100 MEV/100KW ELECTRON LINEAR ACCELERATOR DRIVER OF THE NSC KIPT NEUTRON SOURCE

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Abstract

In NSC KIPT, Kharkov, Ukraine a neutron source based on a subcritical assembly driven by a 100MeV/100kW electron linear accelerator will be constructed. This neutron source is an USA (ANL)-Ukraine (KIPT) Joint project, and its accelerator will be designed and constructed by Institute of High Energy Physics (IHEP), China. The design and construction of such an accelerator with high average beam current and low beam power losses is a technical challenging task. In the paper, the main accelerator features and current status are under discussion.

INTRODUCTION

NSC KIPT, Kharkov, Ukraine neutron source is hybrid nuclear-accelerator facility of a new type [1]. The driver of the facility is 100 MeV electron linear accelerator [2]. To provide a neutron flux of about 10^{13} neutron/s the accelerator should have electron beam power of 100 kW. The design of the accelerator was started in February 2010 in IHEP, Beijing, China and basically was completed in February 2012. Simultaneously, the manufacturing of the accelerator parts was started.

The main accelerator parameters are shown in Table 1. The general layout of the KIPT neutron source facility is shown in Fig. 1.

During the second half of 2012 year the tests of the injection part of the accelerator were carried out. The test results showed the good agreement of the electron beam parameters with design parameters. The accelerator installation and assembling in KIPT will be started in the end of May 2013. It is supposed that accelerator will be put in operation in January 2013.

BASIC DESIGN SOLUTIONS

For a high intensity electron accelerator, both regenerative and cumulative beam break-up (BBU) effects need to be studied. In the accelerator design, the following measures are applied to suppress the BBU effects as much as possible:

- Using short quasi-constant gradient accelerating structure (~1.34m long) to spread the dipole higher order mode (HOM) frequencies along the structure, since dipole HOMs are the major sources of the BBU effects;
- Applying solenoid magnetic field along the 1st accelerating structure;
- Increasing the accelerating gradients of the 1st and 2nd accelerating structures to enhance the beam energy boosting rate at the low energy stage as high as possible; Decreasing the pulsed beam current to 0.6 A and beam pulse length to 2.7μs;
- Introducing triplet quadruples at the downstream of every one or every two accelerating structures;
- Adopting a better alignment with the accuracy of less than 0.2 mm (1σ);
- Employing beam orbit correctors to control the beam orbit close to the accelerating structures' axes as possible;
- Decrease the disk hole diameter from 27.887mm to 23.726 mm in a stepwise fashion along the structure;
- To detune the dipole mode quickly, dipole mode frequency spread was increased by increasing the disk hole diameter step to ~0.122mm;
- 11mm hole will be drilled at the 3rd to 6th disk of each accelerating structure. The HEM11 mode frequency will be increased from ~4042MHz to ~4050MHz.

According to simulation, the bunching system has a transportation efficiency of ~90%. There will be ~20% particles at the downstream of the 1st accelerating structure, which cannot meet the required ±4% (peak-to-peak) energy spread at the accelerator exit (determined by the ΔE/E acceptance of the transport line), and will be eliminated at the low energy stage by a chicane system shown in Fig. 2,3.

Table 1: Main KIPT Linac Parameters

Parameter	Value
RF frequency	2856 MHz
Energy	100 MeV
Beam current (max)	0.6 A
Energy spread (1σ)	4 %
Emittance (1σ)	5×10^{-7} m-rad
Beam pulse length	2.7 μs
RF pulse duration	3 μs
Pulse repetition rate	625 Hz
Klystron power	30MW/50kW
Number of klystron	6
Number of ACC. structure	10
Length of ACC. structure	1.336 m
Gun voltage	~120 kV
Gun beam current	2 A

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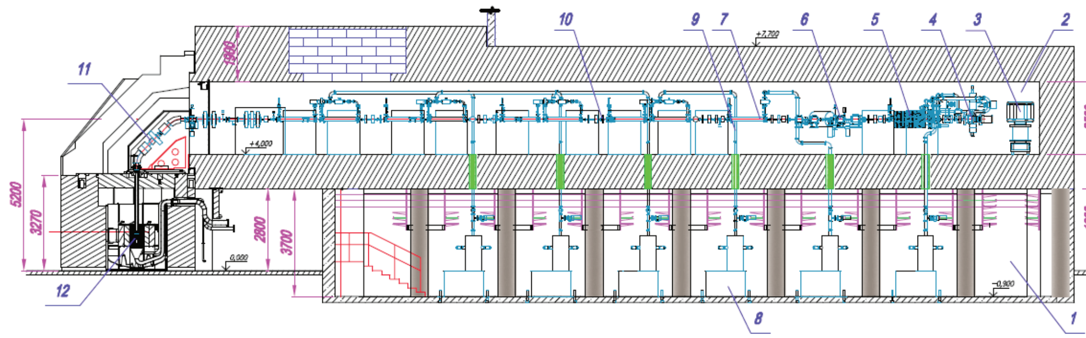

Figure 1: Layout of the accelerator and subcritical assembly systems: 1 – klystron gallery, 2 – accelerator tunnel, 3 – electron gun power supply, 4 – injector part of the accelerator, 5 – the first accelerating section, 6 - chicane, 7 – accelerating section, 8 - klystron, 9 – wave guide, 10 – quadrupole triplet, 11 - electron beam transportation channel, 12 – subcritical assembly.

The beam collimator is located between the 2nd and 3rd bending magnets, and it will be used to collimate the particles with large energy spread. Conclusively, the accelerator would have ~70% transportation efficiency (from gun to accelerator exit). To get better beam performance, the chicane system was designed to be quasi-achromatic at the system exit by optimizing the edge angles of CB2 and CB3 magnets. ~2 kW beam power will be lost in the chicane system. Finally, in order to get 0.60 A electron beam at the accelerator exit, the maximum electron beam current at the gun exit should be ~0.85 A.

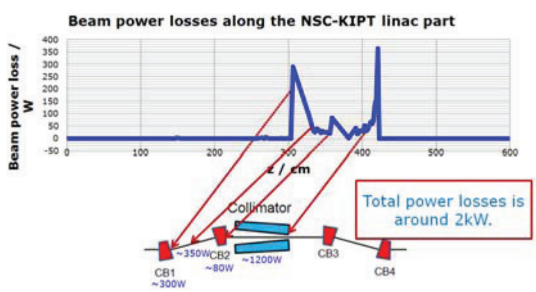

Figure 2: Layout and beam losses distribution in KIPT linac chicane and accelerating system.

The beam bunching process is shown in Fig. 4, in which the longitudinal beam performances (phase spread and beam energy spread) at 5 longitudinal positions (the electron gun exit, the pre-buncher exit, the buncher entrance, the buncher exit and the 1st accelerating structure A0 exit) are shown, respectively. The beam is transversely focused by ~26 solenoids from the electron gun exit to the A0 exit. The beam performance at the bunching system exit is shown in Fig. 5, this kind of energy-phase distribution is appropriate for the beam collimation process to eliminate those particles with very large energy spread. Finally, the beam power losses along the transport line at the downstream of the accelerator exit can be minimized to the largest extent.

The simulation of the beam loss along the linac part is done with PARMELA [3]. Fig. 2 shows the simulation result. Most of the beam power loss located at the chicane system region, where the electron beam has relatively large energy spread and ~1.2 kW beam power are collimated by the collimator. The total beam power loss along the whole accelerator (from electron gun to accelerator exit) is ~2kW, about 2% of the total beam power at the accelerator exit.

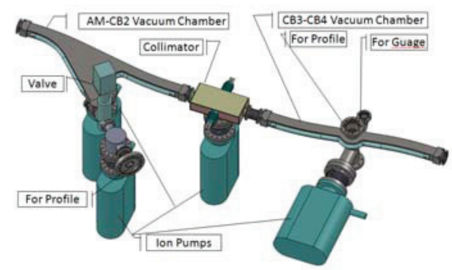

Figure 3: 3D model of chicane vacuum system.

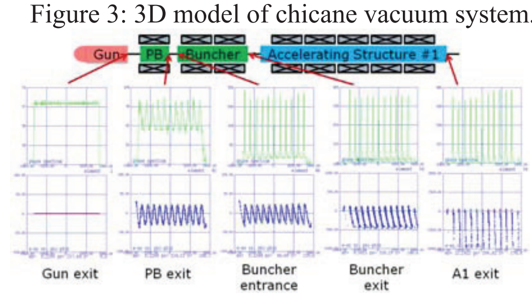

Figure 4: The process of beam bunching.

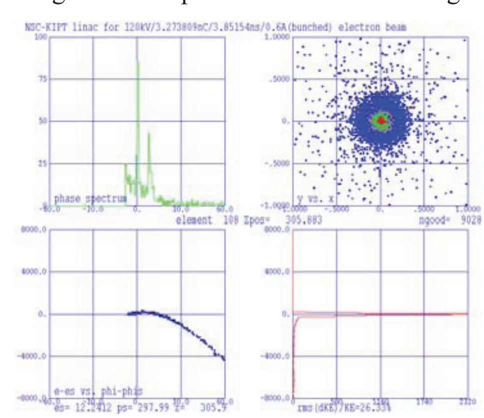

Figure 5: Beam performance at the bunching system exit.

To provide the delivery of the electron beam from the accelerator exit to the target transportation line is designed and developed. The transportation line provides practically losses less beam passing through the line and uniform electron beam distribution at the target surface.

The layout of the transport line is shown in Fig. 6. Two 45º vertical sector bending magnets of 0.4 m effective length, B1 and B2 are used to bend the beam from the accelerator to the target. A quadrupole (Q11) is placed at the middle point of the arc to remove the dispersion. A triplet (Q6, Q7 and Q8) and another two quadruples (Q9, Q10) are used to form the beam size on the target. Because of the uncertainty of the beam twiss parameters at the accelerator exit, the triplet is also used for the emittance measurement together with the profile monitor PR3 by the quadrupole scanning method with very low beam pulse repetition rate (1~3 Hz). The distance between the last bending magnet B2 and the target is about 2.5 m. The scanning system which consists of two deflecting magnets (ScM_H and ScM_V) is placed before B2. The scanning angles are determined by the transportation matrix from the scanning magnets to the target. The horizontal and vertical deflection angles can change from -24 to 24 mrad and -10 to 10 mrad to spread the beam pulses on the target evenly. The beam repetition rate is 625 Hz. According to the strength 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. The other magnet strength changes with multi-step, and the step is very steep (≤1.6 ms).

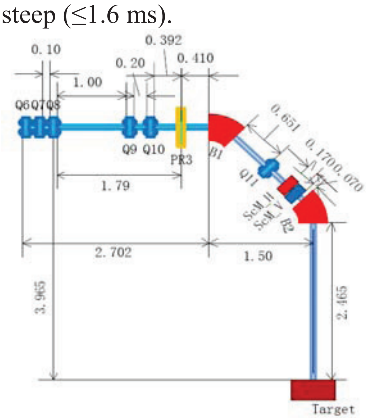

Figure 6: Layout of the transport line.

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 σ ~1.72 σ According to the calculation results, the value 1.4 σ is selected.

ACCELERATOR SUBSYSTEMS

KIPT linear accelerator consists of the following subsystems:

- A ~120 kV triode gun;
- A 2856 MHz pre-buncher and buncher;
- Ten ~1.34 m 2856 MHz travelling wave-accelerating structures;
- A chicane with a collimator to eliminate the electrons with large energy spread.
- Five focusing triplets in certain drift spaces between the accelerating structures;
- The beam transport line and the beam scanning system;
- Six klystrons and the corresponding modulators;
- Low-level RF control system;
- Beam instrumentation system;
- Vacuum system;
- Machine support and alignment system;
- Machine control system;
- Accelerator and transport line cooling system.

The major part of the equipment already manufactured and the installation is going to start in the end of May 2013.

INJECTOR PART TESTS

During the 2012 year the injector part of the accelerator was manufactured, assembled and tested. The beam parameters after electron gun and the first accelerating section were measured and optimized. As a result: the electron beam with pulse current up to 2 A has been registered, the electron beam with pulse current of about 0.6-0.8 A, with pulse duration of 2.7 µs, pulse front edges of about 10 ns and energy spread of about 10 % has been received at the exit of the first accelerating section.

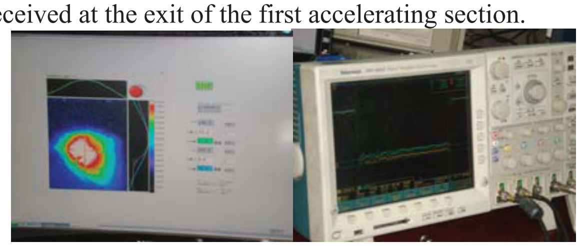

Figure 7: Electron beam profile and pulse at the exit of the fist accelerating section.

CONCLUSION

The 100 MeV/100 kW electron linear accelerator the driver of NSC KIPT neutron source has been designed and is under development. The injector test results show the correctness of the chosen scientific and engineering solutions.

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