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THE NUMERICAL MODELLING OF DYNAMIC PROCESSES IN AUTOPHASE ELECTRON BEAMS

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The article looks into dynamic processes in an autophase TWT in the mood of back energy transformation on the basis of a 3-D numerical model. It has been shown that the mood of back energy transformation is characterized by the dependence of the electron wave interaction on the stable capture mood of an electron beam by the HF-field. The analysis of dynamic defocusing in autophase TWT in the mood of back energy transformation was studied. The defocusing of the electron flow in the dynamic mood is characterized firstly by the increasing field of the space charge density in the capture bunch, and next is radial and azimuth spiral field. The latter's begin to act in the autophase section exit when many electrons exit the capture and partly defocusing of the electron flow takes place under field of the space charge action leading to the local current subsidence. The mechanism of the maximum transformation HF-power achievement is accompanied by gradual potential well shoaling and the bunch breakup.The potential well shoaling to a critical level takes place at significant residual values of the input HF-power.The current subsidence takes place in local regions and it is determined by uncaptured electrons and capture leaving particles. The essential unlaminarity of the electron flow rises the current subsidence on the RS and together with the capture violation decreases the device efficiency. The analysis of phase diagrams makes it possible to monitor the evolution of an electron bunch capture up to its destruction and to allocate the wave length field of an autophase section where the process of energy transformation is still taking place.

Keywords: phase focusing, current subsidence, field of space charge, numerical methods.

There are two opposite opinions about the main causes of the dynamic defocusing, so [1] says the current subsidence is stipulated by the HF- field radial component of the reducing system (RS) generally, but not by the space charge field; [2] claims the opposite. Apparently, it′s explained by the dynamic defocusing processing are more delicate and in principle are needed the 3-D models and programs operating with the large quantities of the big particles are needed for their analysis.

The studies of the electron flow defocusing were carried out by the developed numerical model [3, 4]. The calculations are given for the focusing by the homogeneous magnetic field with the full screen cathode at B=65 mTl. The opening (first) full by the beam of the passing channel was 0,5; the current density spread in the enter crossing was assumed constant [5, 6].

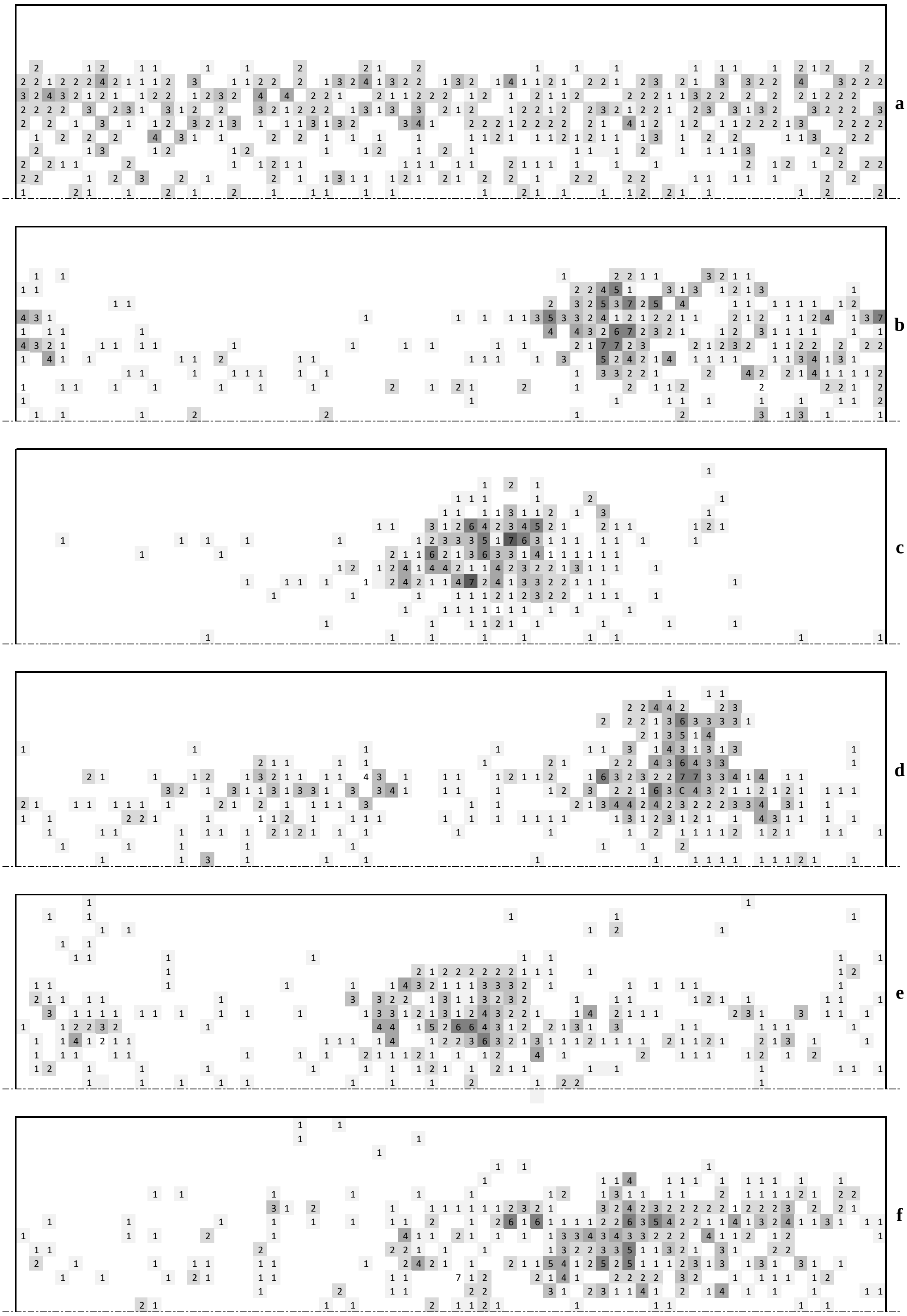
The analysis of the phase picture shows that the phase focusing dynamic in autophase TWT has the following steps: the first step – the maximum group in the exit section of the buncher; the second step – the bunch capture on the autophase section enter, the bunch extra-grouping; the third step –widening of the bunch, its separation on two parts; the forth step – the bunch exits from the capture state.

The first step is the formation of the main bunch in the braking field phase at the buncher exit (Picture 1,b). The particle dynamic is rather simple in this case and «the electron liquid current» is laminar. The braking electrons form the bunch. On the left ($(3\pi/4) \geq \varphi \geq (-\pi/4)$) the rapid electrons come to the bunch from the axe due to the HF-field disfocusing flow in the bunch. On the right ($(5\pi/4) \geq \varphi \geq (-\pi/4)$) the weakly braking particles moving to the axe due to the HF – field focusing enter. In the bunch the electrons are extra broken then the greater part of the strongly braking particles gather in the upper part of the bunch. The first step ends with the formation of the stub of the slow electron flow close to the reducing system border. This stub moves in the opposite direction to the main flow of the rapid particles (near the axe). Then the bunch for the following capture is formed.

The second step is characterized by the bunch capturing in the potential well at the autophase section enter including the partial debunching of the electron flow (Picture 1,c). The braking electron stub becomes larger slightly because it takes the uncapture electron group. The slow electron flow is extra broken by electrostatic field near the RS, and electrons giving its kinetic energy to the braking field subside on RS. In general these electrons determine the local current subsidence at the autophase section beginning from the second step. The particle motion in the bunch is oscillating. This oscillation amplitude is not more than the potential well depth in the second step.

In the third step the effectiveness of the electron flow interaction with electromagnetic wave decreases due to the distortion of the potential well form. The factors distorting the potential well form and influencing the electron movement (the field of space charge, the first and the second harmonic amplitudes of the HF – field, electrostatic field) promote the bunch widening and its breakup in two bunches that oscillate antiphased. This step is characterized by the formation of the withdrawn stub transporting the particle flow from one bunch to another one (Picture 1,d).

In the fourth step (Picture 1,e) the bunch exits from the capture state due to the potential well shoaling. The extra crossing and the phase trajectory chaotization appear, the bunch smears. The intensive mix of the layers and the strong flow turbulization take place, its structure is not similar to the initial one at the autophase section enter. In this case the radial and azimuth electron speeds increase that together with electron flow radius rise makes the increasing of the dynamic current subsidence on RS violently. The back energy transformation stops. The spatio – temporal diagrams show that the particle movement in the bunch, the bunch and rarefaction structure have a complicated form. At the device exit region there is the flying electron flow not only periodical pulsating, but there is the sequence of the formation having the fast changing structure – about two HF – oscillation period.



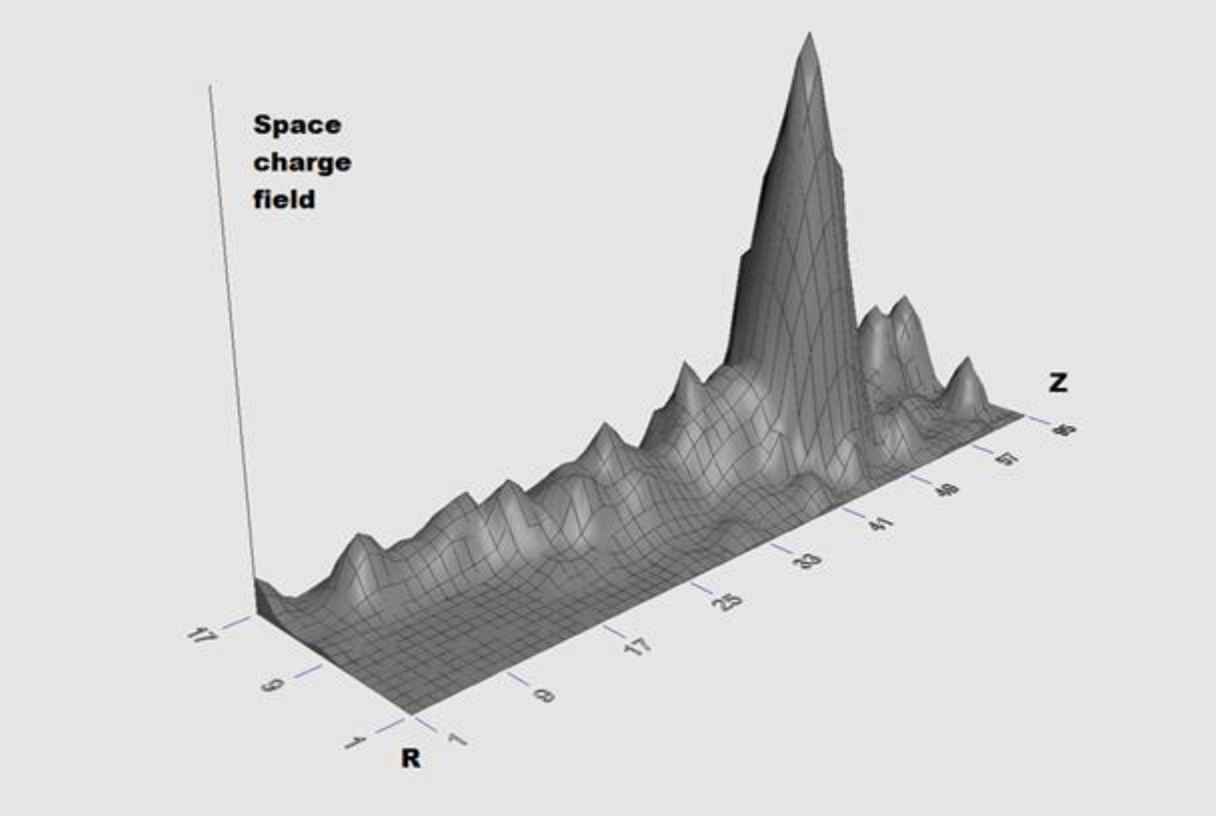
Picture 1 - The space-time diagrams of the electron flow

The radial removal conventional by dynamic effects begins to appear already on the region z_i = 0,5…0,6. The cross trajectory flow begin to arise at z_i > 0,6 and at $z_i \geq$ 0,8…0,9 the flow becomes unlaminar essentially. The essential unlaminarity of the electron flow rises the current subsidence on the RS and together with the capture violation decreases the device efficiency.

The dynamic current subsidence begins in the area of the first harmonic current maximum. Behind the efficiency maximum the flow is strong stirring, the current subsidence continues. The turbulization leads to the existence of the electron from the all layers on the electron flow periphery.

The calculation analysis shows that the braking electrons having large azimuth and radial speeds can be on the different distance from the axe while the faster electrons gather in the region close to the axe.

The calculation of the particle density at the autophase section exit (z_i = 0,5…0,6) shows if the capture state keeps then the big particle density in the bunch exceeds the average value about over two times, but in the rarefaction it is less the average value about over three times. At the same time the volume density is found less because of the electron flow radius in the bunch changes. The coulomb forces estimation shows that they are about over two times bigger at the bunch periphery than at the rarefaction periphery.

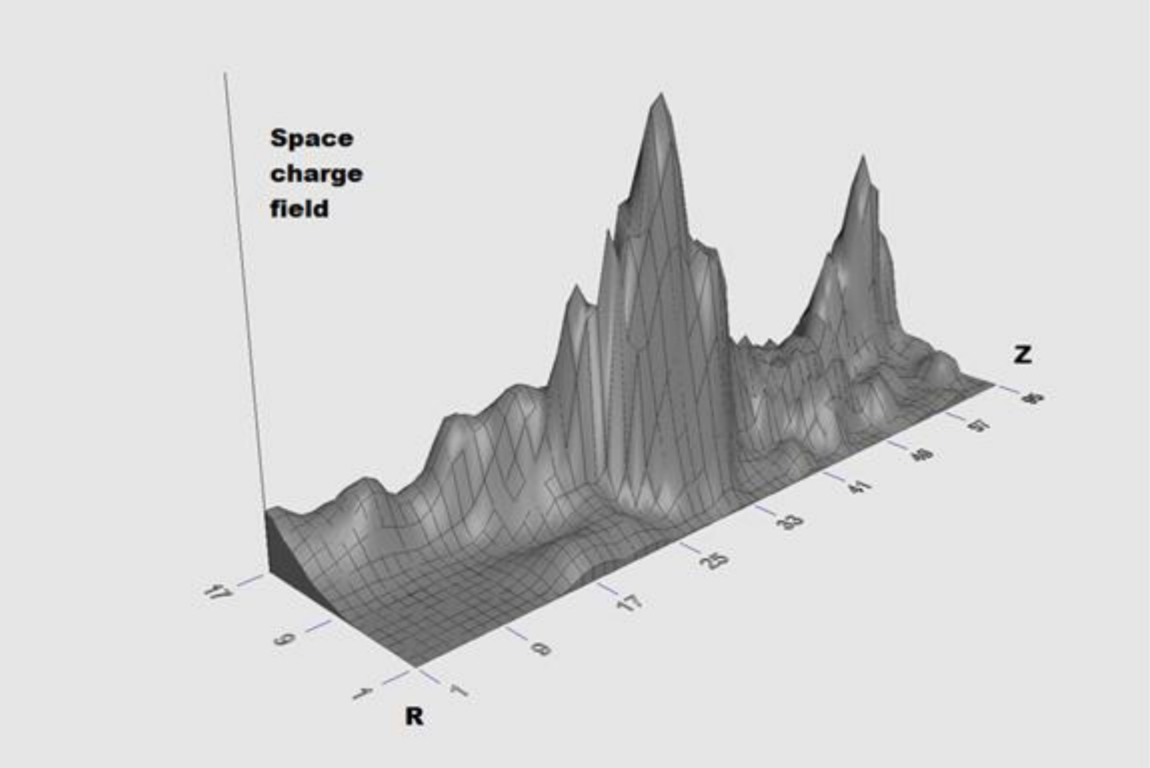


Picture 2 - The density distribution of the space charge on the a wave length
(the second step of the dynamic focusing)

The analysis shows at the autophase section exit part if the capture condition disturbs because the potential well shallow the current subsidence is determined not only by periphery defocusing electrons coming to pass channel walls under braking electrostatic field action but also the refocused large particles that rushes to the axe and cross it before subsidence.

The physical meaning of this phenomenon is the following. In the stirring flow each particle moves separately, the others create its background. Over capture state disturbs the breaking electrons are squeezed out on the electron flow periphery and left the flow. The «halo» is observed because the breaking electrons are spread over the whole volume of the electron flow while the fast electrons gather in the region close to the axe.

The 3-D model examination of the nonlinear effects in the autophase TWT suggests that the first reason for the electron flow defocusing in the dynamic order is the increasing field of the space charge density in the capture bunch, and next is radial and azimuth spiral field. The latter's begin to act in the autophase section exit when many electrons exit the capture and partly defocusing of the electron flow takes place under field of the space charge action leading to the local current subsidence. The essential electron flow nonlaminarity increasing current subsidence on the braking system together with the capture disturbance decreases the device efficiency.



Picture 3 - The density distribution of the space charge on the a wave length
(the third step of the dynamic focusing)

The phase patterns analysis and the density distribution of the space charge (Picture 2) according the second step of the phase focusing dynamic confirm that the reverse energy transformation is connected with the bunch capture increasing at the autophase section enter, HF – field and its shift under braking electrostatic field action to the accelerating HF – wave phase. The potential well shoaling takes place as the bunch disperse starts. The potential well form distortion leads to the second bunch formation (Picture 3) and its capture by the second harmonic field that reduces the efficiency growth. At the point of the maximum efficiency two approximately equal density bunches form, they are situated symmetrically in regard to the wave phase. The further well shoaling leads to the total bunch breakup and its exit from the capture.

So, the mechanism of the maximum transformation HF – power achievement is accompanied by gradual potential well shoaling, the bunch breakup and bunch's exit from the capture. The current subsidence takes place in local regions and it is determined by uncaptured electrons and capture leaving particles.

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ДИНАМИЧЕСКИХ ПРОЦЕССОВ В АВТОФАЗНЫХ ЭЛЕКТРОННЫХ ПОТОКАХ

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На основе трехмерной численной модели исследованы динамические процессы в автофазной ЛБВ в режиме обратного преобразования энергии. Показано, что режим обратного преобразования энергии характеризуется зависимостью электронно-волнового взаимодействия от устойчивого состояния захвата электронного сгустка полем ВЧ волны. Проведен анализ динамической расфокусировки в автофазной ЛБВ в режиме обратного преобразования энергии. Расфокусировка электронного потока в динамическом режиме определяется, прежде всего, увеличением плотности пространственного заряда в захваченном электронном сгустке, а затем уже радиальным и азимутальным ВЧ полем замедляющей системы. Последние начинают действовать в выходной части автофазной секции при выходе большого числа электронов из состояния захвата и частичной расфокусировке электронного потока под действием сил поля пространственного заряда. Механизм достижения максимального преобразования ВЧ мощности сопровождается постепенным обмелением потенциальной ямы и развалом электронного сгустка. Обмеление потенциальной ямы до критического уровня имеет место при значительных остаточных величинах входной ВЧ мощности. Токооседание происходит в локальных областях и обусловлено незахваченными электронами и частицами, вышедшими из состояния захвата. Существенная неламинарность электронного потока, приводящая к увеличению токооседания на замедляющую систему, совместно с нарушением состояния захвата, приводит к уменьшению коэффициента полезного действия прибора. Анализ фазовых диаграмм позволяет детально проследить за эволюцией захваченного электронного сгустка, вплоть до момента его разрушения и выделить область длин автофазной секции, на которых процесс преобразования энергии еще имеет место.

Ключевые слова: фазовая фокусировка, токооседание, поле пространственного заряда, численные методы.

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