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ACCELERATOR OPERATION PERFORMANCE DURING THE NSC KIPT SCA NEUTRON SOURCE PHYSICAL START UP*

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Abstract

To ensure physical start-up of NSC KIPT subcritical assembly (SCA) "Neutron Source", 100 MeV/100 kW electron linear accelerator should provide stable operation mode with 100 MeV electron beam energy, 20 Hz repetition rate, 35-40 mA pulse beam current, ± 3% beam energy spread and about 3 mm beam sizes. During preparations to the facility start-up (PS) the required beam parameters were adjusted and secured. The accelerator showed the stable operation performance.

The procedure of the accelerator stable operation mode tuning and adjustment secure during the whole period of the PS are described in the paper.

INTRODUCTION

In National Science Center "Kharkiv Institute of Physics and Technology" (NSC KIPT, Kharkiv, Ukraine) a neutron source based on the subcritical assembly driven by electron linear accelerator was designed, constructed and is under PS [1, 2] now. The neutron source is a hybrid facility. The main facility components are an electron linear accelerator, a transport channel (TCH) for electron beam transportation from linear accelerator to the target, neutron production target, subcritical assembly, biological shield, neutron channels and auxiliary supporting systems. An electron beam from a horizontal accelerator is fed down to a neutron-producing target using two 45-degree bending magnets. The beam is scanned on the target using two scanning in both transversal directions magnets (vertical scanning magnet SBV and horizontal one SBH) located between the bending magnets.

In its turn, the accelerator includes:

- Triode electron gun;
- Injection section;
- Electromagnetic chicane;
- 9 regular accelerating sections;
- Beam focusing system;
- Beam transportation channel;
- Diagnostic, supporting, power and RF power supply and other necessary systems.

100 MeV/100 kW electron linear accelerator was designed by NSC KIPT and IHEP, Beijing, China [3], manufactured in IHEP, delivered to NSC KIPT, installed, put in operation and adjusted for the facility PS [4].

To provide successful and efficient operation performance of the accelerator during PS and further during pilot and regular facility operation the whole procedure of the accelerator adjustment were divided for a few steps as a follow:

- Test of the operation region of such parameters as electron beam current and beam energy;
- Adjustment of the accelerator for PS;
- RF conditioning for the full power operation;
- Adjustment of the accelerator for the full power operation.

In the end of 2021, the PS experimental part was done successfully and the accelerator is under preparation to the full power operation.

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BEAM PERFORMANCE OPPORTUNITY TESTS

Triode Electron Gun

During triode electron gun technical tests and in order to prepare the accelerator for the PS stage and further full power operation the necessity to modify the gun pulser were found out to provide operation with low beam current value. The gun pulser was modified and now the gun can be operated in current range of 0.02 – 2 A. Now the gun shows stable performance with pick current stability of about 2% [5].

Beam Energy and Energy Spread

To verify the capability of the accelerator RF power supply system and accelerating system to produce 100 MeV electron beam a lot of tests has been done. After preliminary RF conditioning the tests were carried out with 2 Hz beam repetition rate and low electron beam current to avoid equipment irradiation during the tests. A few proper sets of the modulator HV amplitudes were found that allows to produce 100 MeV electron beam in case of proper accelerating section phasing.

As a result of the accelerator injection part adjustment and beam parameter tuning the 12.5 MeV electron beam with average energy spread of about ± 1.5% was stably produced. The shape and width of the beam energy spectrum is in a good agreement with simulation results [4]. The electron beam bunching and phasing was done for the different initial gun pulse current in the range of 20-800 mA.

The beam energy distribution after injection section tuning is shown in Fig. 1.

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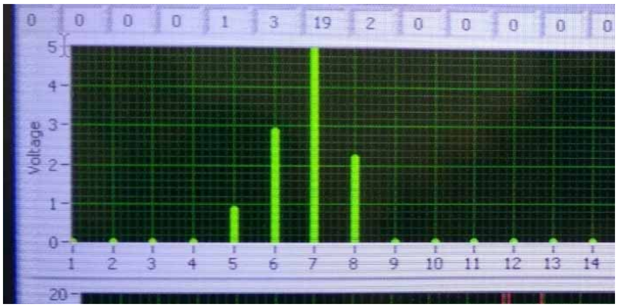

Figure 1: The beam energy distribution after injection section.

To provide proper electron beam energy and energy spread in the end of the accelerator the efficient accelerating section phasing should be done (Fig. 2).

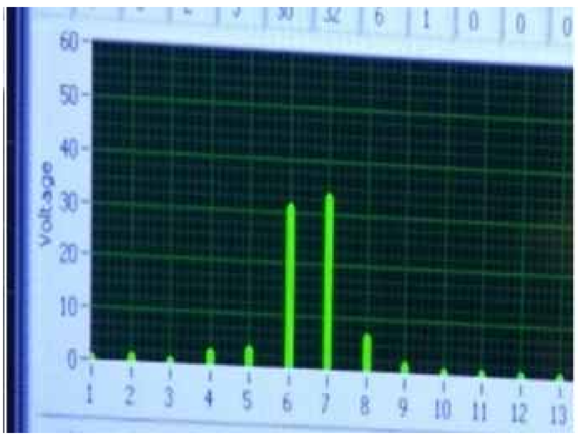

Figure 2: Electron beam energy distribution at of 100 MeV electron beam.

Beam Position and Distribution at the Target

To calibrate the SCA during PS and operate the facility at full power it is important to put the electron beam in the neutron generating target center and provide uniform beam distribution at the surface to avoid target overheating at full power operation. NSC KIPT subcritical facility "Neutron source" uses scanning method [6, 7]. To realize this method two scanning magnets were manufactured and installed at the TCH.

At the first stage of NSC KIPT subcritical facility adjustment the dependence of neutron flux on the electron beam position at the target was measured. Because absence of beam diagnostic equipment in the end of accelerator TCH it is possible to confirm real beam position with neutron flux measurements only. By moving the electron beam over the target surface, one can observe the picture of neutron flux distribution change and find the edges of the target.

The neutron flux measurements were done with set of three 10^{-3} sensitivity sensors of the measurement system [8, 9]. By changing of the excitation current of the second bending magnet (TB2) in TCH we can move the electron beam along one of the transversal target axes (coinciding with s-axe of xys accelerator system). The beam displacement can be calculated in accordance with TB2 geometry and distance till the target surface. Two scanning magnets of the TCH were used to shift the electron beam along both transversal target axes.

Figure 3 shows the sum of neutron counts of all three detectors in depends on electron beam shift from the target center by the TB2 magnet. One can see that neutron flux is within ± 1 % range when electron beam is at the target surface. When the beam reaches the edge of the target (± 32 mm) the total flux is dropped down. The measurements were done during 5000 electron beam pulses with beam repetition rate of 20 Hz and pulse beam current of about 35 mA. Simultaneously the electron beam charge was registered.

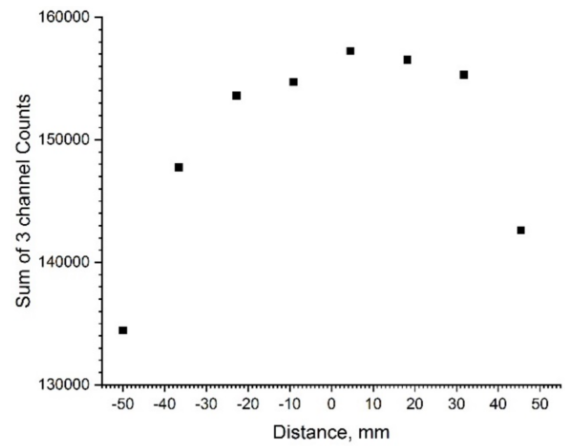

Figure 3: The results of neutron counts registration in dependence on beam shift by TB2 magnet.

Figure 4 shows the normalized neutron counts from all three measuring channels depending on beam displacement by TB2 magnet and by SBV one.

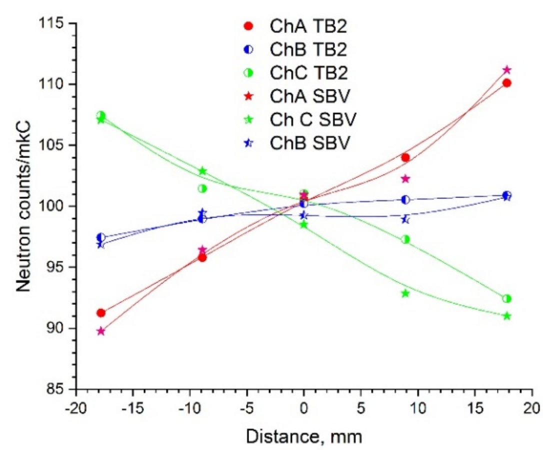

Figure 4: Normalized neutron counts in depends on electron beam displacement from target centre (● with B2 magnet, ☼ with SBV)

Figure 5 shows the normalized neutron counts depending on current in horizontal scanning magnet excitation coils.

Figures 3, 4 and 5 explain the procedure for c the electron beam entering on the target. This procedure was carried out before each session of measurements of the neutron-physical parameters of the facility. The scanning

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system provides uniform beam distribution at the target surface without beam losses.

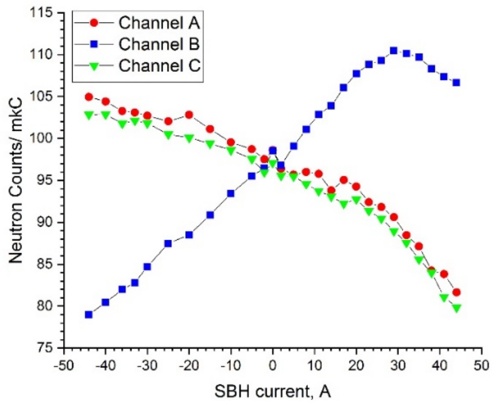

Figure 5: Normalized neutron counts in depends on current in SBH excitation coils.

PHYSICAL START-UP BEAM PARAMETERS AND PERFORMENCE

Before the final electron beam tuning the alignment accuracies of all accelerator and TCH electromagnetic elements were checked. The positions of elements were installed with accuracy within 100–200 μm.

To provide proper beam position correction the layout of correctors was changed by installation of two correctors pairs that can change beam position without effect of any other focusing magnetic element. Such correction scheme allows to separate the tasks of beam position correction in horizontal and bending parts of TCH and provides a required beam focusing. Figure 6 shows the electron beam shape at the first TCH bending magnet entrance.

The analysis of the beam dynamics in designed TCH lattice showed serious sensitivity of both beam position and size to the alignment errors of the magnetic elements [10]. The reason of the effect is the high gradients of the quadrupole lenses of both final triplet and doublet. Redesign of the original lattice allowed to decrease the quadrupole strengths significantly. As a result, new channel lattice is much less sensitive to the alignment errors. This mode was used during last electron beam tuning experiments and the facility PS.

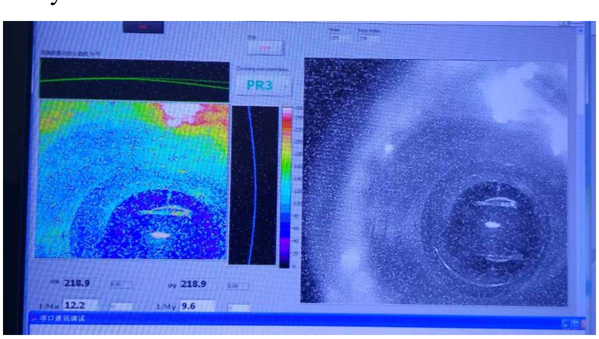

Figure 6: Electron beam profile at the first TCH bending entry.

Using the above described results, the operation mode with stable beam parameters was realized. Further neutron flux measurement sessions (more than 100 ones with average duration of about 30 000 – 40 000 registered beam pulses each) showed good stability and repeatability. All mentioned above allows to claim that 100 MeV/100 kW electron linear accelerator has stable beam parameters satisfying to the PS requirements.

CONCLUSION

After accelerator system adjustments and beam parameters tuning 100 MeV/100 kW electron linear accelerator meets the requirements for SCA Neutron Source PS: Electron beam energy is 100 MeV, energy spread is ± 3%, pulse repetition rate is 20 Hz, beam size at neutron generating target is ∼3 mm, pulse beam current is 35 mA.

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