PROPOSALS FOR ELECTRON BEAM TRANSPORTATION CHANNEL TO PROVIDE HOMOGENEOUS BEAM DENSITY DISTRIBUTION AT A TARGET SURFACE*

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Abstract

NSC KIPT neutron source will use 64x64 mm rectangular tungsten or uranium target. To generate maximum neutron flux, prevent overheating of the target and reduce thermal stress one should provide homogeneous electron beam distribution at the target surface. In the facility transportation channel three different possibilities of electron beam density redistribution along the target surface can be realized. It can be the fast beam scanning with two dimensional scanning magnets; the method of uniform beam distribution formation with linear focusing elements (dipole and quadrupole magnets) and nonlinear focusing elements (octupole magnets), when final required rectangular beam shape with homogeneous beam density is formed at target; and combined method, when one forms the small rectangular beam with homogeneous beam density distribution and scan it over the target surface with scanning magnets. In the report the all tree methods are considered and discussed considering the layout of the NSC KIPT transportation channel. Calculation results show that the proposed transportation channel lattice can provide uniform beam of rectangular shape with sizes 64x64 mm without target overheating.

INTRODUCTION

In National Science Center "Kharkov Institute of Physics and Technology" (NSC KIPT, Kharkov, Ukraine) a neutron source based on the subcritical assembly driven by electron linear accelerator are under design and development [1]. Neutron source is a hybrid facility. The main facility components are an electron linear accelerator, a system for electron beam transportation from linear accelerator to the target, neutron production target, subcritical assembly, biological shield, neutron channels and auxiliary supporting systems. Photonuclear reactions, induced by hard electromagnetic radiation emerging at retarding of the beam of relativistic electrons in the target from heavy element, are used to generate primary neutrons. Two options of the target are under consideration: tungsten and natural uranium. Energy of electrons in driven beam is 100 MeV. It is expected that facility will provide neutron flux of about 2.4×10^{13} neutron/s. All activity is supported by Argon National Laboratory, Chicago, USA. 100 MeV/100 kW electron linear accelerator is under design and manufacture in IHEP, Beijing, China [2].

For generation of maximum neutron flux without overheating of the target and with minor thermal stress one should provide accurate beam transportation with homogeneous electron beam distribution at the target surface.
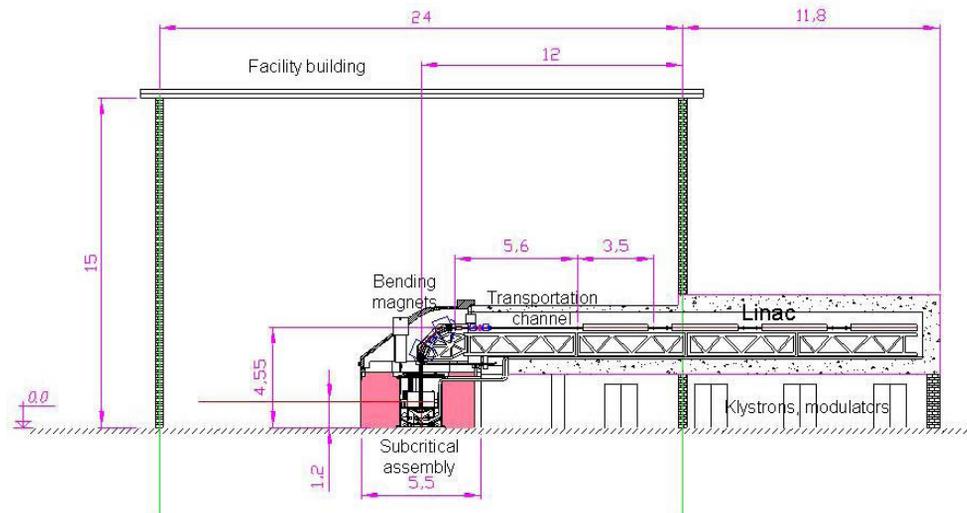

Figure 1: Layout of the NSC KIPT neutron sour ce on the base of subcritical assembly driven by linear electron accelerator.

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LAYOUT OF THE FACILITY AND TRANSPORTATIONCHANNEL

The layout of the facility is shown in Fig. 1. After long discussions it was decided to simplify the facility scheme and put linear accelerator to the second floor of the neutron source building. In such configuration transportation channel became much shorter and simpler compare with previous channel version. [3] but should meet the same 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 ±32 mm in both transversal directions with small value of the beam divergence;
- electron beam density distribution at the targetshould be uniform.

The sketch of the transport line is shown in Fig. 2. Two 45° vertical sector bending magnets of 0.51 m radius, B1 and B2 are used to bend the beam from the linac to the target. A quadrupole (Q11) is placed at the middle point of the arc to cancel the dispersion. A triplet (Q6, Q7 and Q8) and another two quadrupoles (Q9, Q10) are used to form the beam size on the target. Because of the uncertainty of the beam twiss parameters at the linac exit, the triplet is also used for the emittance measurement together with the profile monitor PR3 by the quadrupole scanning method. The distance between the last bending magnet B2 and the target is about 2.5 m.
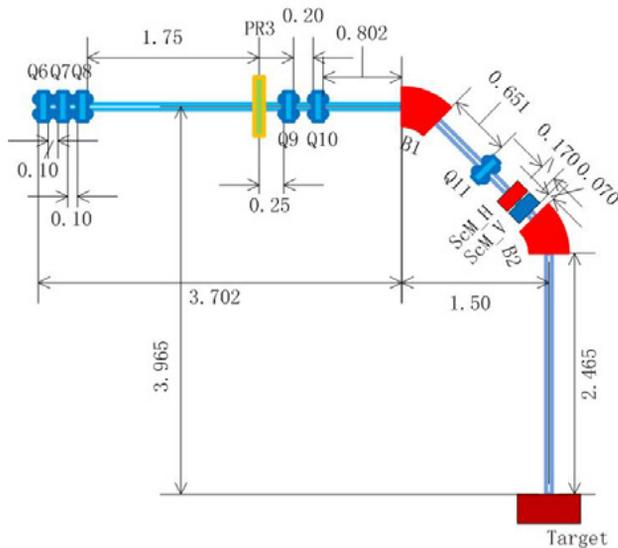

Figure 2: Layout transport line.

Figure 3 is the beta function and dispersion function along the transport line calculated with MAD code [4] with the assumption that ε=0.5 mm·mrad, β=10 m and α=0. Fig. 4 is the MAD calculation result assumed β=55 m on the target that shows the flexibility of the lattice.
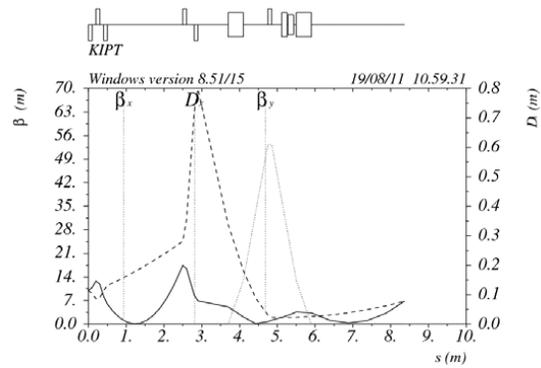

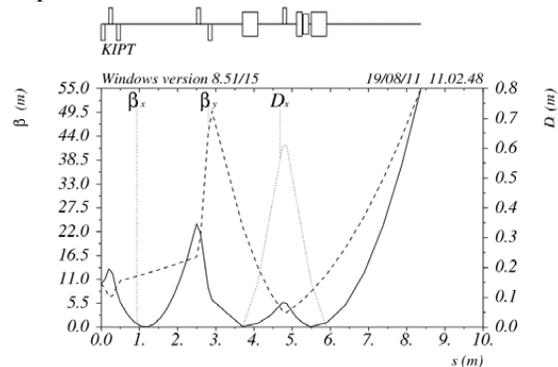Figure 3: Beta function and dispersion along the transport line.

Figure 4: Beta function and dispersion along the transport line with β=55 m.

ELECTRON BEAM HOMOGENEITY AT THE TARGET

Three different ways to provide homogeneous electron beam distribution at the target surface were considered during design of the transportation channel such as:

- the fast beam scanning with two dimensional scanning magnets;
- the method of uniform beam distribution formation with linear focusing elements (dipole and quadrupole magnets) and nonlinear focusing elements (octupole magnets), when final required rectangular beam shape with homogeneous beam density is formed at target;
- combined method, when one forms the small rectangular beam with homogeneous beam density distribution and scan it over the target surface with scanning magnets.

Scanning System

The scanning system which consists of two deflection magnets (ScM_H and ScM_V) is placed before B2 (Fig. 2). The scanning angles are determined by the transportation matrix from the scanning magnets to the target. The horizontal and vertical deflection angles change from -24 to 24 mrad and -10 to 10 mrad to spread the beam pulses on the target evenly, as it is shown in Fig. 5. The beam repetition rate is 625 Hz. According to the strength settings in Fig. 6, the scanning magnets deflect these beam pulses to 625 different places in a second, which means there are 25 horizontal and 25

vertical steps. Because of the beam pulse time interval is very short (1.6 ms), the changing frequency of one magnet should be 12.5 Hz with saw-tooth waveform (blue line in Fig. 6. The other magnet strength changes with multi-step (red line in Fig. 6) with step ≤1.6 ms.
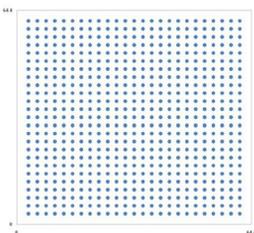

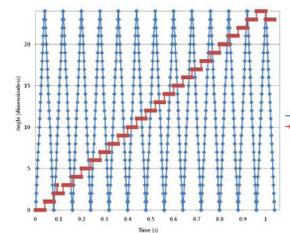Figure 5: Beam pulses distribution on the target.

Figure 6: Scanning magnets strength settings in a second.

The scanning method determines the distance between the nearest two beam pulse positions on the target. The selection of the beam size, i.e. the selection of beta function is very important to increase the beam density uniformity on the target. On the assumption the beam having a Gaussian density profile, the distance between the beam pulse positions on the target should be $0.73\sigma \sim 1.72\sigma$, where σ is the RMS beam size. The beam density uniformity can reach 1% at most regions of the target. Fig. 7 shows difference of the beam density at a corner of the target with different pulse position gap. According to the calculation result, 1.4σ is selected. To reduce the beam loss, a 3.2 mm edge space is spared on the target. And the beam loss is about 0.5%. The beta function on the target is 6.9 m

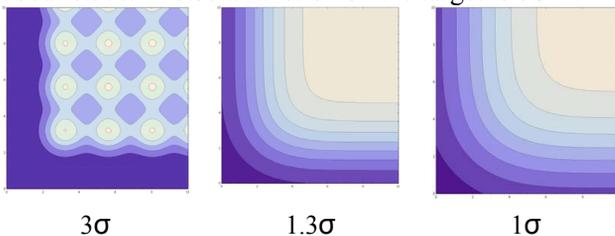3σ 1.3σ 1σ

Figure 7: Partial drawing of beam density contour with different beam pulse position gap on the target.

Method with Nonlinear Optics

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.

This method was successfully used at design of previous version of the neutron facility layout [3]. The same calculations were made with DeCA code for the new transportation channel. Two octupole magnets were set between Q6-Q7 and Q7-Q8 respectively and were used to change electron beam distribution

function. The final electron beam distribution at the target surface is shown in Fig. 8. The beam losses at walls of vacuum chamber due to nonuniformity of the beam distribution are of about 1.5 %. The main disadvantage of the method is big beam sizes in bending magnets. With use of the method one should have about 100 mm gap in bending magnets of the transportation channel that leads to the big magnet sizes and unreasonable power consumption.
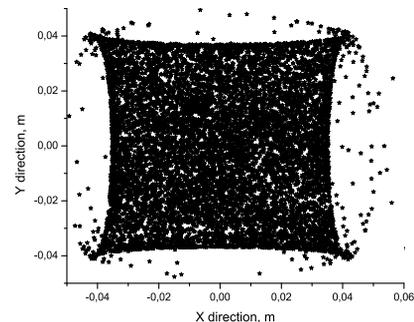

Figure 8: Distribution of the transversal coordinates of electrons at the target.

Combined Method

It seems that combination of two methods described above gives the best opportunity to form homogeneous electron beam density distribution. Preliminary calculations show that it possible to improve the value of particle losses in the transportation channel forming rectangular shape of the beam at target with 5.26×5.26 mm and use scanning system described above. In case of need to improve energy losses and beam uniformity the presented transportation channel lattice allows modifications.

CONCLUSION

The presented scheme of NSC KIPT neutron source on the base of subcritical assembly driven with linear accelerator transportation channel allows to deliver electron beam from linear accelerator to neutron target with beam losses of about 0.5 % and electron beam density distribution homogeneity of about 1 %.

REFERENCES

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[3] A. Zelinsky, I, Karnaukhov, "Transportation channel with uniform electron distribution for the Kharkov neutron source based on subcritical assembly driven by linear accelerator", Proceedings of EPAC08, Genoa,, Italy, June 24-29, THPC077, pp. 3164-3166.; http://www.JACoW.org.