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ADJUSTMENT AND IMPROVEMENT OF 100 MeV/100 kW ELECTRON LINEAR ACCELERATOR PARAMETERS FOR THE NSC KIPT SCA NEUTRON SOURCE*

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Abstract

The NSC KIPT SCA neutron source (subcritical assembly) uses 100 MeV/100 kW electron linear accelerator as a driver for the production of the initial neutrons. The linac was designed and manufactured by the Institute of High Energy Physics (IHEP) of China. At present, the accelerator was assembled at NSC KIPT, all the components were tested, and the first beam commissioning results are obtained. The pilot operation of the accelerator was started in 2018. The progress in the accelerator system operations and improvement of the electron beam performance are described in the paper.

INTRODUCTION

100 MeV/100 kW electron linear accelerator is a driver of the ADS NSC KIPT neutron source (accelerator driven source) [1-3]. The design parameters of the accelerator are shown in Table 1:

Table 1: Main KIPT Linac Parameters

Parameter	Value
RF frequency	2856 MHz
Beam energy	100 MeV
Pulse beam current (max.)	0.6 A
Average beam power	100 kW
Energy spread (1σ)	1.3 %
Emittance (1σ)	5×10^{-7} m rad
Beam pulse length	2.7 μs
RF pulse duration	3 μs
Pulse repetition rate (max)	625 Hz
Klystron power	30 MW/50 kW
Number of klystron	6
Number of ACC. Structure	10
Length of ACC. Structure	1.338 m
Gun voltage	~120 kV
Gun beam current (max)	2 A

In 2015 and 2016 the technological systems commissioning and beam commissioning were started [4], and in spring 2017 the design value of pulse electron beam current was obtained in the end of the accelerator regular part. During the first half of 2018 Regulator approved the program of individual State accepting tests and all accelerator technological systems and control system were prepared for the individual State accepting tests.

In early July of 2018, the individual accepting tests were carried successfully with few experts' comments that should be satisfied until the SCA neutron source integrating tests.

During the tests accelerator demonstrated the possibility to operate with 50 Hz repetition rate and 600 mA pulse current, but the majority of the tests were done with 2 Hz repetition rate and pulse current of about 200 mA.

IMPROVEMENT OF ACCELERATOR TECHNOLOGICAL SYSTEM PERFORMANCE

After State integrating tests the main directions of the activity were:

1. Maintenance and preparation to the SCA physical start up of all accelerator technological systems and control system.
2. Modification of technological system and electron beam parameters optimization.

Besides, a few systems important for the beam operation and the facility nuclear safety were modified, commissioned and tested.

The fast interlock block (FIB) of the accelerator was designed and tested. The FBI allows to stop trigger signal of the first klystron modulator and triode electron gun simultaneously in a case of alarm signal from any technological system or device at any of 22 input sockets. The time of interlock is 400 μs. In addition, the block was equipped with light alarm signalization set in control room.

Additional water interlock system of so called "direct action" with analog electrical elements only was designed. The task of the system is to switch off the magnetic element DC power supply in the case of water circulation absence or blockage at some of the element of cooling loop. The system uses relays and air switchers only (without controllers use).

Strip-Lame Screen Monitor (SLS) of the KIPT neutron source is used to measure the beam energy spread in the injector and the transport line. During pilot operation, it was found that graphite electrode diameter and secondary emission capacity of the designed SLSs do not provide appropriate signal from electrodes to amplifiers. In addition, some errors have been done during electronics design and development. That is why, we changed the graphite electrodes with aluminium foil electrodes of 7 mm width that

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provide maximum overlapping of the vacuum chamber aperture (Fig. 1). 16 electrodes were installed in SLS1 (injector) and 14 electrodes were mounted in SLS2 (transportation channel).

Figure 1: Modified SLS1 and SLS2.

LLRF system is one of the key accelerator subsystems. Beam loading compensation method is based on feed forward method and the phase drift is based on feedback method. The KIPT LLRF system consists of a 2856 MHz signal generator, klystron drive amplifier (SSA, Solid State Amplifier), 6 controllers (one for each klystron) and some other related RF front end signal processing circuits. Each controller includes a digital signal processing board, which generate proper waveform to compensate heavy beam loading effects and the slow phase drift of the RF system.

LLRF was commissioned and put in operation. Now the system is under testing. The current system configuration does not use output accelerating section signals for feedback correction, but uses input RF signal only. Nevertheless, system configuration allows to use output accelerator section signal too. The further tests of the system are needed.

BEAM PERFORMANCE

Triode Electron Gun

Linac of the KIPT neutron source uses triode electron gun. The first beam tests showed the good agreement with design parameters and tests carried out in IHEP, Beijing, China. The gun provide stable current pulse in operation range of 0.2 - 0.8 A [5]. However, the requirements of the individual and integrating tests arise the necessity to modify the gun pulse to provide operation with lower beam current value. The gun pulser was modified and now the gun can operate in current range of 0.02 – 1 A. After modification, the gun shows stable performance with pick current stability about 2 % (Fig. 2).

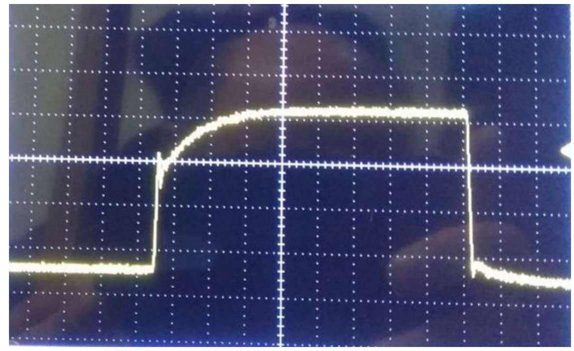

Figure 2: The gun current pulse shape.

Beam Energy Spread

To provide efficient electron beam transportation through the accelerator, the electron beam energy spread must be less than ± 4%. It is supposed to adjust correct mode of the electron beam phasing in the injection part of accelerator and along the whole accelerator. Besides, the measurement of the beam energy spectrum should be provided.

Because SLSs were under investigation and modification, the single wire sensor was applied at the injection part of the accelerator. After SLS1 removing vacuum chamber was flanged; the wire aluminium sensor was installed in the centre of the vacuum chamber flange in the air. The electron beam was bended to the direction of beam dump with the first bending magnet of the chicane. Fig. 3 shows the chicane layout, SLS and beam dump. Changing CB1 magnet excitation current and measuring secondary emission signal one can measure the energy distribution of the electron beam.

The measured beam energy distribution and its Gaussian approximation are shown in Fig. 4. As it is clear from figure, the average beam energy is 14.4 MeV and rms beam energy spread after injection section is of about 3 %.

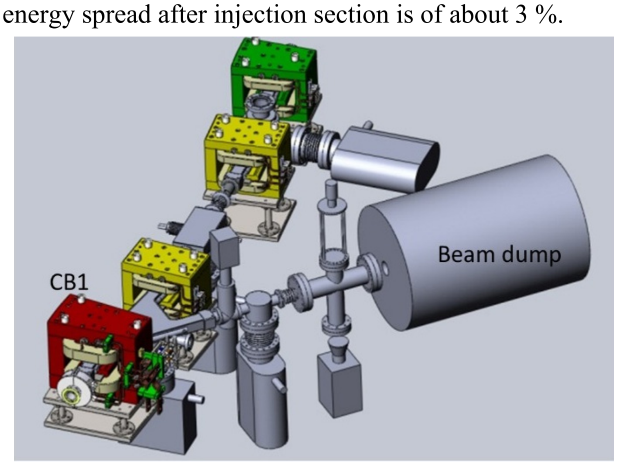

Figure 3: Layout of the chicane and beam dump.

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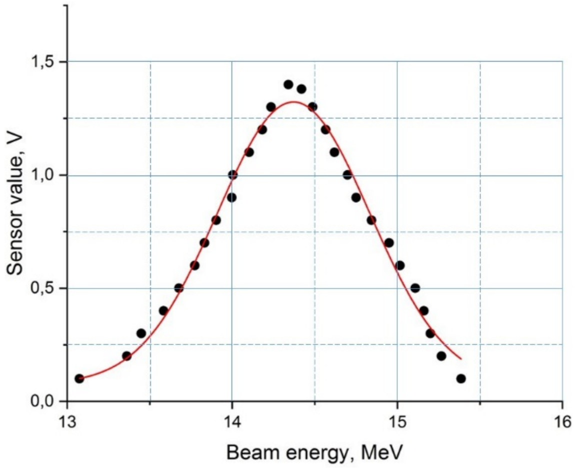

Figure 4: Electron beam energy distribution after injection section.

Beam Energy Spread Measurements With SLS

After modification of SLS1 and SLS2 the measurements of the beam energy spread were done at the injection part of the accelerator and in the middle of transportation channel. The results of the measurements are shown in Fig. 5.

Taking into account the SLSs placing, their geometry and the dispersion values at the SLSs azimuths one can estimate corresponding beam energy spreads. These measurements are very preliminary and we will improve them further.

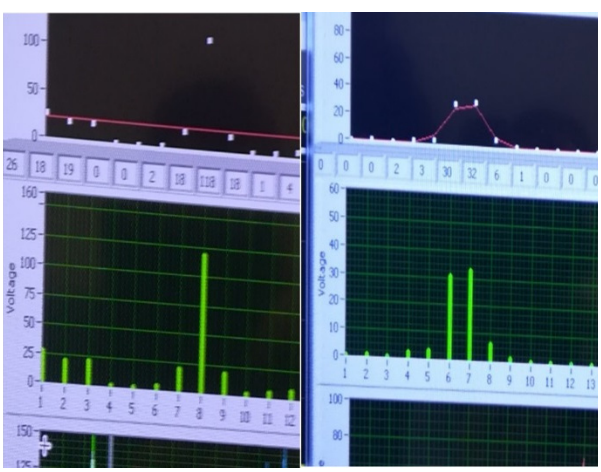

Figure 5: Electron beam energy distribution at SLS1 and SLS2.

Beam Transportation Efficiency

After LLRF system commissioning several changes of the accelerator operation modes were carried out to optimize the beam transportation efficiency and focusing. The results of one of the efficient phasing and focusing mode is shown in Fig. 6. The total efficiency of the beam transportation trough the accelerator is about 75 % with pulse beam current of 125 mA.

The further tests on optimization of beam focusing and phasing modes for different beam current values are needed.

Figure 6: Beam current monitor signals: green – FCT2 (chicane entering), blue - FCT3 (after chicane), yellow – FCT4 (ending of linac regular part), red – FCT5 (after first bending to neutron target).

CONCLUSION

100 MeV/100 kW electron linear accelerator for the NSC KIPT Neutron Source has been assembled and main accelerator technological systems were tested. The first beam commissioning results showed the correspondence of the realized technical solutions to the original design. At present, linac can operate with pulse beam current up to 600 mA and repetition rate of 450 Hz. The further accelerator adjustment will be done during 2019 year.

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