING THE ENERGY SPREAD OF RELATIVISTIC ELECTRON BUNCHES FOR A FREE ELECTRON LASER

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Abstract

The object of this work is a device called dechirper, which is used to decrease energy spread in relativistic electron bunch for free electron laser application. This system is based on cylindrical dielectric waveguide with vacuum channel needed for electron bunch passing. The Vavilov-Cherenkov radiation excited in waveguide is used to profile electromagnetic field inside the bunch and therefore to achieve the required energy distribution. The work includes numerical modeling of the electron beam passage through a waveguide structure, the generation of wake radiation and the interaction of this radiation with an electron bunch. We made original code to carry out numerical modeling, where the method of macroparticles and the method of Green's function are implemented. The dependences of the energy compression coefficient and the length at which the maximum energy compression coefficient is achieved on various parameters of the dielectric waveguide structure and the physical parameters of electron bunches were identified. Various recommendations were also made on the choice of a waveguide used as a dechirper.

INTRODUCTION

The use of undulators for the generation of monochromatic laser radiation is related with energy spread reducing inside electron bunch, implemented with the help of dechirpers. The main advantage of plasma-based dechirpers [1] is the high values of the generated fields, but the realization of such a scheme is associated with high cost of technical implementation and plasma nonstability. Widespread dechirpers based on rectangular dielectric waveguide [2] due to simplicity manufacturing technology of waveguide as well as possibility of adjustment distances between plates. Dielectric rectangular structures are used in STFC Daresbury Laboratory developing Free Electron Laser (FEL) CLARA [3]. Th structure consisting of pairs of flat, metallic, corrugated plates is used in SLAC [4] which, despite its simplicity, has a significant limitation in the form of a low breakdown voltage. This work is concentrated on reducing of energy spread of bunch in cylindrical dielectric waveguide, as it becomes possible to generate higher fields compared to rectangular structure with the same charge and bunch length. In addition, in this case, there are no problems of instability of the structure that accompanies the plasma waveguide.

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INITIAL PARAMETERS

Dechirper is a part of a FEL that serves for energy spectrum correction of relativistic electron bunch, Fig. 1.

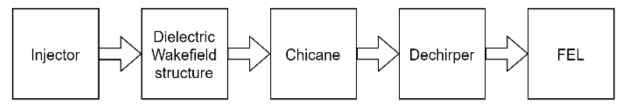

Figure 1: Beam preparation scheme for FEL.

After being generated in the injector, the bunch enters in the wakefield dielectric structure where it is placed in field of another bunch, called "driver". The bunch is placed at a point in the field to create an energy distribution along the bunch when the energy of "head" is less than the energy of the "tail", Fig. 2. This energy distribution is needed for chicane (system of dipole magnets), where it is compressed and then enters in the dechirper. Last one is represented by cylindrical dielectric waveguide (CDW), Fig.2, where the bunch creates a wakefield within itself to profile the energy with minimum spread. There is a clear dependence of its radiation spectrum on the energy distribution along the bunch length. A higher monochromaticity of FEL radiation is observed with a more uniform distribution of energy.

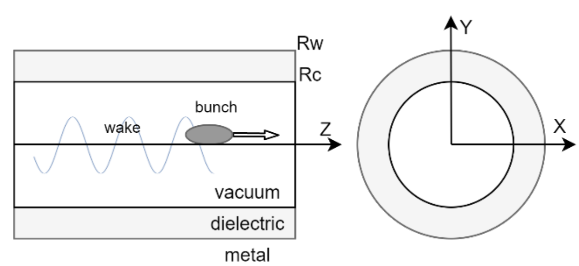

Figure 2: Dechirper based on cylindrical dielectric waveguide.

This paper considers a problem in which a relativistic electron bunch with a given energy distribution along the length enters in CDW(*Rc* – inner radius, *Rw* – external radius, ε – dielectric constant), Fig.2, with dielectric filling and physical parameters of the bunch: *Q* – charge of bunch; *W* – bunch energy; Δ*W* – the spread of the energy; *offset_x* – dismission of the bunch along the *X*-axis, σ_x, σ_y, σ_z is the standard deviation of Gaussian bunch along the corresponding direction.

The monoenergetic coefficient *C* is obtained from the ratio of the maximum energy difference of the particles in the bunch (ΔW_{max}) and the average energy of the bunch *W*. The energy compression coefficient (ECC) *D* is obtained from the ratio of C_0 in start of calculation and C_f at

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the end of calculation. The distance at which the maximum of ECC is reached will be denoted by L_{Dmax}.

We used Euler's numerical method and the macroparticle method [5] to calculate the beam dynamics along a cylindrical waveguide. The main equations are the equations of relativistic kinematics.

ANALYSIS OF RESULTS

The dependence of the ECC on W in a cylindrical waveguide is present for next parameters of CDW: Rc = 0.5 cm, Rw = 0.6 cm, ε = 3.75. The plot on Fig.3 shows the dependence of the distance L_{Dmax} on energy W. The ECC practically does not change. The efficiency of energy redistribution between particles decreases due to difference between the speed of the bunch and the phase velocity of the electromagnetic wave in the medium, therefore L_{Dmax} depends on W as linear function.

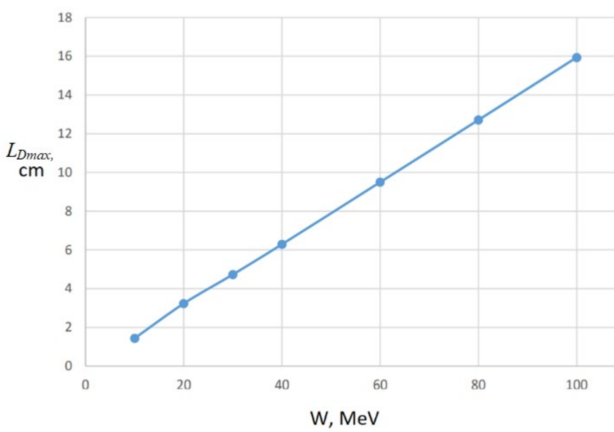

Figure 3: Dependence of L_{Dmax} on energy.

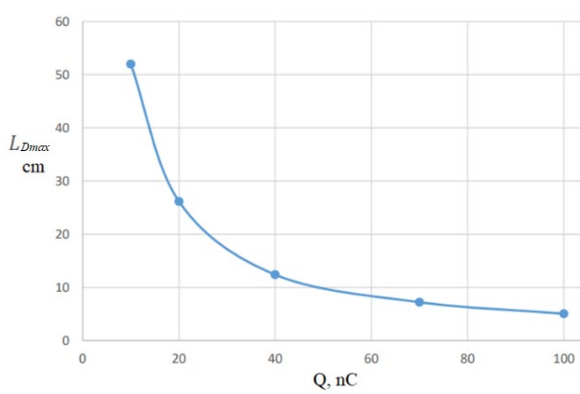

Figure 4: Dependence of L_{Dmax} on bunch charge.

From the plot on Fig. 4, the L_{Dmax} is decreases sharply as a function of Q due to proportionality of charge and wakefield amplitude. The value of wakefield limits the distance L_{Dmax}. The ECC changes in a small range of quantities since the field structure does not change with variation of bunch charge.

Table 1 shows the dependence of D_{max} on the ε, which is determined by superposition of modes in the wakefield for next parameters: Rc = 0.5 cm, Rw = 0.6 cm, Q = 100 nC, W = 50 MeV, ΔW = 5 MeV, $\sigma_x = \sigma_y$ = 0.00035 cm, σ_z = 0.001 cm. Symmetrical modes make the main role in the formation of the field structure after value of ε = 5. The values of D_{max} depending on the ε at *offset_x* = 0. 002 cm decreases after the value of ε = 5 due to the excitation of a greater number of asymmetric modes.

Table 1: Calculation Results for Different Values of ε

ε	*offset* = 0 cm		*offset* = 0.002 cm	
	D_{max}	L_{Dmax}, cm	D_{max}	L_{Dmax}, cm
2	1.03972	9. 35	1.03511	6.54
2.25	1. 0468	10. 91	1.04235	8.69
2.5	1. 4086	9. 47	1.03957	7.19
3	1.36150	8. 36	1.03747	6.80
5	1.03278	7. 88	1.03328	6.95
8	1.03500	9. 38	1.03279	6.98
12	1. 3688	11. 21	1.03295	7.76
20	1.03622	13. 19	1.03094	8.81

The values of D_{max} and L_{Dmax} increase with the thickness of the dielectric, which is also explained by the growing of excited modes (see Table2). This calculations were made for next parameters: Rw = 2 cm, Q = 100 nC, W = 50 MeV, ΔW = 5 MeV,$\sigma_x = \sigma_y$ = 0.00035 cm, σ_z = 0.001 cm.

Table 2: Calculation Results Different Values of Rc

Rc, cm	D_{max}	L_{Dmax}, cm
1.0	1.01920	12.80
1.1	1.01952	14.29
1.2	1.01997	16.03
1.3	1.02181	19.39
1.4	1.02124	20.32
1.5	1.02111	21.76
1.6	1.02113	23.47
1.7	1.02118	25.27
1.8	1.02118	27
1.9	1.02170	29.73

With the growth of the transverse bunch displacement *offset_x* from the waveguide axis, the number of excited asymmetric modes also grows. Therefore, the field amplitude module and its structure are changed, which in this case leads to an increase in the value of D_{max} and a decrease *of* L_{Dmax}, Fig 5. However, the bunch location nearby dielectric layer leads to Beam BreakUp Instability (BBU) [6] due to the transverse effect of asymmetric fields.

CONCLUSION

Based on the obtained dependencies, we give some recommendations for choosing a waveguide structure used as a dechirper. During the analysis, it was obtained that the value *of* L_{Dmax} is influenced by the energy, charge, and bunch displacement from the axis of the waveguide, as well as the thickness of the dielectric layer.

The selection of these parameters can achieve the desired length of the dechirper. It must be considered that in dechirpers of small length (about 3-5 cm) the wakefield

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will not have time to fully form and, accordingly, the dechirping effect will not be observed.

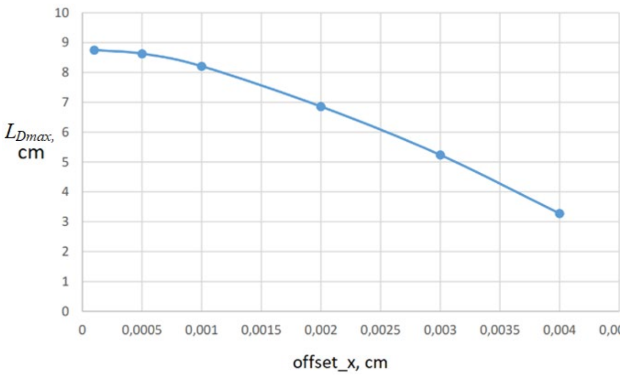

Figure 5: Dependence of L_{Dmax} on transverse displacement.

Low values of energy and charge lead to the instability of the bunch and the formation of a field with a weak amplitude. These parameters practically do not change the structure of the field. So, it is possible to achieve the desired length of the dechirper almost without changing the structure of the field. By changing the dielectric permeability, dielectric thickness, and bunch displacement, it is possible to achieve a suitable ECC, but it should be borne in mind that changing several of these parameters at once does not always lead to an increase in the ECC.

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