

ELECTRON BEAM DYNAMICS WITH SPACE CHARGE IN LINEAR ACCELERATOR

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Abstract

This paper describes electron beam dynamics with space charge in existing linear accelerator of Kurchatov source of synchrotron radiation. The linac structure operates with standing wave mode pulse power and without particle prebuncher. The results of comparison of electron beam parameters at the linac output with and without space charge consideration are presented. Electron beam shaping process starting from continuous beam to bunched beam on initial stage of acceleration under the action both of linac RF field and particle space charge field is considered. The main attention gives to calculate particle space charge field of the electron beam, which bring in essential contribution into beam dynamics on initial stage of shaping and accelerating electron bunches. The results of computer simulation of the electromagnetic field into linac structure taking with the help of ANSYS code are presented.

INTRODUCTION

Linac structure operates with standing wave mode pulse power. The pulsed diode gun with hot cathode is the electron beam source [1]. The main parameters of electron beam at the exit of a gun are given in Table 1.

Table 1: The main parameters of electron beam at the exit of a gun.

Parameter	Value
Beam current	4 A
Pulse duration	18 ns
Beam energy	40 keV
Microperveance	$0.5 \mu\text{A}/\text{V}^{3/2}$

Linac acceleration structure is made as biperiodic series of coupled cavities (DAW acceleration structure) [1]. It has 112 regular accelerating cells and 2 accelerating one half length cells. The special coaxial cavity, located in the center of linac, is the input of RF power. Along accelerating structure the aperture for the beam is small – a diameter of a diaphragm is 8.7 mm. The main parameters of linac are given in Table 2.

The electrons are accelerated due to stored energy which is reduced by $\sim 10\%$ after electron beam passage through acceleration structure.

The structure with washers and diaphragms has several advantages when working with stored energy:

- High shunt impedance.
- High coupling coefficient.
- High stored energy.

Table 2: The main parameters of linac.

Parameter	Value
RF frequency	2.797 GHz
Shunt impedance	95 M Ω /m
Q factor	28000
Time constant	1.8 μs
Length	6 m
Repetition rate	1 Hz

At Figure 1 we presented photo of existing linear accelerator of Kurchatov source of synchrotron radiation and at Figure 2 - photo and design of linac structure.



Figure 1: Linear accelerator.

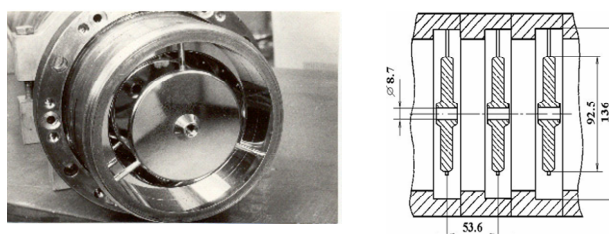


Figure 2. Linac structure.

RF FIELDS SIMULATION

For simulation of electromagnetic field in acceleration structure we used ANSYS program code. Here we present the results of simulation.

Absolute value of electric field distribution into one cell of linac accelerating structure you can see at Figure 3. We can see that electric field has good uniformity in all volume of accelerating cell.

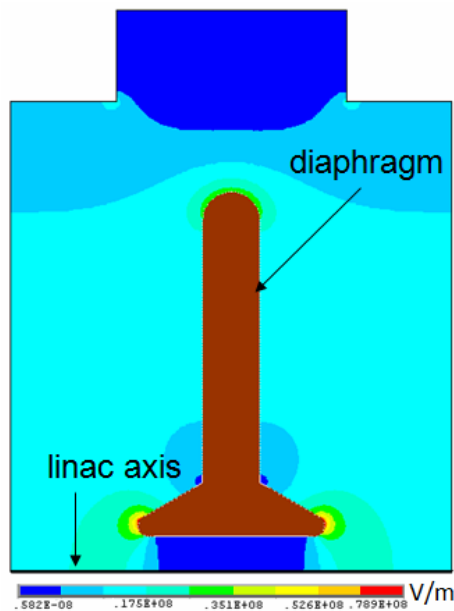


Figure 3. Absolute value of electric field into one cell of linac accelerating structure.

At Figure 4 we presented amplitude distribution of longitudinal electric field component at the linac axis ($r = 0 \text{ mm}$, red solid line) and near diaphragm aperture ($r = 4.3 \text{ mm}$, blue dotted line). Amplitude of radial electric field component (red solid line) and transverse magnetic field component multiply by speed of light (blue dotted line) near diaphragm aperture ($r = 4.3 \text{ mm}$) are presented at Figure 5. Presented amplitude field distributions are in accelerating gap, which is located between two adjacent diaphragms.

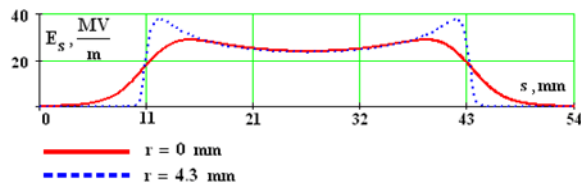


Figure 4. Amplitude distribution of longitudinal electric field component at the linac axis and near diaphragm aperture.

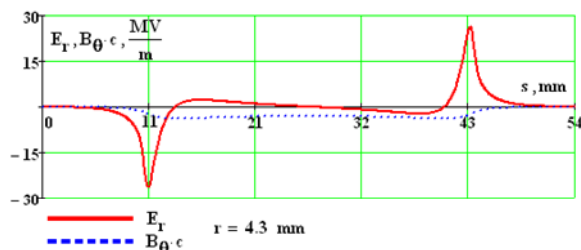


Figure 5. Amplitude of radial electric field component and transverse magnetic field component multiply by speed of light near diaphragm aperture.

At presented pictures we can see near diaphragm the increase of field amplitude, due to accelerating cell geometry.

ELECTRON BEAM DYNAMICS

In our calculations we used the following approximation:

- The model of macroparticle is used.
- The θ -component of the velocity of electrons is zero.
- Electron beam and linac axis are coaxial.

To calculate electron beam dynamics we use equation of motion (1):

$$\frac{d\vec{p}}{dt} = e\vec{E} + e[\vec{v} \times \vec{B}] \quad (1)$$

The electro-magnetic fields consist of two components: RF fields and fields generated by the space charge of electron beam.

Electro-magnetic fields generated by the space charge of electron beam were obtained by solving Maxwell's equations, there the source is a spatial-temporal distribution of electron beam. And a spatial-temporal distribution of electron beam was obtained by influence the external RF fields and beam self fields. So we have self-consistent problem.

To defined self electro-magnetic fields we solve Maxwell's equations with the help of particle-mesh method. Instead of solving Maxwell's equations we will solve wave equations for scalar electric and magnetic vector potentials. Differential operators into the equations were replaced by finite-difference approximations on the mesh. Mesh-defined charge and current densities were obtained by using the "cloud-in-cell" scheme. Potentials and forces at electron positions were obtained by interpolation on the array of mesh-defined values.

The unbunched electron beam pulsed by diode gun is injected into first cell of the linac accelerating structure. The shaping of electron bunches occurs mainly during the fly through several first accelerating cells (see Fig. 6,7).

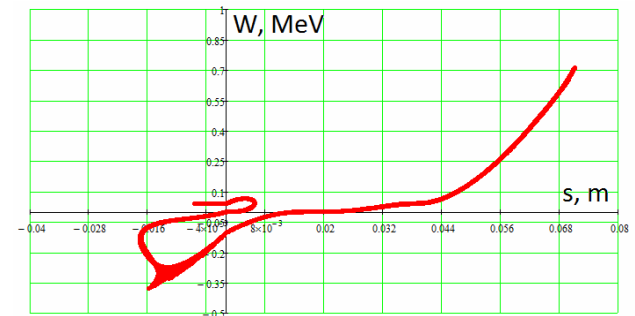


Figure 6. Electrons grouping process and bunches acceleration in the first cavity of linac.

The electrons grouping process in the first accelerating cavity is presented at Figure 6. The first cavity of linac is located at point $s = 0 \text{ m}$. The electrons with negative energy and position are moving back from linac. These electrons will be lost on the walls of vacuum chamber of channel between electron gun and linac.

The most part of electrons (about 75%) injected into linac will be lost in a few first accelerating cells on linac

aperture or on the walls of vacuum chamber of beam transfer line.

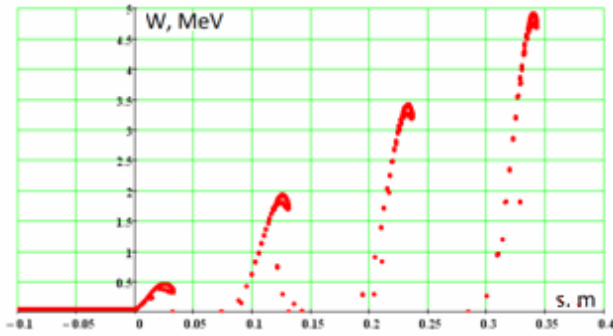


Figure 7. Electrons acceleration process in a few first cavities of linac.

At the exit of linac structure the current pulse represents a series of bunches (about 50) following each other with 2.8 GHz frequency. Average energy of accelerated electrons is 80 MeV, full beam current is about 1 A. Energy-longitudinal distribution of electron beam after acceleration is shown at Figure 8.

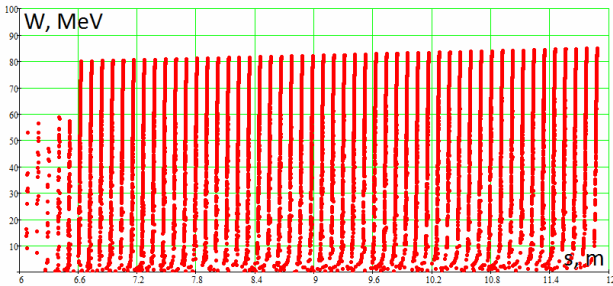


Figure 8. Energy-longitudinal distribution of electron beam after acceleration.

The first electron microbunch after acceleration is presented at Figure 9. The most part of particles are located at "the head" of microbunch and other particles are located at the long "tail" of microbunch.

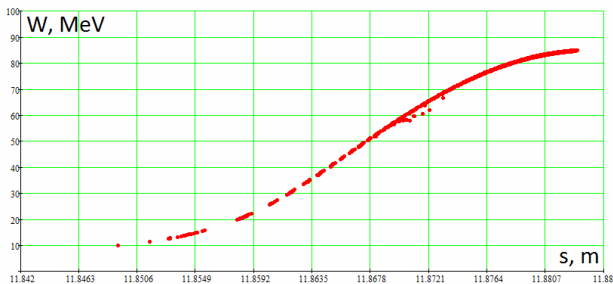


Figure 9. The first electron microbunch after acceleration.

The energy spectrum of electron beam after acceleration is presented at Figure 10. In the electron

beam the most part of particles have 80 MeV energy. The energy spread is 7% at half maximum. This result has good agreement with the measurements of electron beam properties performed at the commissioning stage [1].

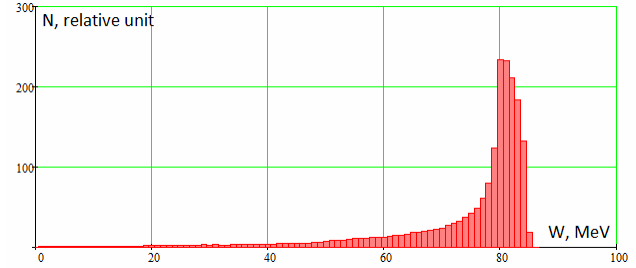


Figure 10. Energy spectrum of electron beam after acceleration.

The horizontal phase space distribution of the electron beam at the end of linac is presented at Figure 11. This phase portrait corresponds to electron beam with 7% energy spread.

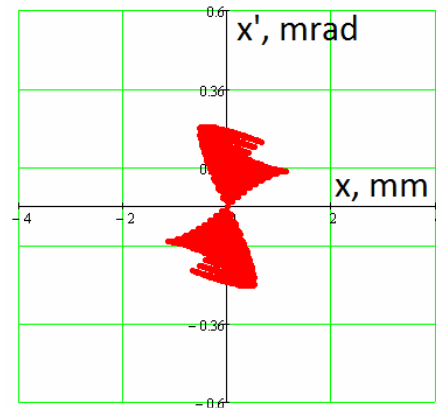


Figure 11. The horizontal phase space distribution of the electron beam at the end of linac.

The influence of space charge effect of the beam dynamics is not very strong. Taking into account this effect we obtained the reduction of beam current by 20%. The beam dynamics is almost unchanged and is still primarily dependent on the external RF electro-magnetic fields.

REFERENCES

[1] A.G. Valentinov et al., Linac – forinjector of the dedicated synchrotron radiation source in RRC “Kurchatov Institute”, Preprint BINP, 2002-29, Novosibirsk, 20p. 2002.