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THE FIRST RESULTS OF TRIAL OPERATION AND PERFORMANCE IMPROVE OF THE 100 MeV/ 100 kW ELECTRON LINEAR ACCELERATOR OF THE NSC KIPT SCA NEUTRON SOURCE*

O. Andreev, V. Androsov, O. Bezditko, O. Bykhun, Yunlong Chi[1], A. Gordienko, V. Grevtsev, A. Gvozd, V. Ivashchenko, I. I. Karnaukhov, I. M. Karnaukhov, V. Lyashchenko, M. Moiseenko, A. Reuzayev, D. Tarasov, V. Trotsenko, NSC KIPT, Kharkov, Ukraine
A. Zelinsky, NSC KIPT, Kharkov, Ukraine
[1]also at Name of IHEP, Beijing, China

Abstract

The NSC KIPT SCA Neutron Source uses 100 MeV/ 100 kW electron linear accelerator as a driver for the generation of the initial neutrons. The trial operation of the accelerator was started in 2018. To provide design electron beam parameters is the primary task of the first stage of the trial operation. During the first stage of the accelerator operation the following tasks were under consideration: minimization of the electron beam losses along accelerator, providing of the stable electron beam pulse current, adjustment of the electron beam position along accelerator and providing of the uniform electron beam distribution at the tungsten neutron generating target. The main results of the accelerator operation and methods of performance improve are described in the paper.

INTRODUCTION

100 MeV/100 kW electron linear accelerator that is a driver of the ADS NSC KIPT Neutron Source [1-3] was designed and manufactured in IHEP, Beijing, China and assembled in NSC KIPT, Kharkov, Ukraine during 2010-2014 [4, 5].

In 2015 and 2016 the accelerator technological systems commissioning and beam commissioning were started [6] and in spring 2017 the design value of pulse electron beam current was obtained at the end of the accelerator horizontal part. During the last year the main task of the accelerator commissioning was to optimize the technological system parameters and improve the accelerator performance in accordance with basic design parameters listed in Table 1.

ACCELERATOR COMMISSIONING

The linear scheme of the NSC KIPT 100 MeV/100 kW accelerator equipment installation is shown in Fig. 1. The basic elements of the accelerator are triode electron gun (GUN), 10 accelerating sections (A0-A9), pre-buncher, and buncher (PB, Buncher), magnetic chicane (CB1-CB4), accelerator regular part focusing triplets (Q0-Q5), 90 degree transportation channel with dipole magnets and focusing quadrupole magnets (Q6-Q12 and B1-B2), horizontal and vertical target scanning magnets (SC) and beam instrumentation devices (see Fig. 1). During assembling and testing of the accelerator systems all equipment were tested and prepared for the accelerator electron beam commissioning. As it was shown during preliminary accelerator testing in 2017 [3, 6] the accelerator can provide the design beam pulse current of 600 mA and required pulse parameters of 3 μs pulse duration, pulse flatness and stability, about 20 ns pulse edge durations. The further accelerator commissioning and electron beam parameters adjustment require accurate measurement of the beam parameters along the accelerator and in the end part of the accelerator.

Table 1: Main KIPT Linac Parameters

Parameter	**Value**
RF frequency	2856 MHz
Beam energy	100 MeV
Pulse beam current	0-0.6 A
Average beam power	0.005 – 100 kW
Energy spread (1σ)	2 %
Emittance (1σ)	$5\text{x}10^{-7}$ m-rad
Beam pulse length	2.7 μs
RF pulse duration	3 μs
Pulse repetition rate	2 - 625 Hz
Gun voltage	~120 kV
Pulse beam current	0-1 A

Unfortunately, the typical ADS facility layout and radiation background at the end part of the accelerator does not allow to accommodate the proper, regular beam instrumentation equipment at the end part of the accelerator [1-4]. To provide the possibility to observe and tune the electron beam parameters at the end part of the accelerator the neutron generating dummy was replaced by the stainless steel pipe with alumina window at the bottom (1 in Fig. 2). The alumina window is used as scintillation screen for the CCD camera that installed beside the screen (3 in Fig. 2) to observe the beam size and position during electron beam focusing and scanning and as output electron beam window to the lead Faraday cup that is installed in 20 cm under stainless steel pipe to register the electron beam current (2 in Fig. 2). The SCA tank is filled with the distilled water, so that distance between alumina window and Faraday cup is filled with water.

The typical results of the electron beam commissioning sessions are shown in Fig. 3.

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† zelinsky@kipt.kharkov.ua

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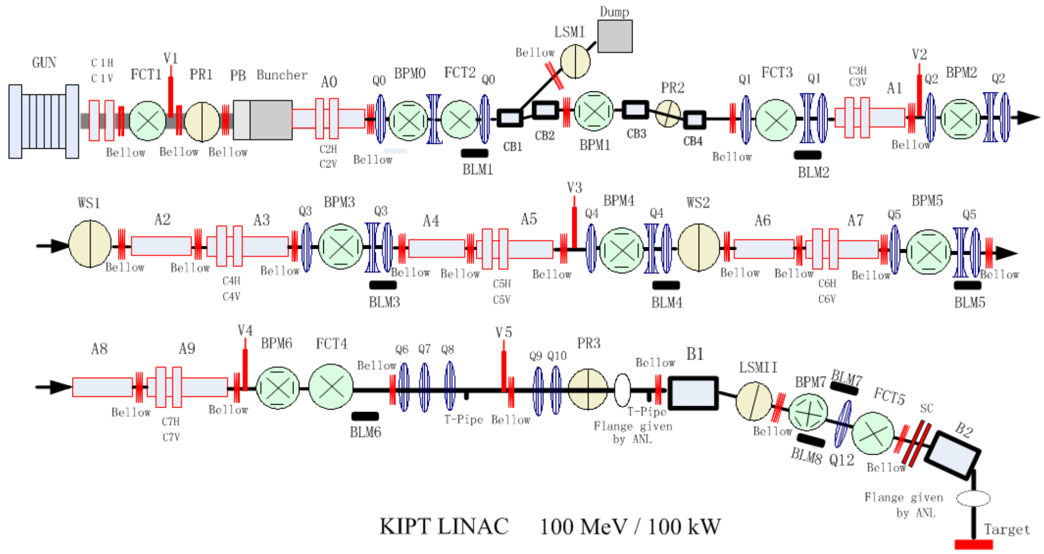

Figure 1: Layout of the accelerator with beam instrumentation devices: Gun is triode electron gun, PB and Buncher are pre buncher and buncher, A0-A9 are accelerating sections, CB1-CB4 are magnetic chicane dipole magnets, B1,B2 are transportation channel 45 degree dipole magnets, SC are horizontal and vertical target scanning magnets, Q0-Q5 are focusing triplets of the regular part of the accelerator, Q6-.Q12 are electron beam transportation channel quadrupole focusing magnets, FCT1-FCT5 are fast current transformers (beam current monitors), PR1-PR3 are scintillate screen monitors, BPM0-BPM7 are electrostatic beam position monitors, LSM1, LSM2 are lame screen monitors, WS1, WS2 are wire screen monitors, V1-V5 are vacuum valves.

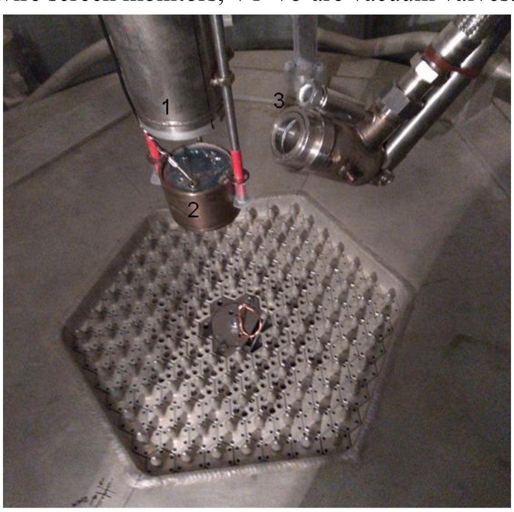

Figure 2: Testing beam instrumentation equipment at the end of the NSC KIPT SCA Neutron Source: 1 is stainless steel pipe with alumina window, 2 is lead Faraday cup, 3 is CCD camera.

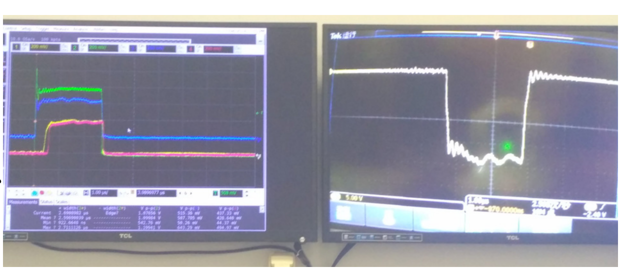

Figure 3: The electron beam current along accelerator (left photo, green line is FCT 1 pulse, blue line FCT 2, yellow is FCT 4, purple is FCT 5) and at the Faraday cup at the Neutron generating target (right photo).

As one can see, the pulse electron beam current (green line in Fig. 3) meets to the design parameters of about 1 A. The pulse electron beam current after injection section A0 is about 0.8 A. As it was shown during beam commissioning, the efficiency of the electron beam transportation trough the A0 section can be up to 87 %. The efficiency of the acceleration and transportation of the electron beam trough the accelerating sections is about 75 % (0.6 A at the end of the horizontal part of the accelerator, yellow line, Fig. 3). The efficiency of the beam transportation trough the first bending magnet of the transportation channel is 100 % (yellow and purple lines in Fig. 3). The registered pulse current and shape at the Faraday cup allows to conclude that efficiency of the beam transportation is about 100 %. Therefore, for the further accelerator adjustment it is necessary to improve the efficiency of the beam transportation and accelerating efficiency to the design parameters that are 2 % losses instead 25 % that is observed now.

ELECTRON GUN PERFORMANCE

100 MeV/100 kW electron linear accelerator uses triode electron gun with EIMAC Y824 Tungsten matrix. During beam commissioning the gun showed the stable performance in pulse current range of 0.5 – 1 A (green line in Fig. 3) [5, 6]. During the NSC KIPT Neutron commissioning, facility tests, neutron flux measurement system calibration and official State accepting tests and to avoid unnecessary equipment irradiation it is necessary to operate electron gun at low pulse beam current (10-100 μA). To test the performance of the gun in low current mode the gun current-voltage

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characteristic was measured. Fig. 4 shows the anode electron gun current measured with FCT1 beam current monitor in dependence on gun grid pulser voltage. 50 V bias voltage was installed during the measurements. The pulser grid voltage can be controlled in the range of 0-200 V. As one can see from the figure, the minimal electron gun at 0 V grid pulser voltage is about 225 mA. To have possibility to decrease beam current to zero it is necessary to have possibility to put negative voltage to the grid pulser. The current version of the pulser control scheme does not allow to provide negative grid pulser voltage and addition pulser modification should be done.

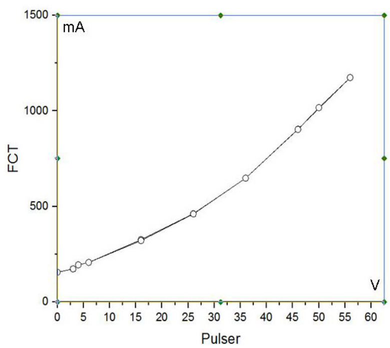

Figure 4: Triode electron gun current vs grid pulser voltage. Bias voltage is 50 V.

RF CONDITIONING

6 modulators and klystrons of the accelerator high power RF system were conditioned during 2017. Accelerator RF system was operated up to 45 kV charging unit voltages and maximum value of repetition rate equal to 400 Hz (with maximal design value repetition rate of 625 Hz). The RF system showed stable performance up to 100 Hz repetition rate. With repetition rate increasing several cases of high voltage cable breakdowns took place (Fig. 5). With 400 Hz repetition rate the high voltage cable breakdowns became regular and RF conditioning has been stopped.

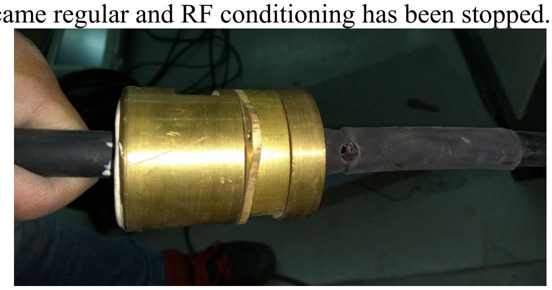

Figure 5: The example of the HV voltage cable breakdowns.

It was supposed that the cause of the cables heating and breakdowns is RF ringing in the modulator circuits. The measurements, that have been carried out, showed that the frequency of the ringing in 100 MeV/100 kW NSC KIPT accelerator modulator has frequency of about 9-10 MHz. Fig. 6 shows the RF ringing in the modulator circuit, Purple and green lines are thyratron grid ringings. Yellow line is thyratron anode voltage ringing. The further investigation of the modulator circuits is needed in order to avoid further cables breakdown and provide design parameters of the accelerator in high power mode.

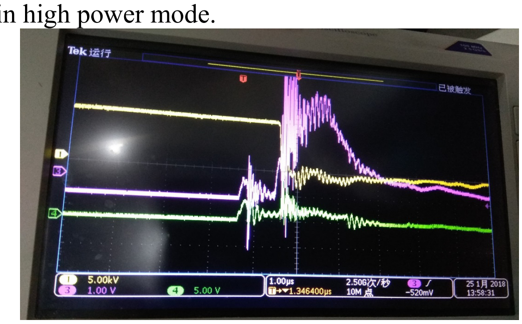

Figure 6: Thyratron circuit RF ringing. Purple and green lines are thyratron grid ringings. Yellow line is thyratron anode voltage ringing.

CONCLUSION

100 MeV/100 kW electron linear accelerator for the NSC KIPT Neutron Source is under commissioning and tests. The accelerator shows performance within design parameters. Some technical solutions should be developed and implemented in gun and modulator electronic circuits to provide regular and safe operation of the accelerator in NSC KIPT Neutron Source facility.

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