TRANSITION RADIATION INDUCED BY NONRELATIVISTIC ELECTRON BUNCHES

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The experiments showed that the Bernstein – Green – Kruskal (BGK)-waves can be used to form short electron bunches with time durations ranging between 50 and 100 ps. Experiments on generating electromagnetic pulses (EMPs) by using nonrelativistic electron bunches passing through diaphragms of various radii and complex geometries are described. Results obtained may also be used in designing devices for generating EMPs with tunable characteristics.

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1. INTRODUCTION

As it is well known, electromagnetic radiation may be generated not only by charged particles being accelerated but also by those moving with a constant velocity. In the last case, the presence of a material medium is essential for electromagnetic wave generation. A charged particle moving rectilinearly and uniformly either near or through a conducting medium generates time-varying currents in it. The currents induced produce electromagnetic radiation. Uniform motion of charged particles near insulators results in a local space–time polarization and, hence, in radiation of electromagnetic waves with intensities substantially lower that in the former case. Thus, electromagnetic radiation arises due to the reconfiguration of the field of a charged particle–medium system. The above electromagnetic phenomena gives rise to definite types of radiation, such as transition radiation, diffraction radiation, and Smith–Purcell radiation [1]. Cherenkov radiation, which is generated by charged particles moving rectilinearly and uniformly with velocities exceeding the phase velocity of light in a given medium, stands somewhat apart from these types of radiation. Today, generation of short high-power EMPs is of considerable interest. Specifically, EMPs are generated by rapidly reconfiguring the field of a system where a charged electron bunch interacts with conducting solid. Wide-band transition radiation is intended to be employed in pulsed radar. It should be noted that to date microwave generators employing diffraction radiation have been designed and found wide application. In this paper, the influence of apertures of various configurations and materials on electromagnetic wave generation by electron bunches passing through the apertures is studied.

2. EXPERIMENTAL RESULTS

The objective of this research was to make a feasibility study on production of short electron bunches, using the BGK-waves [2], and to generate electromagnetic pulses by using nonrelativistic electron bunches passing through diaphragms of various radii and complex geometries. The setup of the experimental facility is given in Fig. 1. Two inter-penetrative electron beams (1, 2, Fig.1) were passed through a metallic pipe placed in a homogeneous magnetic field of the strength 400 Oe (6, Fig.1). The velocities of both beams exceeded the critical one and were $3 \cdot 10^9$ and $3.6 \cdot 10^9$ cm/s, the total current was 40…50 mA.

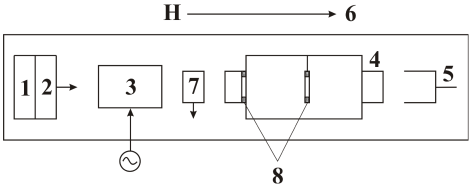

Fig. 1. Experimental setup: 1, 2 – electron guns; 3 – modulator; 4 – cavity resonator; 5 – collector; 6 – coil of magnetic field; 7 - capacity probe; 8 – aperture

The effective pressure in the chamber was $2 \cdot 10^{-6}$ Torr. The initial perturbation was made when the oscillator fed high-frequency voltage to the modulator (3, Fig. 1). The modulating voltage at the frequencies 500…1200 MHz came from 1W-oscillator. Downstream from the collector (5, Fig. 1) there was an electrostatic analyzer used to measure the energy characteristics of the beams.

The measurements were made of the wave amplitude distribution along the system's length and wave phase velocities with a movable high-frequency probe which was an antenna terminated by a resistance that was equal to the characteristic impedance of the cable. The phase velocity of oscillations for different modulation frequencies was measured by using a technique of comparing the reference signal phase and probe signal. To measure the harmonic content of the oscillations of the bunch potential we used a capacity probe (7, Fig. 1) terminated to the characteristic impedance of the cable. In further experiments, downstream from the modulator there was a circular movable cavity resonator (4, Fig. 1), signals from which were detected using a coupling loop and fed to either an oscillograph, or a spectral analyzer operating in the range up to 40 GHz. Apertures (8, Fig. 1) disposed at the input and in the center of the cavity resonator were used to generate transition radiation when the electron bunches passed through them [2].

In the absence of the modulating signal the two-beam electron system was stable, because the beams were under beyond-the-critical conditions. The feeding of the finite amplitude signal brought the system into unstable state, the wave amplitude grows exponentially with an increasing modulator-probe distance. The phase velocity, as taken at different beam velocities and modulation frequencies, was $(3 \ldots 4) \cdot 10^9$ cm/s.

Upon reaching certain amplitude, the wave captured electrons of the beams and a non-linear BGK wave was thus formed so the phase velocity variations became impossible.

The evaluation of the capture amplitude was made according to the capture formula:

$$\varphi_0 \vdash \frac{m}{2e}\left(v_b \quad v_{ph}\right)^2,$$

where v_b - beam velocity, v_{ph} - wave phase velocity. The capture amplitude was as high as 10…15 V at different beam energies and modulation frequencies.

Knowing the bunch velocity and its potential half-width, one could now evaluate its longitudinal dimension. Thus, for example, for the modulation frequency f_0=925 MHz the bunch longitudinal dimension was on the order of 3 cm, the bunch transverse dimension determined by sizes of the cathode and was 0.6 cm.

The particle density in the bunch was $10^8 cm^{-3}$, the total number of electrons was $N = 4\text{Ч}10^7$.

The aperture was placed in centre and at the output of resonator. For the latter case the dependence of radiation intensity on aperture radius 0.2 cm was studied under the constant bunch radius 0.3 cm. Measurements were made on the lowest mode with 6.38 GHz frequency. As it is seen from Fig. 2 the transition radiation amplitude is maximum when aperture radius is close to the bunch radius and it decreases when aperture radius increases. The dependence of the radiation amplitude on aperture thickness under optimal aperture radius is shown in Fig. 3.

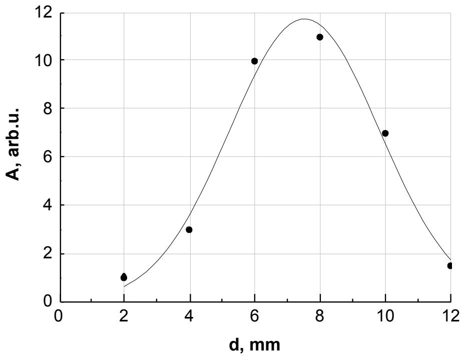

Fig. 2. Radiation amplitude dependence on diaphragm aperture diameter

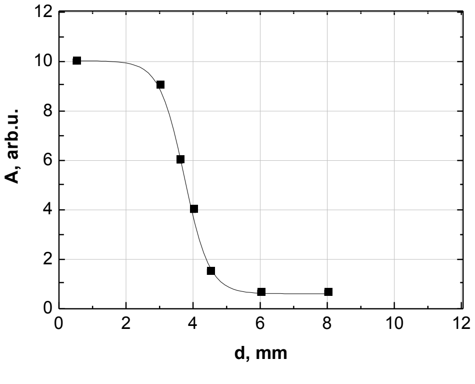

Fig. 3. Radiation amplitude dependence on diaphragm thickness

The transition radiation amplitude sharply decreases when aperture thickness increases and it almost disappears when aperture thickness is more than electron bunch length. The radiation spectra for thin (0.2 cm) and thick (0.6 cm) apertures are shown in Fig. 4 it is seen that on thin aperture spectrum achieves 30 GHz whereas on thick aperture it stops at 14 GHz value.

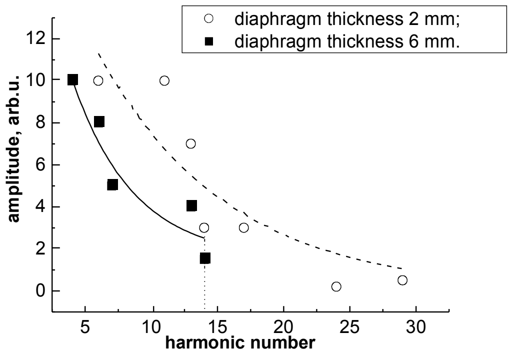

Fig. 4. Radiation spectra for thin and thick diaphragms

On 965 MHz modulation frequency spectra was measured for rounded and rectangular cupric apertures of equal area and thickness (0.2 cm) (Fig. 5).

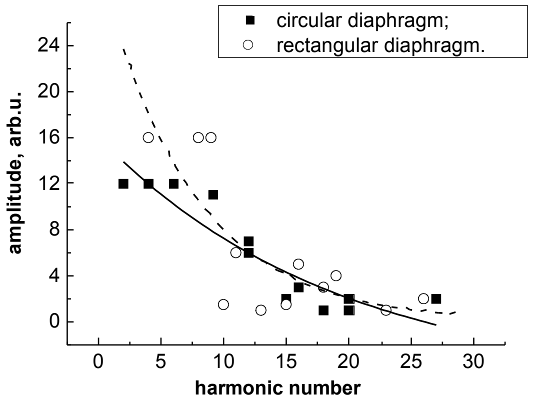

Fig. 5. Radiation spectra for circular and rectangular diaphragms

In a frequency range up to 7.5 GHz on rectangular aperture amplitudes are higher, than the ones on rounded aperture. For high frequencies spectra almost coincide. Average power measurement in the range (0.03…7.5) GHz in equal experimental conditions gives us the value 10 mW for rectangular aperture and 6 mW for rounded aperture.

In equal experimental conditions spectra values on ordinary and modified apertures were measured (Fig. 6, 7). When comparing spectra one can say that to increase high frequency constituents of transition radiation spectrum one has to drill small apertures in the conductive screen with large central aperture (ordinary aperture). Thus using different aperture geometries we can control transition radiation spectra.

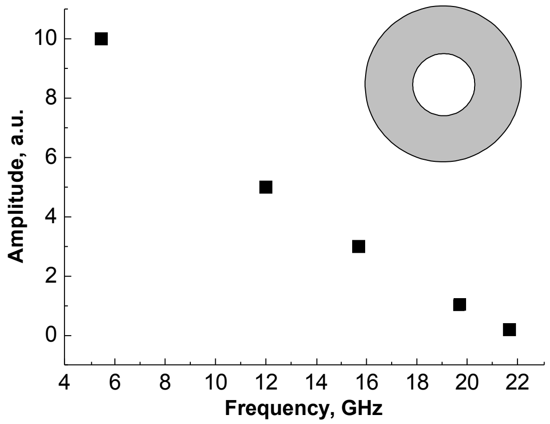

Fig. 6. Radiation spectrum for circular diaphragm with aperture

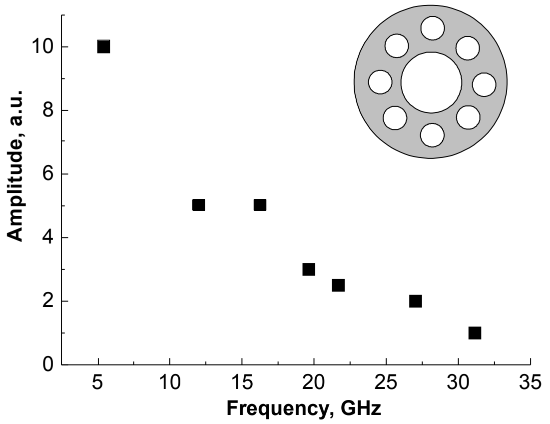

Fig.7. Radiation spectrum for modified diaphragm

When studying electron bunches passage through modified apertures we succeed only at experimental measuring of transition radiation spectrum envelope.

3. CONCLUSIONS

In a two-electron beam system a quasi-stationary non-linear wave was produced in constant magnetic field with a large number of particles captured, if its amplitude exceeded the capture amplitude. Our research tends to show that by using this wave one can form non-relativistic electron bunches the potential of which over time is a narrow pulse (100 ps). When passing through diaphragms made of different materials with apertures of various geometries, the electron bunches generate electromagnetic radiation. Thus, we demonstrated the possibility to create the short (0.1 ns) electromagnetic pulses. The characteristics of the EMPs (the intensity and pattern of the radiation, spectral composition, etc.) can be controlled by using diaphragms that may have different configurations and be made of different materials.

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ПЕРЕХОДНОЕ ИЗЛУЧЕНИЕ, ГЕНЕРИРУЕМОЕ НЕРЕЛЯТИВИСТСКИМИ ЭЛЕКТРОННЫМИ СГУСТКАМИ

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Рассматривается возможность генерации коротких электронных сгустков протяженностью от 50 до 100 пс волнами Бернштейна-Грина-Крускала (БГК) и формирования электромагнитных импульсов (ЭМИ) с управляемыми характеристиками на диафрагмах разных геометрий. Эксперименты продемонстрировали, что БГК-волны могут использоваться для формирования коротких ЭМИ с управляемыми характеристиками.

ПЕРЕХІДНЕ ВИПРОМІНЮВАННЯ, ЩО ГЕНЕРУЄТЬСЯ НЕРЕЛЯТИВІСТСЬКИМИ ЕЛЕКТРОННИМИ ЗГУСТКАМИ

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Розглядається можливість генерації коротких електронних згустків тривалістю від 50 до 100 пс хвилями Бернштейна-Гріна-Крускала (БГК) і формування електромагнітних імпульсів (ЕМІ) з керованими характеристиками на діафрагмах різної геометрії. Експерименти продемонстрували, що БГК-хвилі можуть бути використані для формування коротких електронних згустків з керованими характеристиками.