In the process of pulse generating the voltage on the base is reduced through the rectifying of the base-emitter diode, that charges the capacitance C in the greater extent, the larger was the previous pulse. And the longer is the process of discharge of the capacity to a level, at which the transistor is opened and can create the next pulse.

As for the magnitude of most pulses, it is determined, perhaps, by the level of noise or interference, from which starts the self-excitation of the next pulse generated. The randomness of the noise and interferences causes the random nature of these processes, just as is the case in the absence of regular input signals in some superregenerators [5, 6].

Certain confirmation of these considerations was an experiment when we forcibly connected a slight signal from an external source to the circuit of the base with a frequency near to the frequency of oscillation of the circuit. When the amplitude of this external signal was large enough to exceed the potential of the noise and interference, the value of all the pulses and the intervals between them were identical.

Reference

1. *Bayrachenko I.V.* Radiotechnical circuits and signals / *Bayrachenko I.V.* – Kyiv: PPC "Kyiv University", 1992 (in Ukrainian). 2. *Belkin M.K.* Superregenerative radio receiving / *Belkin M.K.* – Kyiv: Technica, 1986 (in Russian). 3. *Levitsky S.M.* Fundamentals of Radio Electronics / *Levitsky S.M.* – Kyiv: PPC "Kyiv University", 2007 (in Ukrainian). 4. *Ozersky Yu.P.* Nonlinear transformations and radio signals' receiving / *Ozersky Yu.P.* – Moscow: MIPT, 2010 (in Russian). 5. *Polyakov V.* Superregenerator (part1) / *Polyakov V.* // Radio. – 2001. – No11. – P. 51–52 (in Russian). 6. *Polyakov V.* Superregenerator (part2) / *Polyakov V.* // Radio. – 2002. – No3. – P. 50–51 (in Russian). 7. *Samoylo K.A.* Radiotechnical circuits and signals / *Samoylo K.A.* – Moscow: Radio i svyaz', 1982 (in Russian).

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ДЕЯКІ ВЛАСТИВОСТІ АВТОГЕНЕРАТОРІВ З АВТОМАТИЧНИМ ЗМІЩЕННЯМ

У автогенераторах RC-комірка автоматичного зміщення створює зсув фази коливань, що призводить до зсуву генерованої частоти.

У випадку переривчастої генерації (при досить великій сталій часу RC-комірки) при відповідних параметрах RC-комірки та величині зворотнього зв'язку періодичність імпульсів стає нерегулярною. Це спричиняється внутрішніми шумами які обумовлюють момент і величину виникнення чергового імпульсу генерації.

Ключові слова: обертання фази, зсув частоти, переривчаста генерація, нерегулярна періодичність.

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НЕКОТОРЫЕ СВОЙСТВА АВТОГЕНЕРАТОРОВ С АВТОМАТИЧЕСКИМ СМЕЩЕНИЕМ

В автогенераторах RC-ячейка автоматического смещения создает сдвиг фазы колебаний, что приводит к смещению генерируемой частоты. В случае прерывистой генерации (при достаточно большой постоянной времени RC-ячейки) при соответствующих параметрах RC-ячейки и величине обратной связи периодичность импульсов становится нерегулярной. Это происходит засчет внутренних шумов, обуславливающих момент и величину возникновения очередного импульса генерации.

Ключевые слова: вращение фазы, сдвиг частоты, прерывистая генерация, нерегулярная периодичность

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DYNAMICS OF ELECTRON BUNCH IN THE EXTERNAL MAGNETIC FIELD: COMPUTER SIMULATION

Influence of the longitudinal magnetic field on the electron bunch expansion in vacuum was studied. Analytic estimation of the spatial dependence of the bunch radius is compared with the simulation results via PIC method. Results obtained from simulation correlate satisfactory with theoretical estimations for the large magnetic field and low bunch density. Dynamics of the relativistic bunches was also studied.

Keywords: electron bunch expansion, longitudinal magnetic field, simulation via PIC method.

Introduction Problem of dynamics of electron beams and bunches is important for a wide range of branches [2], including inertial thermonuclear fusion and creation of the high frequency vacuum tubes [3], various types of spectrometry, electronic and ionic mycroscopy. In most cases top forming, focusing the bunch, and preventing of it's swelling due to the space charge are the priority tasks [2]. One of the most common ways to prevent swelling is the longitudinal magnetic field imposing to the system. Other methods use the external electric field and the spatial charge of residual plasma (for electron beams). Analytic solution of problem of the dynamics of electron bunch is rough [1]. Therefore the aim of this work is to carry out the computer simulation of the dynamics of electron bunch in a vacuum system with the longitudinal magnetic field.

Analytic estimation The simplest model of the homogeneous cylindrical electron beam of infinite length is treated. From the Gauss theorem one can obtain the electric field on its boundary:

$$E_r = -2\pi Rne = -\frac{2Ne}{R}, \qquad (1)$$

where R is the current cylinder radius, n and $N = \pi R^2 n$ are spatial and linear electron densities, respectively. Note that linear density N remains constant during the beam electrons' transversal oscillations. The motion equations for the electrons at the cylinder boundary have a form:

$$m\frac{dv_r}{dt} = -eE_r - \frac{e}{c}v_\varphi B; \quad m\frac{dv_\varphi}{dt} = \frac{e}{c}v_r B; \quad m\frac{dv_z}{dt} = 0, \qquad (2)$$

where $\vec{B} = \vec{e}_z B$ is the external magnetic field.

From the last equation (2) it is clear that $v_z = const \equiv v_0$.

One can obtain the following equations for the transversal velocity components from (1)–(2):

$$\frac{d^2 v_r}{dt^2} + \Omega^2 v_r = 0; \quad \frac{d^2 v_\varphi}{dt^2} + \omega_c^2 v_\varphi = -\frac{\omega_c e}{m}E_r\left(R(t)\right), \qquad (3)$$

Where $\omega_c = \frac{eB}{mc}$, $\omega_p^2 = \frac{4\pi ne^2}{m}$, $\Omega^2 = \omega_c^2 + \frac{\omega_p^2}{2}$

(note that $v_r = dR/dt$). Initial conditions have a form:

$$R(t=0) = R_0; \quad v_r(t=0) = v_\varphi(t=0) = 0. \qquad (4)$$

For the strong magnetic field one can put

$R = R_0 + \Delta r(t)$ ($|\Delta r(t)| << R_0$),

$E_r(R(t)) \approx E_r(R_0) + (dE_r/dR)|_{R=R_0} \Delta r$.

Then solution of the set (3) with the initial conditions (4) have a form:

$$v_\varphi(t) = \frac{\omega_p^2}{2\omega_c^2} R_0 (1 - \cos\Omega t), \quad v_r(t) = \frac{\omega_p^2}{2\omega_c^2} R_0 \sin\Omega t . \qquad (5)$$

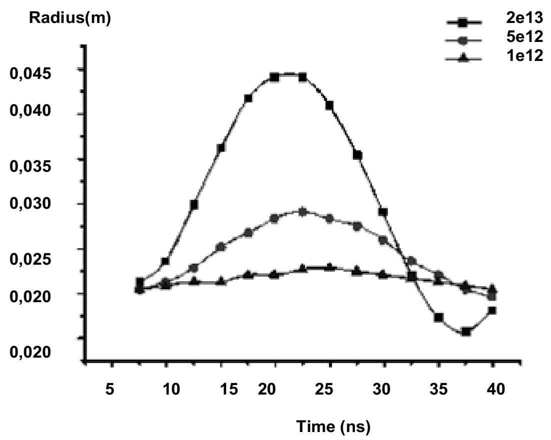
Consequently one can obtain the following formula for the beam radius oscillations' amplitude Δr_m :

$$\frac{\Delta r_m}{R_0} = \frac{\omega_p^2}{2\omega_c^2} . \qquad (6)$$

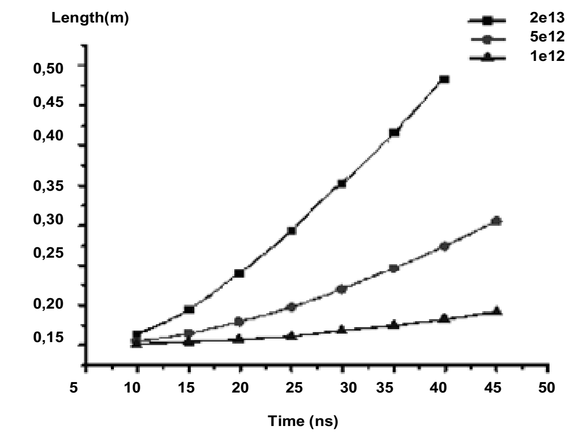
Expression (6) is valid for $\omega_p^2 << \omega_c^2$.

Simulation results for different bunch densities The electromagnetic 2.5D code was used valid for simulation of axially symmetric systems [4]. The simulation results are the spatial distributions of the charge density, radial component of electrical and azimuthal component of magnetic field, which are recorded every $1 \cdot 10^{-10}$ s.

The first series of simulations was carried out for bunches with various electron density (Fig. 1). From Fig. 1 a one can get the frequency and the amplitude of the bunch oscillations: in particular, for the bunch's density of $5 \cdot 10^{12}$ m^{-3} maximal difference from the initial radius is 0,85 cm, and the bunch oscillation period is 34 ns.



a



b

Fig. 1: a - beam radius dependence on time;
b - time dependence of the beam length. Density n (m^{-3}) is indicated on the figure, $v_0 = 3 \cdot 10^7$ m/s, $B_0 = 1 \cdot 10^{-3}$ T

For comparison, estimated values are 0,51 cm and 35,7 ns, respectively. The oscillation period coincides with the period of cyclotron rotation with sufficient accuracy. Calculated amplitudes are related to the first swing, eventually they decrease (see Fig. 2) because of the longitudinal spread of the beam (Fig. 1 b). The rate of the spread increases with the beam density n . From Fig. 3 one can see that difference between simulation results and formula (6) is minimal for small values of the bunch density and increases for large values.

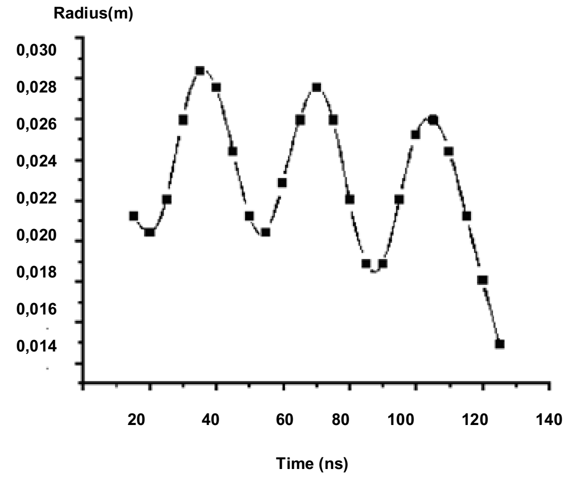


Fig. 2. Time dependence of the beam radius:
$n = 5 \cdot 10^2 m^{-3}$, $v_0 = 1 \cdot 10^7 m/s$, $B = 1 \cdot 10^{-3} T$

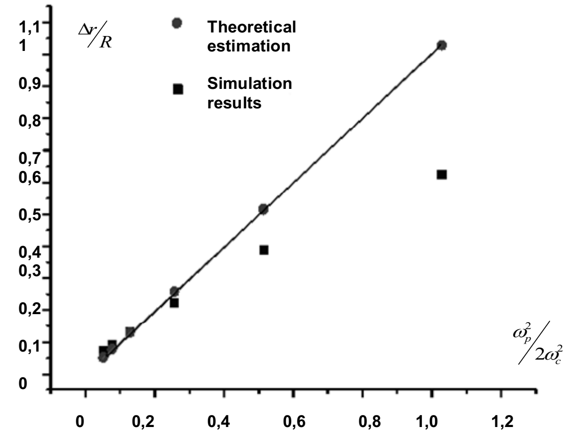


Fig. 3. Simulation and theoretical dependencies of $\Delta r/R$ on $\omega_p^2/2\omega_c^2$.(beam density is varied)

Simulation results for different values of external magnetic field Another series of simulation was carried out for bunches with equal concentration of electrons – $5 \cdot 10^{12}$ m^{-3} and different values of longitudinal magnetic field (Fig. 4).

From the graph one can see that increase of the field reduces the amplitude fluctuation and increases the frequency of radius fluctuations.

It is considered that swelling of the bunch is stopped if the expression $\Delta r/R << 1$ is correct. That means that the inequality $\omega_B << \omega_{ce}$ must be satisfied where $\omega_B = \sqrt{4\pi n e^2/m}$ is Langmuir frequency for the bunch density.

Obviously, the field $B_0 = 0{,}25 \cdot 10^{-3}$ T is not suitable to focus the bunch, but for $B_0 = 4 \cdot 10^{-3}$ T the bunch radius fluctuations are small and in a certain approximation the bunch is focused.

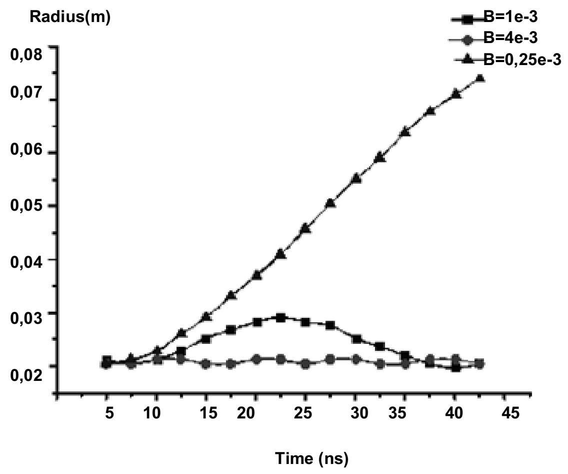


Fig. 4. Time dependence of the bunch radius for different values of external magnetic field (indicated on the figure in T)
$v_0 = 3\cdot10^7\ m/s$, $n = 5\cdot10^2 m^{-3}$

From Fig. 5 one can see that difference between theoretical estimation and simulation results decreases with the growth of magnetic field.

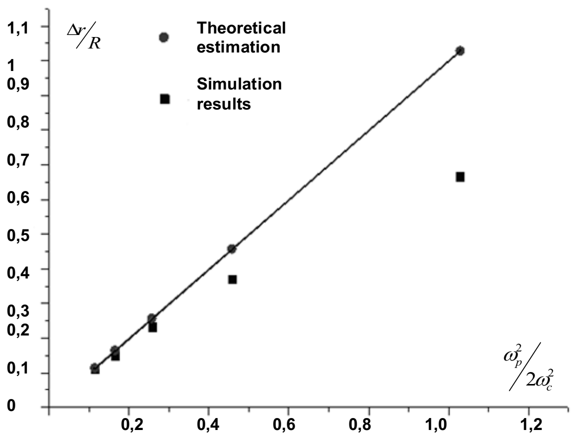


Fig. 5. Simulation and theoretical dependencies of $\Delta r/R$ on $\omega_p^2/2\omega_c^2$.(magnetic field is varied)

Simulation results for relativistic bunch Another series of simulation was intended to study the relativistic bunch, with speed, commensurable with the speed of light, without an external magnetic field. Law of motion for particles with such velocities differs from Newton's law, pulses increase in account of relativistic factor. This can move to deceleration of the bunch expansion. Simulation was carried out for the system with length of 13,5m, without external field, bunch density was $5\cdot10^{12}m^{-3}$, velocity – $2{,}7\cdot10^8$ m/s (v/c=0,9) therefore

$$\gamma \equiv \frac{1}{\sqrt{1-(v/c)^2}} \approx 2{,}3$$

Fig.4 shows a half section of the bunch density distribution at the beginning and at the end of the passage through the system. One can see that during 19 ns the bunch radius expanded only on 1,34 sm. For non-relativistic bunch this value would be 1,5 sm. So for v/c=0,9 influence of relativistic effect is not substantial.

At the forefront the bunch radius is increased and its density is decreased relatively to the bunch bulk. Front and back edges of the bunch are slightly blurred.

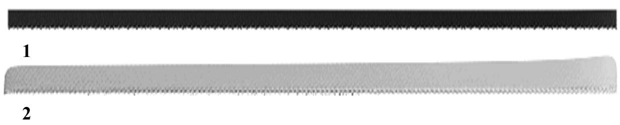


Fig. 6. Half section of the bunch density distribution at time of 0,6 ns(1) and 19 ns (2). v=$2{,}7\cdot10^8$ m/s (v/c=0,9), L=13,5m, n=$5\cdot10^{12}m^{-3}$

Conclusion The results obtained from simulation, correlate satisfactory with theoretical estimations: variation of the bunch is proportional to it's density, the pulse frequency is equal to the cyclotron frequency for the given magnetic field with the sufficient accuracy. Eventually oscilation of the bunch radius decreases because of the longitudinal spread. For low values of magnetic field bunch can not be focused in given system. Increase of the forefront radius of the relativistic bunch can be caused by the following effect: motion of the beam particles forms the azimuthal magnetic field, which focuses the beam. The spreading of the bunch forefront can be caused by the lower magnetic field in this area.

Reference

1. Electronic beam technology. / Gaysing U., Panzer S. // Energy, 1980 (in German). 2. Electron Physics. / Levitsky S.M. // Kyiv, 2005 (in Ukrainian).3. Vacuum and solid-state electronics UHF./ Levitsky S.M., Koshevaya S.V. // Kyiv, High school, 1986 (in Russian). 4. 2.5D relativistic electromagnetic PIC code for simulation of beam interaction with plasma in axial-symmetric geometry. / Tolochkevych Yu.M., Litoshenko T.Eu., Anisimov I.O. // Problems of Atomic Science and Technology. Series: Plasma Electronics and New Acceleration Methods. – 2010. – №4. – P. 47–50.

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ДИНАМІКА ЕЛЕКТРОННОГО ЗГУСТКУ В ЗОВНІШНЬОМУ МАГНІТНОМУ ПОЛІ. КОМП'ЮТЕРНЕ МОДЕЛЮВАННЯ

Досліджено вплив поздовжнього магнітного поля на розбухання електронного згустку у вакуумі. Аналітична оцінка просторової залежності радіуса згустку порівнюється з результатами моделювання методом макрочастинок у комірках. При великих магнітних полях та малих густинах згустків результати аналітичного розрахунку та моделювання добре узгоджуються між собою. Досліджено також динаміку релятивістських згустків.

Ключові слова: розбухання електронного згустку, поздовжнє магнітне поле, моделювання методом макрочастинок у комірках.

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ДИНАМИКА ЭЛЕКТРОННОГО СГУСТКА ВО ВНЕШНЕМ МАГНИТНОМ ПОЛЕ. КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ.

Было исследовано влияние продольного магнитного поля на разбухание электронного сгустка в вакууме. Аналитическая оценка пространственной зависимости радиуса сгустка сравнивается с результатами моделирования методом макрочастиц в ячейках. При больших магнитных полях и малых плотностях сгустков результаты аналитического расчёта та моделирования хорошо соотносятся между собой. Была исследована также динамика релятивистских сгустков.

Ключевые слова: розбухание электронного сгустка, продольное магнитное поле, моделирование методом макрочастиц в ячейках.