LUE-200 LINAC. STATUS & DEVELOPMENT

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Abstract

The general scheme and current status of an electron linac with an S-band travelling wave (f = 2856 MHz) accelerating structure – a driver for a pulsed neutron source (IREN) at the Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research - are presented. The parameters of the accelerating system and the measured parameters of the electron beam – pulse-beam current, duration of the current pulse, repetition rate, electron-energy spectrum, and loading characteristics of the accelerating structure - are given. The beginning of the implementation of the project of the second stage of the IREN facility, which forms the basis for the development of the accelerator aimed at increasing its beam power, is reported. Technical solutions underlying the modernization of the accelerator's electrophysical systems are discussed: accelerating system, RF power supplies, and modulators.

INTRODUCTION

In January, 2009, at the Frank Laboratory of Neutron physics of JINR the physical start-up of the first stage of the **I**ntense **Re**sonance **N**eutron source (IREN) for fundamental and applied investigations in neutron nuclear physics in a neutron energy range from eV to hundreds of keV was carried out [1]. The conceptual scheme of the neutron source is based on the electron linac with an S-band travelling wave (f = 2856 MHz) accelerating structure. The scheme of the linac with a beam energy up to 200 MeV (Fig. 1) and average beam power of ~ 10 kW, consisting of two accelerating sections which was suggested by the Budker Institute of Nuclear Physics [2], is realized in two stages. At the first stage a full-scale accelerator consisting of one accelerating section with constant impedance, which is powered by one klystron with the SLED RF-power multiplication system, was created [3]. The first electron beam was obtained in June 2008, and the first neutrons were produced in the IREN target in December 2008. In February 2009 the regular operation of the accelerator started at a repetition rate of 5-10 Hz, and in May 2010 it began at a rate of 25 Hz. All in all, by the middle of 2014 the accelerator operated in experiments for more than 4200 h.

CURRENT STATUS OF THE FIRST STAGE OF THE LINAC

At the first stage of the linac one accelerating section is powered by one TH2129 klystron with a nominal pulse power of 20 MW. Thus, the design beam power was reduced to ~ 3 kW. In the course of the realization of the project the parameters of the linac were changed. The repetition rate of the operation of the accelerator was reduced to 25 Hz, and in order to increase the resolution power of the time-of-flight neutron spectrometers, the beam pulse duration was decreased from 250 ns to 100 ns. The average power of the electron beam was 0.13 kW for a beam with a current of 1.5 A and 0.2 kW for a beam with a current of 2.5 A. Table 1 presents the initial design characteristics of the linac, the design characteristics corrected for the assembly with one accelerating section powered by klystrons of different power, and the characteristics of the linac obtained at the first stage in a regular operating mode.

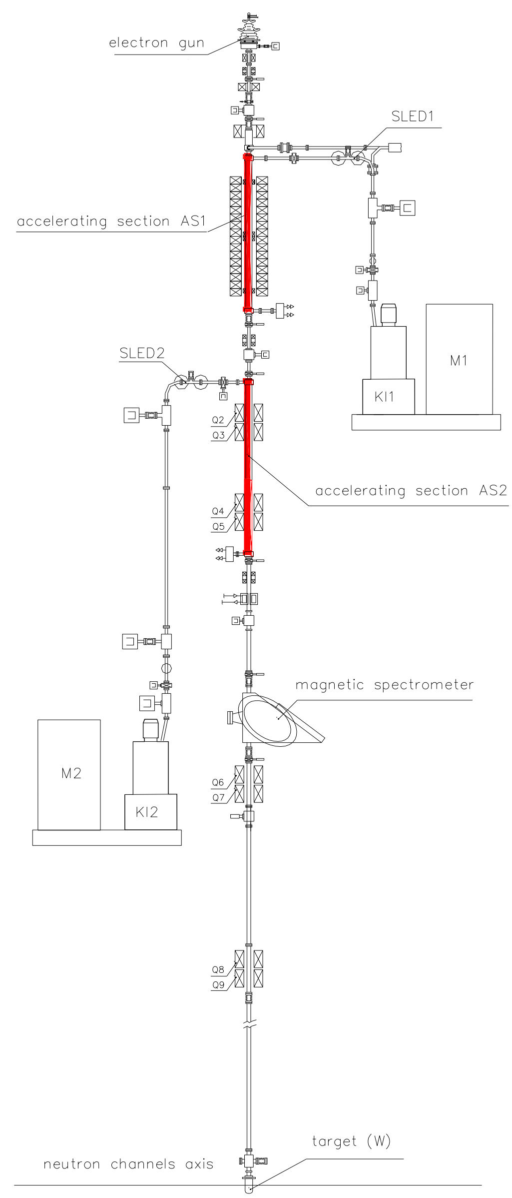

Figure 1: Scheme of the accelerator development.

Table 1: Characteristics of LUE-200

Parameter	BINP project 1993	Project of 1st stage	Expect. of 1st stage	Realisation of 1st stage
Number of accelerating sections	2 sections 2 klystrons	1 section	1 section 1 klystron	1 section 1 klystron
Type of klystron, klystron RF output power	5045 SLAC 67 MW	5045 SLAC 67 MW	TH2129 Thomson 20 MW	TH2129 Thomson 17 MW
Maximum electron energy	212 MeV	106 MeV	57 MeV	32-42 MeV
Average pulse beam currents	1.5 A	1.5 A	1.5 A	1.5 - 2.5 A
Current pulse duration	250 ns	250 ns	250 ns	100 ns
Repetition rate	150 Hz	150 Hz	150 Hz	25 Hz
Average beam power	≈ 12 kW	≈ 6 kW	3.2 kW	0.13–0.2 kW

The electron energy value given in Table 1 for design values and for expected values for the first stage is determined by a scaling according to the dependence of the energy of the particles accelerated in the travelling-wave structure with klystron power: $E \sim (P_{klystron})^{1/2}$. Based on this dependence, in the case of using TH2129 klystron the maximum values of electron energy was expected to be up to 57 MeV. However, in the obtained energy spectra of the beam (Fig. 2) the maximum energy values appeared to be 33 ÷ 42 MeV (depending on the beam current). This can be partly explained by the fact that in routine operating modes TH2129 klystron was not used at full power. Taking into consideration that, in a routine operating regime of the accelerator, no more than 17 MW are removed from TH2129 klystron, the upper limit of the energy spectrum should decrease down to 52 MeV, which still appears to be above the measured values.

The more important factor, which determines a decrease in the energy characteristics of the beam accelerated in the travelling-wave structure, is the "beam-loading" of the structure with a space charge of the accelerated beam. In the design project of the accelerator [2] possible energy losses of the beam owing to the beam-loading of the accelerating structure are estimated to be 10-20 % depending on the beam current. In work [4] calculations of the beam-loading effect were made for the accelerating structure with a constant gradient depending on the beam current duration. For a structure with the parameters similar to the parameters of the accelerating section of LUE-200, at the beam current duration of 100 ns the estimated "beam-loading" was more than 15 MeV. The "loading characteristics" of the accelerating section of LUE-200 measured at the initial stage of operation of the linac [3], – dependence of the position of the maximum of the beam energy spectrum on the accelerated beam current also has a declining character. As the beam current increased from 0.7 A to 2.6 A, a decrease in the beam energy reached 9-10 MeV. Thus, it is possible to assume that the difference between the measured energy parameters and the expected ones to a large extent can be explained by the beam-loading of the accelerating structure.

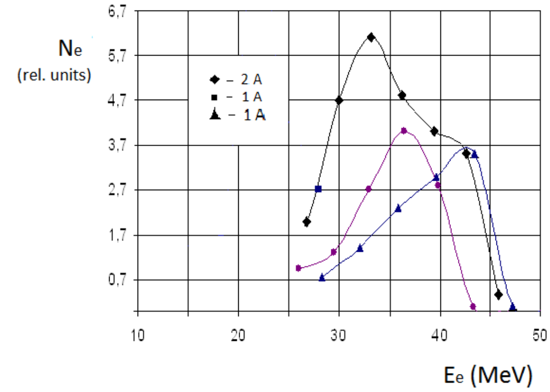

Figure 2: Energy spectra of the linac first stage measured at various beam currents.

The estimates of the integrated flux of neutrons produced in a tungsten photo-target, which were made at a distance of 10 meters from the target, give a value of $(3÷5)·10^{10}$ n/s. The density of the neutron flux on the shortest (available for experiments) flight path (10 m) is $(2.4÷4)·10^3$ n/cm^2·s. The results of the experiments performed on the neutron beams of the IREN facility were presented at the International Seminar on Interaction of Neutrons with Nuclei ISINN [5].

MAIN DIRECTIONS OF THE ACCELERATOR DEVELOPMENT

The main goal of the development of the linear accelerator is to increase the efficiency of the facility as a neutron source, i.e. to increase the neutron flux by increasing the average electron beam power by way of increasing the electron energy and the repetition rate. The main reference points for the accelerator development to the second stage are presented by the design parameters of 1993 in Table 1, but their realization, as before, will depend on the available possibilities.

The general scheme of the accelerator development is presented in Fig. 1. The main solution is based on the development of the accelerating system – an increase in the number of accelerating sections to two with the corresponding increase in the number of RF power sources (klystrons and modulators). In addition, the basic solution should be supplemented with the replacement of klystrons by more powerful ones (as regards both pulse and average output power) and, correspondingly, with the replacement of modulators by models with higher output power, as well as with the modernization of the electron gun.

The second accelerating section to be installed under the project is an exact analogue of the first accelerating section [6]. In the test experiments carried out with standard sections on a preinjector of the accelerating VEPP-5 complex the accelerating gradients up to 45 MeV/m were obtained at a beam current of ~ 1 A and

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duration of 15 ns [7]. The installation of the second section should be accompanied by the installation of the second RF-feeder feeding RF-power from a klystron together with the second SLED system. The additional acceleration of the beam in the second section should provide a gain in the beam energy comparable with the energy received by the beam in the first section.

In the new version of the modulator for PFN charging, special powerful high-voltage sources are proposed to be used [8]. The new modulator should form on-load high-voltage pulses of up to 23 kV, with a pulse power of up to 180 MW and a pulse rate of up to 120 Hz. A distinctive feature of the new modulator will be a possibility of reorganization of parameters within certain limits to match the impedance of the load, which can vary depending on the value of the impedance of klystron (variation of impedance in the range of 800-880 Ω).

The key elements that determine the possibilities of increasing power consumption of the accelerated beam are klystrons (RF-power supplies). Their output pulse power parameters determine the accelerating rate, and the value of maximum output average power determines the possibilities regarding the maximum pulse rate.

For the LUE-200 linac 5045 SLAC klystrons are the most preferable. However, because of their high commercial cost these klystrons still have limited application. The S-band klystrons that are developed and offered in the world market by Japanese (TETD, Mitsubishi) and Chinese (Hubei Hanguang Technology Co., LTD) companies, rank below 5045 SLAC klystrons both in output power and other operational parameters, but commercially are quite affordable. Klystrons of E37*** Toshiba series (more than 10 names) made by the Toshiba Electron Tubes and Devices Co., LTD, have a wide range of parameters as regards both output power and pulse duration. There are no exact analogues of 5045 SLAC klystron among them, but in 2011 the TETD company announced readiness to develop klystrons under a code name E37317 Toshiba for working with an RF-pulse width of 4 μs with output pulse power of 50 MW and capable to work with a pulse rate of up to 120 - 150 Hz. In the case of realization of these intentions the klystron choice options will be expanded.

The variants of the LUE-200 linac parameters upon the development of the second stage are presented in Table 2. When determining the main parameters of the accelerator second stage the following circumstances were taken into consideration:

- in order to increase the resolution of the time-of-flight neutron spectrometers, the beam pulse duration is reduced to 100 ns;
- real shortage of beam energy due to the beam-loading effect in the accelerating structure can reach 13-15 MeV.

As the next step toward the realization of the project of the linac second stage after the installation of the second accelerating section the modulator and klystron TH2129 will be replaced with klystron E3730A Toshiba. Therefore, with increasing repetition rate up to 50 Hz, the average power of electron beam may amount to ~ 1.5 kW.

Table 2: LUE-200 accelerator parameters upon the development of the second stage

Parameter	**BINP project**	**2-nd stage (options)**		
Number of accelerating sections	2 sections 2 klystrons	2 sections 2 klystrons	2 sections 2 klystrons	2 sections 2 klystrons
Type of klystron, klystron power	5045 SLAC 67 MW	5045 SLAC 60 MW	E37XXX Toshiba 50 MW	E3037A Toshiba 50 MW
Maximum electron energy	212 MeV	>180 MeV	167 - 180 MeV	167 - 180 MeV
Average beam current in pulse	1.5 A	1.5 A	1.5-2.5 A	1.5-2.5 A
Current pulse duration	250 ns	100 ns	100 ns	100 ns
Repetition rate	150 Hz	150 Hz	120 Hz	50 Hz
Average beam power	≈ 12 kW	4 kW	3.1-4.6 kW	1.3-1.9 kW

CONCLUSION

The proposed variants of the linac development will allow us to increase an electron beam average power by a factor of 5-10, which should enhance the neutron flux intensity in the same proportion. The further development of the IREN facility to achieve the design parameters can be accomplished by using klystrons with high average power, and also by replacing a non-multiplying target with a multiplying subcritical assembly.

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