TRANSPORTATION CHANNEL WITH UNIFORM ELECTRON DISTRIBUTION FOR THE KHARKOV NEUTRON SOURCE BASED ON SUBCRITICAL ASSEMBLY DRIVEN BY LINEAR ACCELERATOR*

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Abstract

An electron beam transportation channel from a linear accelerator to the neutron target of NSC KIPT neutron source should provide uniform distribution of electrons on target surface to prevent overheating of the target and reduce thermal stress. In the presented channel the method of uniform beam distribution formation with linear focusing elements (dipole and quadrupole magnets) and nonlinear focusing elements (octupole magnets) were used. Linear focusing elements were used to provide particle transportation through the channel without losses and to form required beam sizes at the target. Nonlinear focusing elements were used to modulate transverse velocity of peripheral particles. In such a way we can provide uniform particle density distribution at the target. As a result, the uniform electron beam of rectangular shape can be formed at the target.

In the report the main principles of transportation channel design and results of calculations for NSC KIPT neutron source based on subcritical assembly driven by electron accelerator are presented. Lattice and parameters of focusing elements are presented. Calculation results show that the proposed transportation channel lattice can provide uniform beam of rectangular shape with sizes 66x66 mm.

INTRODUCTION

For a neutron source on the base of subcritical assembly it is very important to produce uniform electron distribution at the target. Such kind of particle distribution provides homogeneous thermal stress on surface of the target and uniform distribution of the generated neutron flux. Recently to uniform an initial particle beam distribution at the target a method of nonlinear focusing with use of multipole magnets has been used [1-3]. The method allows to change shape of final particle distribution depending on the initial shape of particle density distribution. Devices, that form shape and sizes of final beam distribution, can be installed far away from the target. It is important for the experiments with hard radiation conditions.

In the paper the results of transportation channel design for NSC KIPT neutron source based on subcritical assembly driven by linear electron accelerator are presented. It is shown, that method of nonlinear focusing allows to produce pseudo-uniform density distribution of the electron beam at the target. Two octupole lenses were used to form the final shape of the distribution at the target.

In linear approximation calculations were carried out with TRANSPORT code [4]. Nonlinear field effects were taken into account in calculations with DECA code [5]. Calculations were carried out with Gaussian distribution of the initial electron beam as well as with beam distribution produced by simulation of RF gun with PARMELA code [6].

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LAYOUT OF THE TRANSPORTATION CHANNEL

The electron beam transportation channel from the electron linear accelerator to the target should meet the following requirements:

- transportation of the high current electron beam from the driving linear accelerator to the subcritical assembly without particle losses;
- electron beam size at the subcritical assembly should be of about ±33 mm in both transversal directions with small value of the beam divergence;
- electron beam density distribution at the target should be uniform.

The following parameters of the driving electron beam were considered at the transportation channel design:

- electron beam energy - 150 MeV;
- geometrical emittance - 10^{-7} m rad;
- electron beam size at the entrance of the transportation channel are ± 10^{-3} m in both transversal directions.

The layout of the transportation channel is shown in Fig. 1. After accelerator electron beam is bended with bending angle 90° (two bending magnets, 45° bend in each magnet). The first magnet is aligned with 45° angle to the horizontal plane, the second magnet is aligned in the same plane. Next, the beam is turned on 22.5° angle with two 11.25° bending magnets in vertical plane and turns in horizontal position. In the last turn the reference trajectory of the beam is bended with angle 90° in vertical plane by two 45° bending magnets and is aimed to the target straight from vertical direction.

The design of the transportation channel was based on the following principles:

- to minimize particle losses of the driving electron beam along transportation channel each turn of the channel should be achromatic;
- beam focusing is made with 6 independent focusing sections, with separate functions (Fig. 1);
- sections 1, 3, 6 provide achromatic bend of the beam (Fig. 1);
- section 2 is objective with three lenses, that together with sections 1 and 3 allow to make practically parallel transportation of the driving beam to the horizontal part of the transportation channel;
- section 4 is nonlinear objective for transformation of initial Gaussian beam to uniform distribution at the target;
- section 5 provides obtaining of the required beam sizes at the target.

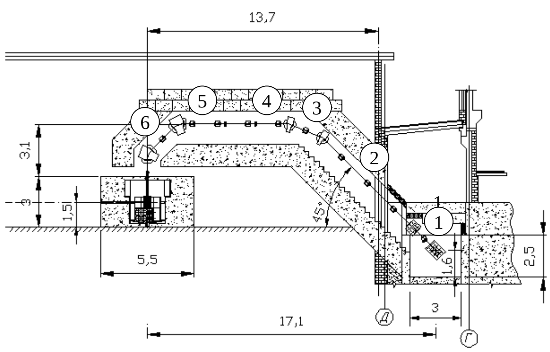


Figure 1. Layout of the transportation channel.

Optimization of transportation channel lattice has been carried out with TRANSPORT code [4]. Beam envelopes are shown in Fig. 2. As one can see in Fig. 2, the beam sizes at sections 1-3 are not bigger than 1 mm. Such focusing provides beam transportation to the section 4 without particle losses. In section 4 one realizes beam unfolding in one transversal direction and focusing in another direction and then, vice versa. Such procedure is needed for effective use of octupole lenses of nonlinear objective. Increasing of beam sizes in sections 5, 6 can be explained by the requirements to the beam sizes at the target. Aperture of the transportation channel at the sections 1-4 is ±20 mm and at section 5, 6 is ±70 mm. The total beam length is 27.542 m.

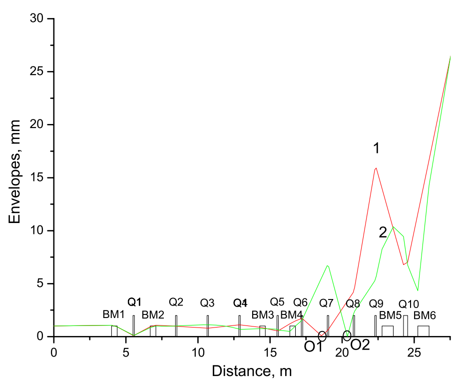


Figure 2. Beam envelopes in the transportation channel. BM1-BM6 – bending magnets, Q1-Q10 – quadrupole magnets, O1-O2 – octupole magnets.

NONLINEAR OPTICS OF THE TRANSPORTATION CHANNEL

The method of distribution function correction of particle density in a charged particle beam is based on changing of transversal velocity of charged particles with nonlinear magnetic field depending on transversal coordinates of a particle. Peripheral particle is much more affected by nonlinear magnetic field, while particles from the central part of the beam distribution practically have no effect of the field. As a result, peripheral particles from tails of beam distribution are shifted to the central part of beam distribution [1-3].

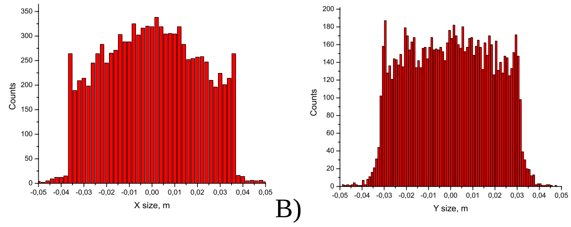
As it was shown in [3], in order to produce uniform distribution of the beam density in X and Y directions simultaneously it is necessary to use nonlinear objective with two quadrupole magnets for beam focusing and defocusing in X and Y directions, octupole magnets for redistribution of the particle density and set of quadrupole magnets to form beam sizes one needs.

In the transportation channel of the Kharkov neutron source two octupole magnets, that are set in place 1 and 2 (Fig. 2), are used. In the point 1 the octupole effects distribution function in horizontal direction. Octupole magnet in the point 2 transforms beam distribution in vertical direction. Optimization of octupole strength has been carried out with DeCA code [5]. Initially it was assumed that electron beam at the entrance of the transportation channel has Gaussian beam density distribution functions in both horizontal and vertical directions with the same RMS sizes (1 mm and 1 mrad).

In Fig. 3 (A, B) profiles of electron beam at the target formed with nonlinear objective are shown. In Fig. 4 the phase map of the beam at the target in the X-Y plane is depicted. One can see from the Fig. 3 that use of octupole magnets allows to realize pseudo-uniform distribution of particle density at the target. The shape of beam profile can be corrected with slight changing of octupole strengths. The final distribution width can be edited with changing of quadrupole magnets Q8 and Q9 strengths. The proposed lattice of the transportation channel does not provide total independence of vertical and horizontal oscillations. The effect of the octupole of the point 2 (Fig. 2) to the horizontal profile of the beam is quite visible. This is originated from not too big amplitude of betatron horizontal oscillations in the point 2.

As the next step of the transportation channel design the real electron beam distribution at the entrance of the channel should be taken into account. Beam distribution at the entrance of the transportation channel was simulated with PARMILA code [8]. In Fig. 5 (A, B) results of beam simulations profile at the entrance of the transportation channel are shown. The beam distribution is distorted Gaussian distribution with more dense presence of the particle in the center and tails of the distribution. Such type of particle distribution makes production of the uniform distribution at the target more difficult. Octupoles have strong effect on tail particles, that can lead to particle losses on the walls of the channel vacuum chamber. At the same time, particles from the center of the distribution are under weak effect of the nonlinear magnetic field and, therefore, the shape of the central part of the beam distribution is changed very slightly. In Fig. 5 (C, D) the shapes of the beam distribution at the target with the optimized strength of the octupoles are shown. With such beam distribution and chamber apertures, that were mentioned above, the particle losses due to nonlinear magnetic field are ~ 2.5 %.

As the next step, the simulation of the reference orbit displacement due to misalignments of the transportation channel alignment was carried out with DeCA code[7]. The following values of the alignment errors were taking into account: in directions X, Y, Z – 200 μm, rotation angles in planes XY, YZ, ZX – 200 mrad. In Fig. 6 the results of simulation of one random realization of the element alignments with RMS value of errors, that were mentioned above, are shown. In calculations the initial Gaussian distribution of the beam density was used.



A) B)

Figure 3. A, B are final distributions of beam particles at the target.

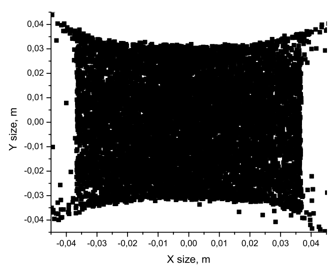
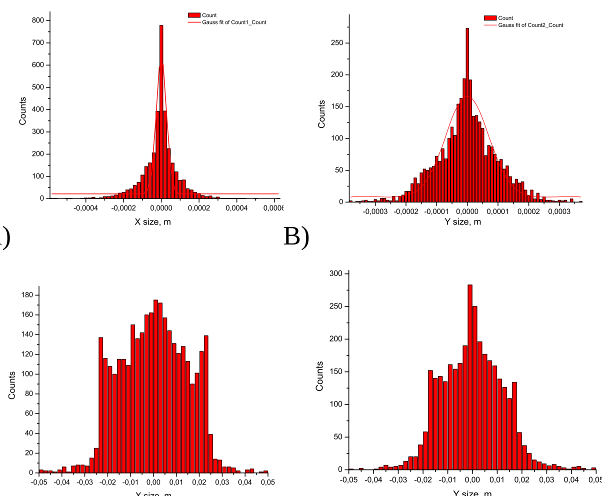


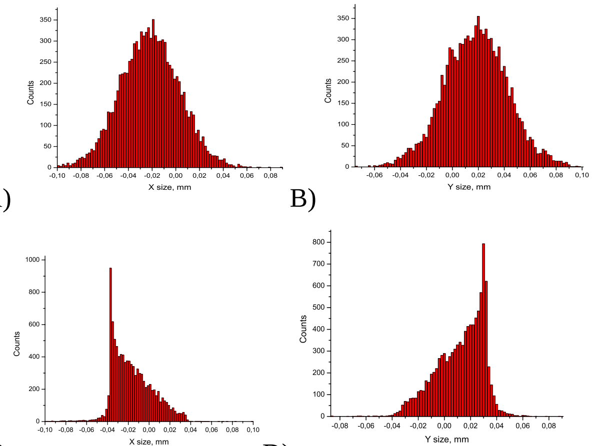
Figure 4. Distribution of the transversal coordinates of electrons at the target.



A) B) C) D)

Figure 5. Electron beam distributions: A, B – at the entrance of the channel simulated with PARMILA code, C, D – at the target with taking into account octupole effect.

As it can be seen from Fig. 6 (A, B), magnetic element alignment errors with octupoles, that were switched off, lead to the shift of the distribution center at the target with value of about ~ 0.02 m in both transversal directions. When octupoles were switched on, with strengths optimized for error-free case for uniform distribution production (Fig. 3,4), beam distributions at the target become axially-unshifted but their shapes are triangular. It can be explained by influence of sextupole magnetic field component, that effects beam particle traveling through an octupole with the shifted center. As it was shown in [3], effects of such type can be compensated with sextupole field, that can be combined to the octupole. To describe the effect in more details the further calculations should be done.



A) B) C) D)

Figure 6. Distribution, of beam particles at the target taking into account errors of element alignments: A, B – witout octupoles, C, D – with octupoles.

CONCLUSIONS

In the paper the possibility to produce pseudo uniform particle density distribution at the target of Kharkov neutron source based on the subcritical assembly driven by linear accelerator was shown. To produce such type of the beam distribution two octupole magnets were used with position where the beam is as plane as it is possible to suppress oscillation coupling caused with octupoles. Initially, calculations were carried out for Gaussian accelerator beam distribution. Calculations, that were carried out, taking into account beam distribution simulated with PARMILA code, showed effectiveness of the method. Calculations with taking into account magnetic element misalignments showed that uniform beam distribution at the target can be produced if the combined sextupole field includes in the octupoles to compensate errors effects.

REFERENCES

[1] P.F. Meads, “A Nonlinear Lens System to Smooth the Intensity Distribution of a Gaussian Beam”, IEEE Trans. Nucl. Sci. 30, p.2838-2840.

[2] Y. Batygin, “Beam intensity redistribution in a non-linear optics channel”, NIM, B79(1993), p.770-772.

[3] Y. Yuri et al. Uniformization of the Transverse Beam Profile by Means of Nonlinear Focusing Method, Phys. Rev. Special Topics, Accelerators and Beam, 10, 104001 (2007) 16 p.

[4] D. Carey et al. “Third-Order TRANSPORT with MAD Input a Computer Program for Designing Charged Particle Beam Transport Systems”, Fermilab-Pub-98/310, 1998.

[5] P. Gladkikh, M. Strelkov, A. Zelinsky, “The Application Package DeCA for Calculating Cyclic Accelerators”, PAC-93, May, 1993, Washington, USA, pp. 194-196.

[6] H. Takeda et al., ‘Recent Developments in the Accelerator Design Code PARMILA,” Proceedings of the 1998 Linear Accelerator Conference, Chicago, **IL,** August 23-28, 1998.