RESEARCH OF HIGH-CURRENT ELECTRON BEAM TRANSPORT AND CONVERGENCE ONTO A COMMON BREMSSTRAHLUNG TARGET

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PACS numbers: 29.27.Eg

1 INTRODUCTION

One of the approaches to creation of new generation super-power bremsstrahlung sources is based on construction of multi-modular systems, whose every module is to generate pulse power beams of 10^{12}-10^{13} W. To realize this concept the Defense Threat Reduction Agency, USA, finances the design of the DECADE system, which in its final version will consist of 16 modules. Each of the DECADE modules is designed to transfer a beam with energy of about 1 kJ and pulse duration of ≈ 10^{-7}s to the bremsstrahlung radiation converter. To increase the radiation source intensity the electron density on the target should be increased, what may be achieved by combining the beams from the modules into a single beam, as well as by compressing the combined beam cross-section. Realization of such a scheme assumes some space available for the beams to be transported to the point of their overlapping and for the bremsstrahlung target to be installed. To transport the beams (with allowance for their currents exceeding considerably the Alfven current (>10^6A)) efficiently, virtually full compensation of the beams' self-fields is required. To solve this problem a lot of physical researches are to be carried out.

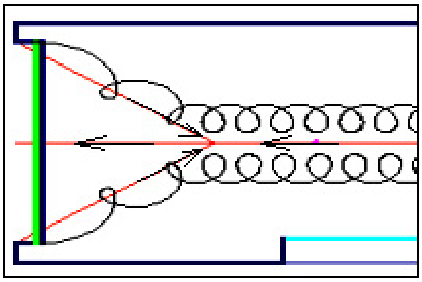
Kharkiv National University in close collaboration with DTRA and Naval Research Laboratory, USA, studies the beam transport using the method of electron gradient drifting in an azimuthal magnetic field created by the linear conductor current. In this beam transport method the magnetic fields are compensated by plasma which is generated when the beam is injected into some rarefied gas the transport channel is filled with [1].

2 TRANSVERSAL COMPRESSION OF A BEAM

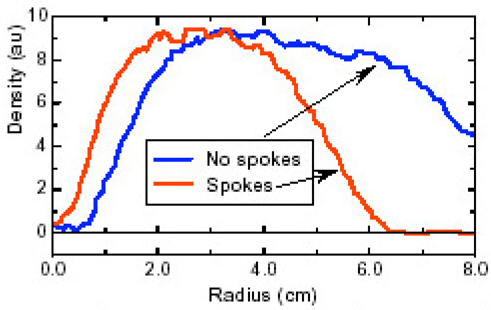
For effective capture of electrons, leaving the diode, by an azimuthal magnetic field, the beam should have tubular form and small wall thickness. It requires creation of special diodes capable to generate annular electron beams of terawatt power at the output windows.

The outer beam diameter may be reduced by developing drop of the azimuthal magnetic field along the drift chamber axis.

As the computer simulation has shown the negative-going gradient of the magnetic field along the drift the chamber axis is more expedient to be set just behind the diode output window, with the transition area between high and low magnetic field zones having the shape of a cone, with its vertex facing inward the drift chamber along the beam trajectory, and the cone base not going beyond the beam inner diameter, see Fig. 1 a).



a)



b)

Fig. 1. The effect of the magnetic field gradient along the drift chamber axis: (a) Example of motion of the electrons injected into the azimuthal magnetic field with a negative-going gradient along the axis; (b) Experimentally observed radial beam profiles in case the beams are injected into an uniform (along their motion axis) azimuthal magnetic field (the beam was injected at the radius of 7.0 cm), as well as in case of the spoke generated gradient field.

In this case, apart from the beam compression in diameter, range extension of the drift captured electron energies (in the direction of low energies) is achieved as well, what improves the efficiency of energy transfer to the target. Practically achievable, like that, factors of the beam diameters compression are 1.4 - 1.5 that corresponds to the beam density increase by a factor of about 2 (see. Fig. 1 b).

3 BEAMS CONVERGENCE

The technology of consistent propagation of a megaampere beam along a linear current carrying conductor is not completely studied for today because of complex dynamics of physical processes occurring within the beam-plasma dynamic system placed in the applied magnetic field. The processes of the beam self-field compensation need a special study. To achieve high level of the beam charge compensation by plasma generally does not call any problems, while provision of the beam current compensation requires some supplementary theoretical and experimental researches to be conducted. Within the electron energy range of 1.0-2.0 MeV the Alfven currents vary from 48 up to 80 kA. To provide the effective transport the residual uncompensated currents are to be much lower than the Alfven current is. This implies that for a megaampere beam the under-compensation of its current should not exceed 1 - 2 %. This requirement becomes stronger in case of several beams convergence, as in the region of their convergence the beam residual magnetic fields are combined, and the total field structure becomes weakly predicted.

Overlapping of several beams propagating by gradient drift is feasible in case they are biased from the guide conductor axis and are made to drift aside. Such propagation conditions may be provided by bending the guiding conductor. In this case, the electrons are ejected over the radius curvature to the lower field zone due to azimuthal heterogeneity of the magnetic field. Should we create the conditions for bringing the biased beams closer, like this, we may obtain a combined beam with cross-section not much exceeding that of a single beam. Fig. 2 illustrates such a scheme of the beam convergence.

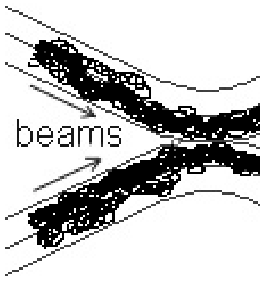


Fig. 2. Scheme of beam convergence with guiding conductors bending.

3 EXPERIMENTAL ARRANGEMENT AND PRELIMINERY RESULTS

a) Beam Generator. The experiments were performed at Kharkiv National University on «Nadia» electron accelerator, which provides voltage pulse of up to 1 MV with a 7 Ω load, the radix pulse width – 90 ns.

b) One-Beam Experiment was carried out to check the numerical calculation results. For this purpose a double diode generating three beams on 140-mm diameter with total current of up to 100 kA was used. At the distance of 200 mm from the diode output windows the beam took an uniform structure over azimuth and was compressed to 100 mm in diameter due to the negative-going gradient of the azimuthal magnetic field (see Fig.1 b). On passing 45 cm the beam turned away from the region of injection into the drift chamber. The experiment scheme is shown in Fig. 3.

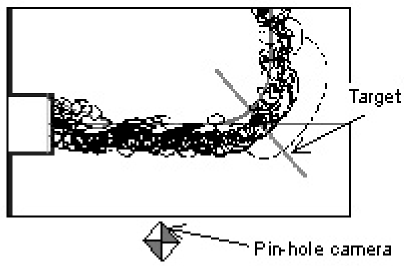
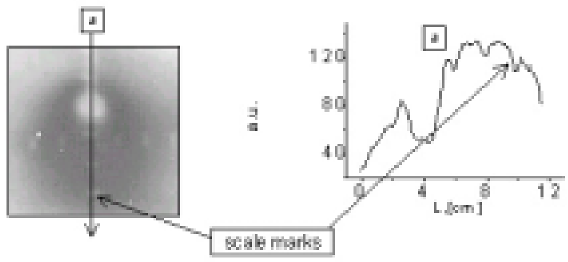


Fig. 3. Scheme of one-beam experiment.

To determine the beam shape and position in the region of the conductor curvature, a thin tantalum target was placed in this region. The beam X-ray trace on this target was registered by a pinhole camera.

The beams positions relative to the guide conductor in the place of its curvature are presented as an X-ray image of *Ta* target in Fig. 4 (a). Distribution density along the indicated direction is also presented in Fig. 4(b).



a) b)

Fig. 4.

As a whole, its behavior agreed with the computer simulation forecasts.

The beam bias relative to the guide conductor depends sufficiently on the particles angular spread: the greater the spread is the larger portion of electron drifts around the conductor without biasing to one side.

c) Two-Beam Convergence Experiment

The geometrical dimensions of the experimental device were adjusted to satisfy operation conditions of the four-module Decade facility.

The shape of the injected beams was specified by the diode output windows (10×25 mm). The beams were injected at a distance of 2 cm from the outside of the conductors producing an azimuthal magnetic field. The distance between the beams in the injection region was 34 cm, the mean angle of the beam injection – 22° outwards the transport channel axis. The two-beams transport channels had square cross-section 100×100 mm, the length of transport to the point of the beams convergence – 40 cm, angle between the channels axis – 44°.

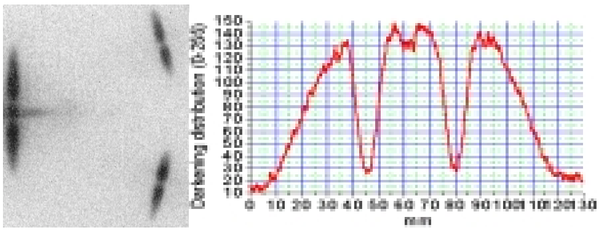
The guiding magnetic field was generated by the current pulse in the conductors, 40 kA in each.

To make the X-ray images of the drifting electron beams the transport channels were filled with Xenon at about 110 Torr pressure.

To make more accurate measurement of the beam cross-section dimensions the transport channels were filled with air at 30 Torr pressure. The beam was visualized in X-rays with the help of three 13-μm *Ta* strips,

(see Fig. 5.)

According to the chosen conditions of the beam injection and transport its diameter on the regular section of transport was 65-70 mm (determined at the half-height of the bremsstrahlung radiation intensity of its trace in the underground gas and on Tantalum foil placed across the beam).



a) b)

Fig. 5. Beam traces on thin Ta strips made in X-rays: (a) strips image made by a pin-hole camera; (b) digital image processing in the place of the beams convergence.

In Fig. 5 an example of the combined beam traces and numerical processing results of the experimental data are presented. Here, two quite different versions of the beams overlapping were studied:

1. When the magnetic fields of the two conductors are not combined, see Fig. 6. In this case the space between the guiding conductors was partitioned by a plate with welded copper wires so that the reverse current flow prevented combining of the azimuthal magnetic fields.
2. The conducting plate between the guiding conductors was moved away. In this case the magnetic field between the conductors decreased strongly and the nature of the particles movement changed: In the space between the conductors the electrons suffer some betatron oscillations, and in case they emerge outside, where magnetic fields from the two conductors are combined, the electrons move at a farther distance from the conductor. The image presented in Fig. 7 corresponds to this case.

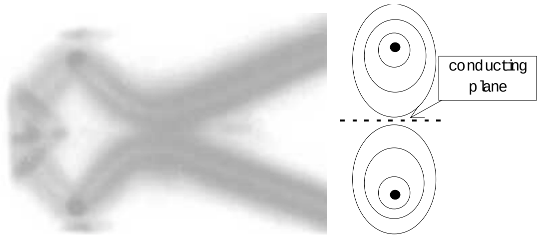


Fig. 6. Two beams convergence with the guiding magnetic fields separated over the whole transport length.

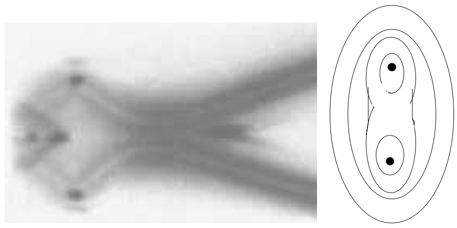


Fig. 7. Variant of the beam convergence with combining the fields from the guiding conductors.

The size of the combined beam in the first case made approximately 1.5 of a single beam diameter. In the second case the beam had more blown up boundaries and increased electron loss on the transport system walls in the region of mutual reduction of the guiding magnetic fields.

4 CONCLUSIONS

Grad-B drift method of beam transport has been shown to be capable of converging power from modular systems.

Decrease of the converged beam size can be achieved by increasing the portion of electrons passing into the space between the conductors. For this purpose the initial angular spread of electrons during their injection into the guide field should be decreased.

REFERENCES

1. James R. Lee, Robert C. Backstrom, John. A. Halbleib, et al. // *J. Appl. Phys.* 1984. v. 56, # 11, p. 3175-3181.

This work is supported by the Defense Threat Reduction Agency, USA, through the Science and Technology Center in Ukraine, Project # 2093.