# The control of the dynamics of intense electron beams coupled through a common field

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***Abstract*— This paper presents the results of a study of the nonlinear dynamics of a system with several electron beams. A review and analysis of the latest results obtained in this area. In this case, the main emphasis in this work is made on controlling the generation characteristics in such a highly nonlinear system. The main dynamic modes typical for this kind of systems are shown.**

**Keywords— PIC, non-stationary processes of electron-wave interaction; numerical simulation; optimization; electron-plasma devices;**

## I. Introduction

Virtual cathode generators (vircator, reditron, virtod, etc.) are one of the most popular devices in superpowerful beam-plasma microwave electronics and are currently being actively studied [1-11]. One of the main advantages of these devices is the generation of heavy-duty electromagnetic radiation with the extreme simplicity of design. At the same time, this type of microwave devices is characterized by strongly nonlinear dynamics. The disadvantages are low efficiency, usually of the order of one percent, and low generation frequency.

One of the possible mechanisms for increasing the frequency of the generation of vircator systems is to increase the density of the injected electron beam. Recall that the generation frequency of this class of devices is directly proportional to the plasma frequency of the injected electron flow, which is determined by its density. Nevertheless, an increase in the frequency in this way leads to a sharp drop in the generation efficiency, due to the existence of an optimal value of the injected current in all known vircator circuits. What makes it unacceptable to use this method to significantly increase the frequency.

A possible solution to this problem is the development of new oscillator circuits on a virtual cathode. In particular, in [10], the question of the synchronization of several virtual cathodes in the drift space region was studied in detail. At the same time, multipath klystrons are very common. The use of several electrons beams in them in place of one is connected with the aim of improving the grouping and, therefore, efficiency, by reducing the forces of the space charge.

The experimental analysis of such systems causes a number of difficulties associated primarily with the high cost of creating a full-size experimental layout. At the same time, modern numerical methods make it possible to solve these problems with a high degree of accuracy of reliability. Numerical modeling was carried out using the PIC method [12, 13].

Taking into account the peculiarities of such sources of ultrahigh-frequency microwave radiation as devices with a virtual cathode, a circuit is proposed in which the power of each of the oscillating virtual cathodes is added in a common resonator (drift chamber) - a multi-beam vircator circuit in which several beams with supercritical currents are loaded on a common resonator [10]. Such a scheme has shown its effectiveness, in terms of increasing the frequency of generation.

Thus, this work is devoted to the continuation of the study of the processes of interaction of several intense electron flows with supercritical current. In this case, the main emphasis in this work is made on controlling the generation characteristics in such a highly nonlinear system.

## II. Results

When several electron beams with a supercritical current are injected into the general drift space, a Bursianos instability begins to develop in each of the beams, leading to the formation of a virtual cathode (VC).

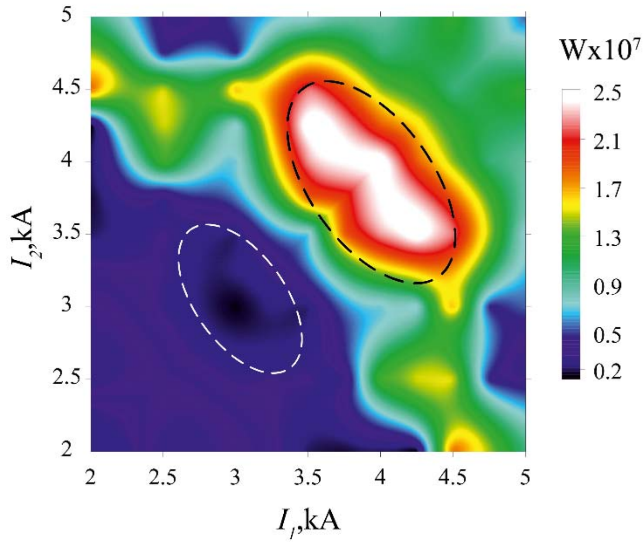


Fig. 1. Dependence of the output power of electromagnetic radiation on the magnitude of the injected currents.

It is well known that the dynamics of a VC is characterized by strong nonlinearity and is determined by the current density [2-4, 13-17]. In the systems under study, electron flows have different current magnitudes. This leads to the fact that the formed VCs have different temporal and spatial scales, as well as different power of electromagnetic radiation. At the same time, the beams interact with each other through the common field of the drift chamber. In view of the differences in the dynamics of each of the beams and the nonlinear coupling between them, it is possible to implement various collective dynamics modes [18-21].

In particular, the interaction of electron flows can lead to synchronization of the oscillations of part of the beams and to an increase in the amplitude of their vibrations. The reverse situation is also possible, namely, desynchronization of VC oscillations and, as a result, suppression of each other's oscillations. Note that it was previously shown that the interaction of several beams due to strong nonlinearity can lead to the randomization of the generated electromagnetic radiation [15].

Figure 1 shows the dependence of the power of electromagnetic radiation on the current value of the injected beams. The black dotted line marks the region characterized by high output power. This area corresponds to the mode of synchronization of oscillations of several VCs. The white dotted line marks the region corresponding to the oscillation desynchronization mode and is characterized by a sharp drop in the output radiation power.

Thus, the control of the oscillation regimes in this system is mainly determined by the ratio between the injected currents.

## ACKNOWLEDGMENT

This work has been supported by Russian Foundation for Basic Research (Project 18-32-20135).

## REFERENCES

[1] Booske, J.H. Plasma physics and related challenges of millimeter-wave-to-terahertz and highpower microwave generation / J. H. Booske // Physics of Plasmas. – 2008. – Vol. 15. – P. 055502.

[2] S. A. Kurkin, A. A. Koronovskii, A. E. Hramov, "Output microwave radiation power of low-voltage vircator with external inhomogeneous magnetic field," Technical Physics Letters, V. 37, no. 4, pp. 356-359, 2011.

[3] Alexander E. Dubinov, Alexey G. Petrik, Semen A. Kurkin, Nikita S. Frolov, Alexey A. Koronovskii, Alexander E. Hramov, "Beam-plasma instability in charged plasma in the absence of ions," Physics of Plasmas, V. 23, no. 4, p. 042105, 2016.

[4] S. A. Kurkin, A. E. Hramov, A. A. Koronovskii, "Nonlinear dynamics and chaotization of virtual cathode oscillations in annular electron beam in uniform magnetic field," Plasma Phys. Rep, V. 35, no. 8, pp. 628-642, 2009.

[5] Shao, H., Liu, G., Yang, Z., Chen, C., Song, Z., & Huang, W. (2006). Characterization of modes in coaxial vircator. Ieee transactions on plasma science, 34(1), 7-13.

[6] S. A. Kurkin, A. A. Koronovskii, A. E. Hramov, "Formation and dynamics of a virtual cathode in a tubular electron beam placed in a magnetic field," Technical Physics, V. 54, no. 10, p. 1520, 2009.

[7] Starodubov, A. V., Makarkin, S. A., Galushka, V. V., Pavlov, A. M., Serdobintsev, A. A., Koronovskii, A. A., & Kalinin, Y. A. (2018, April). Higher harmonics generation in low-voltage vircator system. In 2018 IEEE International Vacuum Electronics Conference (IVEC) (pp. 219-220). IEEE.

[8] Kalinin, Y. A., Starodubov, A. V., & Fokin, A. S. (2019). Hybrid Vircator Microwave Oscillator with a Nonlaminar Electron Beam and an Electrodynamic Section. Plasma Physics Reports, 45(8), 770-776.

[9] Parson, J. M., Lynn, C. F., Scott, M. C., Calico, S. E., Dickens, J. C., Neuber, A. A., & Mankowski, J. J. (2015). A frequency stable vacuum-sealed tube high-power microwave vircator operated at 500 Hz. Ieee electron device letters, 36(5), 508-510.

[10] A. A. Badarin, S. A. Kurkin, A. A. Koronovskii, A. E. Hramov, A.O. Rak, “Processes of virtual cathodes interaction in multibeam system,” Physics of Plasmas, V. 25, no. 8, p. 083110, 2018.

[11] N. S. Frolov, S. A. Kurkin, M. V. Khramova, A. A. Badarin, A. A. Koronovskii, A. N. Pavlov, A. E. Hramov, “Perspective sub-THz powerful microwave generator" nanovircator" for T-rays biomedical diagnostics,” In Saratov Fall Meeting 2015: Third International Symposium on Optics and Biophotonics and Seventh Finnish-Russian Photonics and Laser Symposium (PALS) (Vol. 9917, p. 991721). International Society for Optics and Photonics, 2016.

[12] Birdsall, C.K. Plasma physics via computer simulation / C.K. Birdsall, A.B. Langdon – Taylor and Francis Group, 2005.

[13] S. A. Kurkin, A. A. Badarin, A. A. Koronovskii, N. S. Frolov, A. E. Hramov, “Modeling instabilities in relativistic electronic beams in the CST particle studio environment,” Mathematical Models and Computer Simulations, V. 10, no. 1, pp. 59-68, 2018.

[14] E. N. Egorov, A. A. Koronovskii, S. A. Kurkin, A. E. Hramov, "Formation and nonlinear dynamics of the squeezed state of a helical electron beam with additional deceleration," Plasma Physics Reports, V. 39, no. 11, pp. 925-935, 2013.

[15] A. A. Badarin, S. A. Kurkin, N. S. Frolov, A. O. Selskii, A. E. Hramov, A. A. Koronovskii, “Analyzing Complex Dynamic Modes in Different Modifications of Relativistic Generators on a Virtual Cathode,” Bulletin of the Russian Academy of Sciences: Physics, V. 82, no. 11, pp. 1456-1460, 2018.

[16] A. A. Badarin, S. A. Kurkin, A. E. Hramov, “Multistability in a relativistic electron beam with an overcritical current,” Bulletin of the Russian Academy of Sciences: Physics, V. 79, no. 12, pp. 1439-1442, 2015.

[17] A. A. Badarin, S. A. Kurkin, A. A. Koronovskii, A. E. Hramov, “The effect of the conductivity of drift chamber walls on the dynamics of a relativistic electron beam with a virtual cathode,” Technical Physics Letters, V. 41, no. 12, pp. 1148-1151, 2015.

[18] A. E. Dubinov, A. G. Petrik, S. A. Kurkin, N. S. Frolov, A. A. Koronovskii, A. E. Hramov, “Virpertron: A novel approach for a virtual cathode oscillator design,” Physics of Plasmas, V. 24, no. 7, p. 073102, 2017.

[19] N. S. Frolov, S. A. Kurkin, A. A. Koronovskii, A. E. Hramov, “Nonlinear dynamics and bifurcation mechanisms in intense electron beam with virtual cathode,” Physics Letters A, V. 381, no. 28, pp.2250-2255, 2017.

[20] S. A. Kurkin, A. A. Koronovskii, A. E. Hramov, “Effect of the electron beam modulation on the sub-THz generation in the vircator with the field-emission cathode,” Journal of Plasma Physics, V. 81, no. 3, 2015.

[21] A. E. Khramov, S. A. Kurkin, E. N. Egorov, A. A. Koronovskii, R. A. Filatov, “The program package for the investigation and optimization of nonlinear non-stationary processes in the microwave generators with electron feedback,” Matematicheskoe modelirovanie, V. 23, no. 1, pp. 3-18, 2011.