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DYNAMICS OF THE ELECTRON BEAM GENERATED BY THE MAGNETRON GUN WITH DIFFERENT CONFIGURATIONS OF THE MAGNETIC FIELD IN THE TRANSPORTATION CHANNEL

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The dynamics of the dimensions of the electron beam generated by the magnetron gun in the particle transport channel and the efficiency of focusing the tubular electron beam in the gradient magnetic field are investigated. The experiments were carried out with magnetron guns with secondary-emission cathodes (cathode diameters 36 and 16 mm, anodes diameters 78 and 36 mm) at cathode voltage of 20...80 kV. Magnetic fields were created both by the solenoid and jointly by the solenoid and the permanent magnet. The dependence of the radial distribution of the beam on metal targets on the amplitude and gradient of the magnetic field along the axis of the system is investigated. The possibility of controlling the beam diameter by varying the magnetic field is shown. The imprints of collimated beams were obtained experimentally on targets located at selected distances. The obtained experimental data agree with the results of numerical simulation. It is shown that with an increase in the amplitude of the gradient magnetic field, the effect of radial focusing of the beam is more pronounced.

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INTRODUCTION

The study of electron beams of various configurations and intensities is associated with their use in high-voltage pulsed microwave electronics, accelerator technology, etc. [1, 2]. At the same time, the range of problems for the solution of which electron beams are used is constantly expanding. Irradiation with electron beams with specified parameters makes it possible to regulate the structural-phase state in the surface layers and change the structural capabilities of materials [3, 4]. In practice, beam technologies for material processing are developed and introduced into industrial production. To solve these problems, accelerators of intense electron beams with electron energies of 100...400 keV are widely used [1, 3].

A linear electron accelerator for irradiating metal targets has been created at the NSC KIPT [5]. One of the main elements of the accelerator is the magnetron gun with cold metal cathodes, which operate in the secondary emission mode, in crossed electron and magnetic fields. The secondary emission mechanism of beam generation in such the gun, due to its weakly destructive effect on the cathode material, preserves the emission properties of the electron source for long time (according to estimates up to 100000 hours). Irradiation of various metal targets was carried out [4] and the possibility of irradiating the inner cylindrical surface using a radial electron beam was studied [6].

In his paper presents the results of studying the dynamics of the electron beam in the transport channel for various configurations of the magnetic field and the efficiency of focusing the tubular flow using the gradient magnetic field.

EXPERIMENTAL RESULTS

Experiments on the formation of an electron beam were carried out on a setup, the block diagram of which is shown in Fig. 1.

Experiments on electron beam transportation were carried out with the magnetron gun with the secondary emission cathode (cathode diameter – 36 mm, anode – 78 mm) at different distances from the gun anode cut and for different configurations of the solenoid magnetic field B_z in the electron beam transport channel. The research results were recorded on metal targets at distance of 15...200 mm from the gun anode cut, which made it possible to interpret the dynamics of the electron flow.

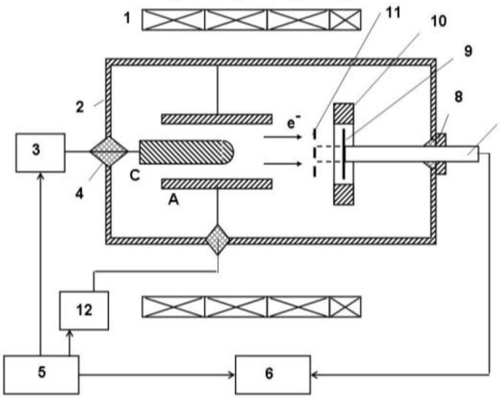

Fig. 1. Block diagram of the experimental setup.
1 – sections-solenoid (I, II, III, IV); 2 – vacuum volume; 3 – high-voltage pulse generator; 4 – insulator; 5 – synchronization unit; 6 – measuring system; 7 – centering rod; 8 – gain; 9 – Faraday cylinder; 10 – ring magnet; 11 – metal target; 12 – generator; A – anode; C – cathode

In Fig. 2 shows the distributions of the magnetic field along the axis of the magnetron gun and the beam transport channel, which were used in the research.

In Fig. 3 shows 3 typical imprints of the electron beam (energy 55 keV) on targets when it moves in the uniform, increasing and decreasing magnetic fields.

The print shown in Fig. 3,a was obtained in the uniform magnetic field (see Fig. 2, curve 3) at distance of 15 mm from the gun edge. Its outer beam diameter was D ~ 40 mm.

In the increasing magnetic field (see Fig. 2, curve 4) at distance of 70 mm from the gun edge, the beam diameter decreased to 36 mm (see Fig. 3,b, imprint 1), and in the decreasing magnetic field (see Fig. 2, curve 2) the beam diameter increased up to 49 mm (see Fig. 3,b, imprint 2).

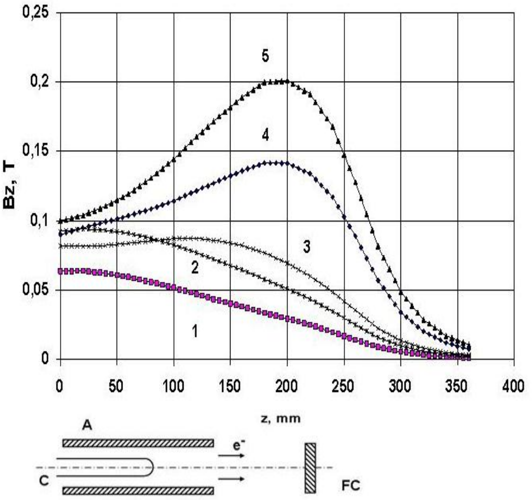

Fig. 2. Distributions of magnetic fields (curves 1-5) along the axis of the magnetron gun and the beam transport channel);
A – anode; C – cathode; FC – Faraday cylinder

In decreasing configurations of the magnetic field (see Fig. 2, curves 2 and 5) at the distance of 180 mm from the gun edge, the beam diameter was $D \sim 80$ mm and $D \sim 54$ mm (see Fig. 3,c).

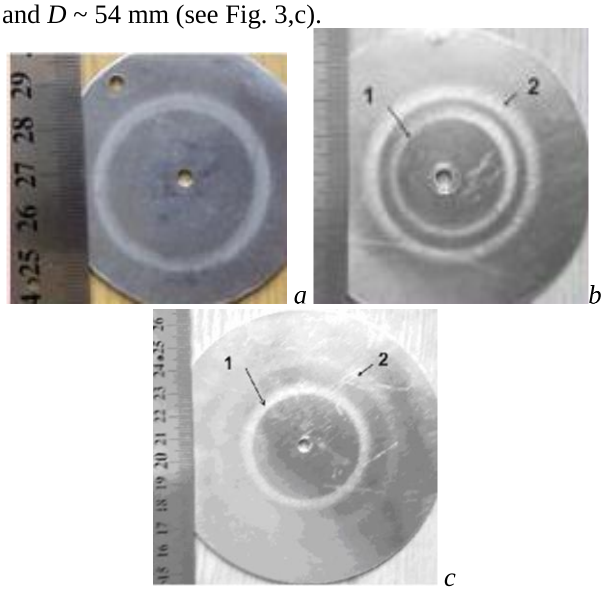

Fig. 3. Target beam prints:
a) is the outer diameter of the beam D ~ 40 mm, B=0.081 T (Fig. 2, curve 3), z=150 mm;
b) 1 – outer diameter of the beam D ~ 36 mm, B=0.146 T (Fig. 2, curve 4); 2 – outer diameter of the beam D ~ 51 mm, B=0.049 T (Fig. 2, curve 2), z=205 mm; c) 1 – outer diameter of the beam D ~54 mm, B=0.5 T (Fig. 2, curve 5; 2 – outer diameter of the beam D ~ 80 mm, B=0.009 T (Fig. 2, curve 1), z=310 mm

The dependence of the transverse dimensions of the electron beam at different distances from the cut of the magnetron gun during the transportation of the electron beam in the magnetic field (Fig. 4), which was created jointly by a solenoid with the permanent magnet, was studied.

From the prints in Fig. 3 it can be seen that for the used three configurations of the magnetic field, the beams in the cross section have the form of concentric rings with the uniform distribution of particles. From the experimental data (Fig. 5), one can see the dynamics of the radial dimensions of the electron beam when it moves in the transport channel.

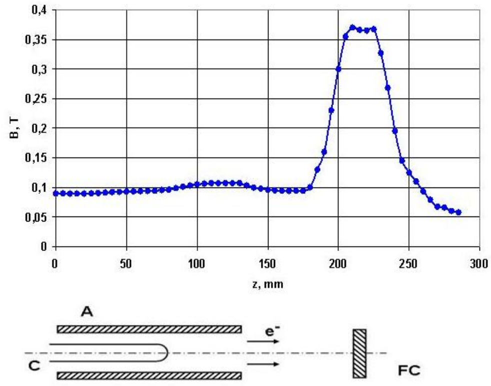

Fig. 4. Distribution of the magnetic field along the magnetron gun and the beam transport channel when using the permanent magnet together with the solenoid with the permanent magnet;
A – anode, C – cathode, FC – Faraday cylinder

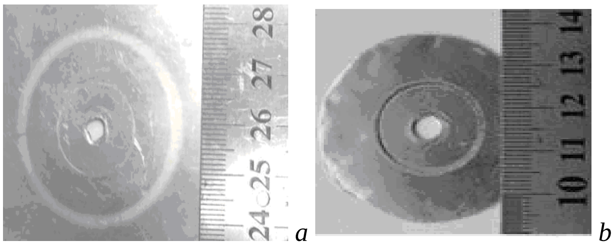

Fig. 5. Imprints of beams on targets:
a) B=0.10 T (homogeneous magnetic field), z=150 mm, outer beam diameter D=39 mm;
b) B=0.37 T (increasing magnetic field), z=205 mm, outer diameter of the beam D=22 mm

As can be seen from the print of Fig. 5,a, in the uniform magnetic field (z=150 mm), the magnetron gun forms the electron beam with an outer diameter of D = 39 mm. During the motion of the electron flux in the increasing magnetic field with the gradient of 0.1 T/cm and amplitude of 0.37 T at distance of 205 mm, there is a marked decrease in the beam diameter to D = 22 mm (see Fig. 5,b), which is determined by focusing the electron flux.

Thus, it was found that when the electron beam is transported in magnetic fields with higher amplitude, the outer diameter and the thickness of the beam wall decrease.

In Fig. 6,a,b shows the dependences of the transverse dimensions of the beam on the amplitude and configuration of the magnetic field. Experimental data (see Fig. 6,a) were obtained when the targets were located at different distances of 150...315 mm. Fig. 6,b were obtained when the target was located at the distance of 205 mm; and the configuration of the magnetic field changed. It is seen that the outer diameter of the beam, depending on the amplitude of the magnetic field, coincides in the first and second cases.

Experiments were carried out to measure the radial dimensions of an electron beam at energy of 30...35 keV at the output of the magnetron gun of different geometry (cathode diameter 16 mm and anode 36 mm). These experiments were carried out at different distances from the gun cut with different configurations of the solenoid magnetic field B_z, which are shown in Fig. 7.

The dependence of the transverse dimensions of electron beams on the configuration of the solenoid magnetic field B_z at different distances from the cut of the magnetron gun is studied. In Fig. 8 shows the obtained imprints of the beams at distances of 150, 205 and 315 mm with uniform, increasing and decreasing magnetic field.

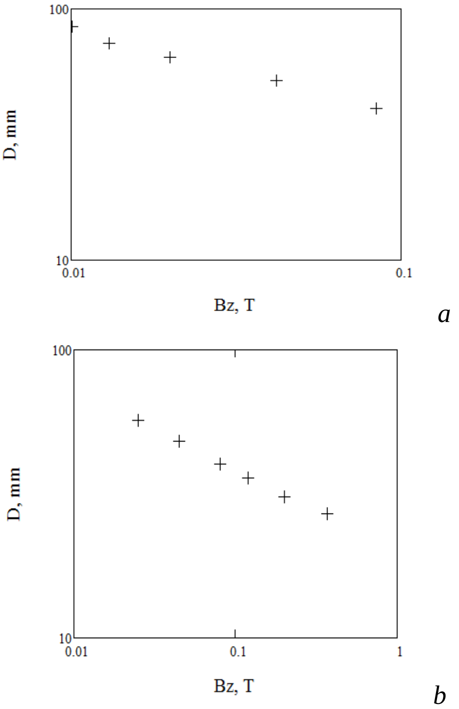

Fig. 6. The dependence of the diameter of the electron beam on the amplitude of the magnetic field at different distances in the transport channel (a) and on the configuration of the field (b) at 205 mm (logarithmic scale)

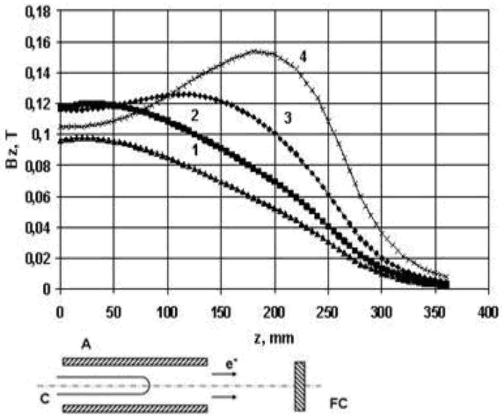

Fig. 7. Distribution of magnetic fields (curves 1–4) along the axis of the magnetron gun and the beam transport channel, placement of gun elements; A – anode; C – cathode; FC – Faraday cylinder (target)

In Fig. 8,a shows the imprint of the beam in homogeneous magnetic field (see Fig. 7, curve 3) at distance z=150 mm, the outer diameter of which is D=20 mm. When the electron flux moves in the increasing magnetic field (see Fig. 7, curve 4) at distance of z=205 mm, its diameter decreased to 17 mm (see Fig. 8,b), and in the descending magnetic field (see Fig. 7, curve 2) at distance of z=315 mm increased to 32 mm (see Fig. 8,c).

From the experimental data of Fig. 8, it can be seen that for the three configurations of the magnetic field used, the beams in cross section have the form of concentric rings with the uniform distribution of particle density, with different inner and outer diameters. It follows from the above studies that when the beam is transported in magnetic fields with the smaller amplitude, both the outer and inner diameters increase.

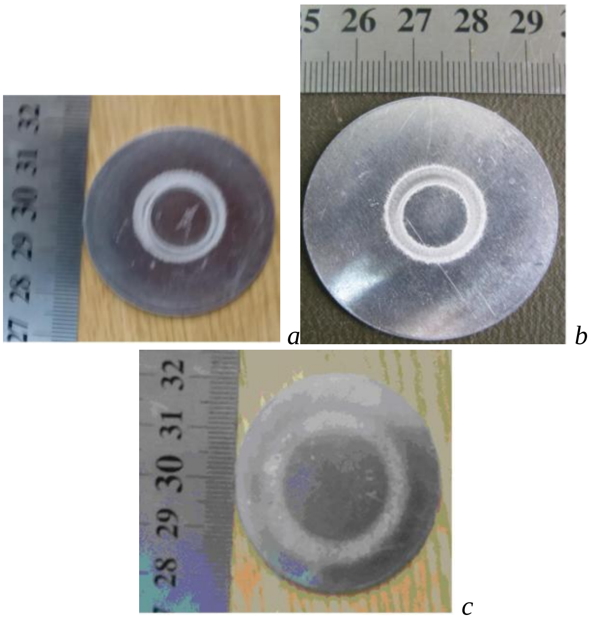

Fig. 8. Beam prints on targets at different configurations of the solenoid B_z magnetic field: a) is homogeneous magnetic field, outer diameter of the beam D=20 mm, z=150 mm, B_z=0.11 T; b) is increasing magnetic field with a gradient of 0.0154 T/cm, outer diameter D=17 mm, B_z=0.15 T, z=205 mm; c) is a decreasing magnetic field with a gradient of 0.0062 T/cm, the outer diameter of the beam D=32 mm, B_z=0.0240 T, z=315 mm

One or two permanent magnets were used to focus the electron beam, which made it possible to obtain the amplitude of the increasing magnetic field in the beam transport channel of 0.32...0.42 T.

During the movement of the electron beam in the increasing magnetic field with gradient of 0.08 T/cm and the amplitude of 0.32 T (Fig. 9,a, curve 2) at distance of 205 mm, there is the noticeable decrease in the beam diameter to 10.5 mm (Fig. 9,b), which is determined by the focusing of the electron beam.

The print shown in Fig. 9,d, was obtained under the same conditions as the imprint 9c, but with the larger amplitude of the growing magnetic field of 0.42 T with gradient of 0.12 T/cm (Fig. 9,a, curve 1). Fig. 9,d is shown on the enlarged scale.

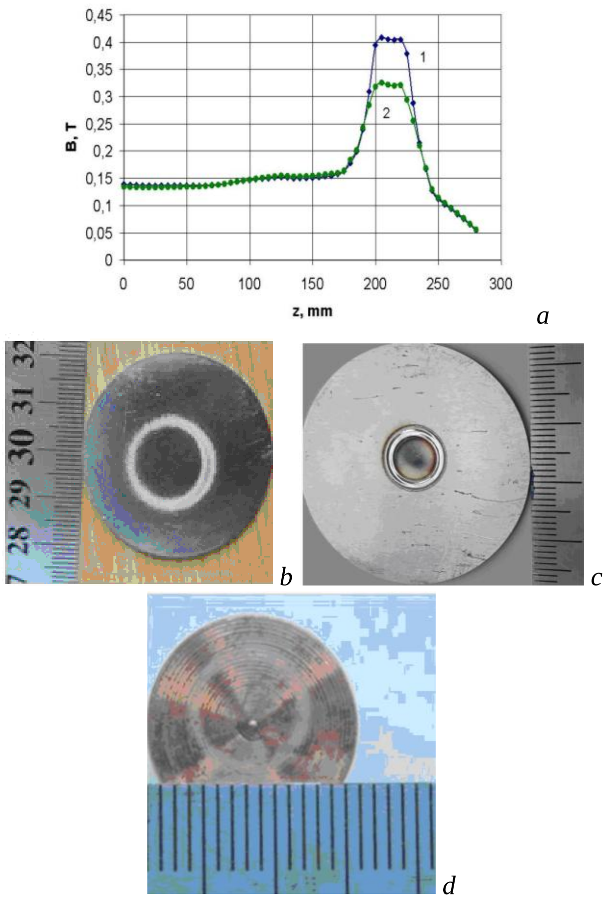

Fig. 9. Magnetic fields and prints on targets:
a) is the distribution of the magnetic field along the axis of the magnetron gun and the beam transport channel;
b) is the imprint of the beam on the target, the outer diameter of the beam D=20 mm, B=0.125 T, z=150 mm; c) is the outer diameter of the beam D=10.5 mm, B=0.25 T (curve 2), z=205 mm;
d) is the outer diameter of the beam D=9 mm, increasing magnetic field, gradient 0.13 T/cm, B=0.43 T (curve 1), z=205 mm

As can be seen from the above prints, for the used magnetic field configurations, the cross sections of the beams have the form of concentric rings with the uniform distribution of particle density with different outer and inner diameters.

It follows from these prints that the fairly good homogeneity of the azimuthally distribution of the electron beam is obtained. These data show that by adjusting the amplitude of the magnetic field, it is possible to control the radial dimensions of the beam along the transport channel.

In Fig. 10,a,b show the dependence of the outer diameter of the beam on the amplitude and configuration of the magnetic field. Experimental data (Fig. 10,a) were obtained in the case when the targets were located at different distances of 150...315 mm, at which the corresponding amplitude of the magnetic field B_z was. The data (see Fig. 10,b) were obtained when the target was located at fixed distance of 205 mm; and the configuration of the magnetic field changed together with the amplitude of the magnetic field B_z.

It can be seen that the outer diameter of the beam, depending on the amplitude of the magnetic field, coincides for the first and second cases of their determination. It can be seen from the figure that as the amplitude of the magnetic field decreases, the diameter of the electron beam increases.

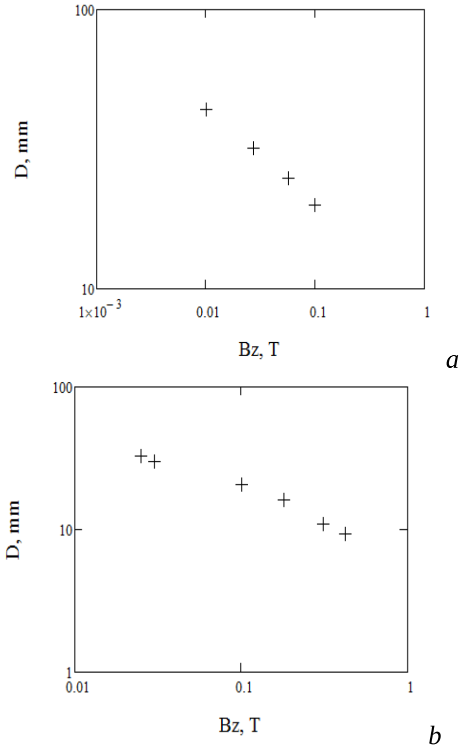

Fig. 10. The dependence of the diameter of the electron beam on the amplitude of the magnetic field at different distances in the transport channel (a) and on the configuration of the field (b) at 205 mm (logarithmic scale)

From Fig. 10 it follows that with increasing amplitude of the magnetic field there is the significant decrease in the transverse dimensions of the beam. Thus, with increasing amplitude from 0.024 to 0.32 T, the beam size decreased from 32 to 9 mm.

CONCLUSIONS

From the conducted researches it follows that the flow of electrons at the output of the magnetron gun feels the rearrangement of the radial distribution, which is formed by the type of magnetic field and its gradient in the transport channel of the beam. The possibility of adjusting the beam diameter by varying the magnetic field is shown. It is shown that the obtained experimental results coincide with the simulation results. It is shown that with an increase in the maximum amplitude or gradient of the field, the effect of the radial focusing of the beam is more pronounced. These experimental results indicate the possibility of focusing the electron beam, can be used when irradiating cylindrical samples, which are located in the region of the increasing magnetic field.

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ДИНАМИКА ЭЛЕКТРОННОГО ПУЧКА, ГЕНЕРИРОВАННОГО МАГНЕТРОННОЙ ПУШКОЙ, ПРИ РАЗЛИЧНЫХ КОНФИГУРАЦИЯХ МАГНИТНОГО ПОЛЯ В КАНАЛЕ ТРАНСПОРТИРОВКИ

А.С. Мазманишвили, Н.Г. Решетняк, В.П. Ромасько, И.А. Чертищев

Исследована динамика размеров электронного пучка, генерируемого магнетронной пушкой, в канале транспортировки частиц и эффективность фокусировки трубчатого электронного потока в градиентном магнитном поле. Эксперименты проводились с магнетронными пушками с вторично-эмиссионными катодами (диаметр катодов 36 и 16 мм, диаметр анодов 78 и 36 мм) при напряжении на катоде 20…80 кВ. Магнитные поля создавались как соленоидом, так и совместно соленоидом и постоянным магнитом. Исследована зависимость радиального распределения пучка на металлических мишенях от амплитуды и градиента магнитного поля вдоль оси системы. Показана возможность регулирования диаметра пучка путем вариации магнитного поля. Экспериментально получены отпечатки коллимированных пучков на мишенях, расположенных на выбранных расстояниях. Полученные экспериментальные данные согласуются с результатами численного моделирования. Показано, что с увеличением амплитуды градиентного магнитного поля эффект радиального фокусирования пучка больше выражен.

ДИНАМІКА ЕЛЕКТРОННОГО ПУЧКА, ЩО ГЕНЕРУЄТЬСЯ МАГНЕТРОННОЮ ГАРМАТОЮ, ПРИ РІЗНИХ КОНФІГУРАЦІЯХ МАГНІТНОГО ПОЛЯ В КАНАЛІ ТРАНСПОРТУВАННЯ

О.С. Мазманішвілі, М.Г. Решетняк, В.П. Ромасько, І.А. Чертіщев

Досліджено динаміку електронного пучка, що генерується магнетронною гарматою, в каналі транспортування частинок і ефективність фокусування трубчастого електронного потоку в градієнтному магнітному полі. Експерименти проводилися з магнетронними гарматами зі вторинно-емісійними катодами (діаметри катодів 36 і 16 мм, анодів 78 і 36 мм) при напрузі на катоді 20...80 кВ. Магнітні поля створювалися як соленоїдом, так і спільно соленоїдом і постійним магнітом. Досліджено залежність радіального розподілу пучка на металевих мішенях від амплітуди і градієнта магнітного поля уздовж осі системи. Показана можливість регулювання діаметра пучка шляхом варіації розподілу магнітного поля. Отримано відбитки колімованих пучків на мішенях, розташованих на обраних відстанях. Встановлено, що зі збільшенням амплітуди магнітного поля ефект радіального фокусування пучка є більше виражений.