https://doi.org/10.46813/2025-156-159

VACUUM SYSTEM OF THE NSC KIPT SCA "NEUTRON SOURCE". THE FIRST SECTION OF THE LINER ACCELERATOR

A.N. Gordienko, V.G. Grevtsev, I.M. Karnaukhov, A.O. Mytsykov, A.Yu. Zelinsky
National Science Center "Kharkiv Institute of Physics and Technology", Kharkiv, Ukraine
E-mail: zelinsky@kipt.kharkov.ua

In the paper the general layout and detail description of the accelerator injection part vacuum system of the 100 MeV/100 kW electron linear accelerator – driver of the NSC KIPT Subcritical assembly is presented. The use of the accelerator vacuum equipment types is justified. The conditions to reach the operative vacuum value are described and results of the vacuum system operation during facility physical start-up are presented.

PACS: 29.17+w.Dh, 29.25.Dz

INTRODUCTION

220 kW Subcritical Assembly Neutron Source (SCA) with 100 MeV/100 kW electron linear accelerator [1] was designed, developed and put in operation in National Science Center "Kharkiv Institute of Physics and Technology" (NSC KIPT). The SCA is the facility of the new type, so called Accelerator Driven System (ADS) and till now is innovation facility without analog in the world. The facility passed through the stage of the physical start-up [2, 3] and now NSC KIPT is preparing to the next stage of the nuclear facility exploitation, that is pilot operation. During the regular operation the facility will provide the wide spectrum of the scientific technological applications like neutron physics, medical isotope productions, material science, nuclear safety, charged particle etc. NSC KIPT SCA neutron source should play key role in investigations with neutrons and nuclear power plants in Ukraine.

The accelerator vacuum system is one of the key support systems that should provide electron beam transportation without beam losses. This system should work under an ultra-high vacuum condition. The vacuum system would select reliable and stabilize high vacuum pumps.

COMPOSICION AND PUMPING PREPARING

The first accelerating section (Fig. 1, 2) is one of the main components for beam formation, electron beam phasing and beam position correction to transport electron beam from electron gun [4] with minimal beam losses through magnetic elements, solenoids, collimator and through the vacuum chamber of the injection part of the accelerator [5] and should provide residual gas pressure not worse than $5.0\cdot10^{-8}$ Torr ($6.65\cdot10^{-6}$ Pa).

To determine the vacuum pump performances and their allocation in the system. It can be done with basic equation of vacuum technic for gas flow in the system:

$$U = {Q}/{(P-P_p)} \tag{1}$$

or

$$1/U = 1/S + 1/S_p, \tag{2}$$

where U is gas flow; P is the pressure at the exit of vacuum camera; P_P is the pressure at the entrance of vacuum camera; Q is the value of gas running through the system in time unit; S is pump performance; S_P is pumping speed.

Summarizing the value of gas flow U_i at each vacuum element between pumps one can determine the gas flow of the pumping section.

$$U^{-1} = \sum_{i=1}^{n} U_i^{-1}. \tag{3}$$

Fig. 1. The first section of the electron accelerator (right view)

Fig. 2. The first section of the electron accelerator (left view)

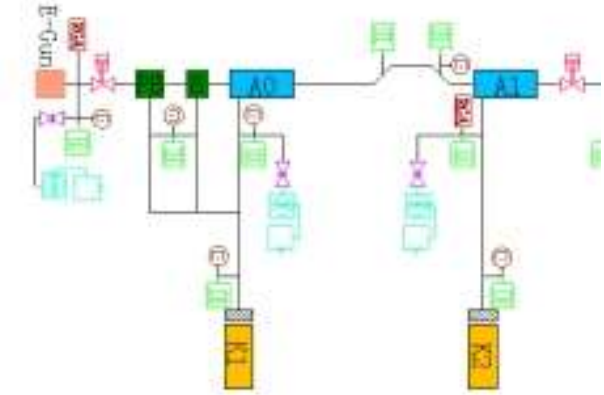


Fig. 3. Layout of the injection part of the accelerator

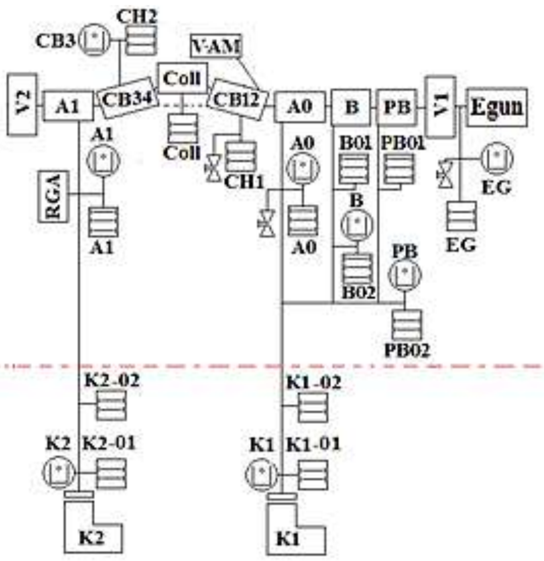
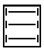
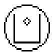


Fig. 4. Layout of the vacuum system of the injection part of the accelerator

At the Fig. 3, 4 the following designation are used:

Egun	– electron gun,		– diode pump,
PB **B**	– pre-buncher and buncher,		– triode pump,
CB.....	– electromagnetic chicane,		– vacuum measurement probe,
Coll	– collimator,		– angular manual valve,
	– klystrons,	**V**-....	– angular manual probe
A –....	– accelerating sections,		

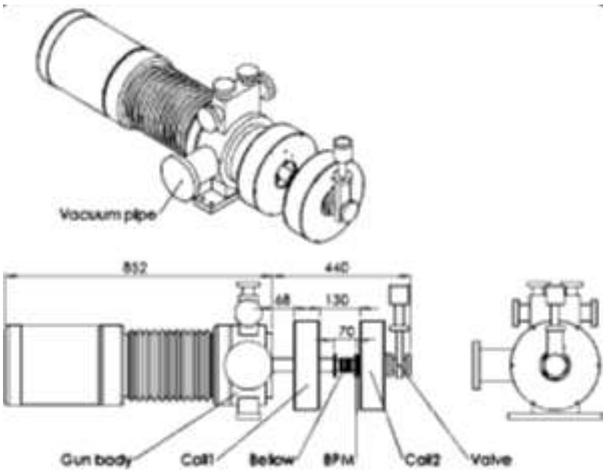


Fig. 5. Components layout between the electron gun and the pre-buncher

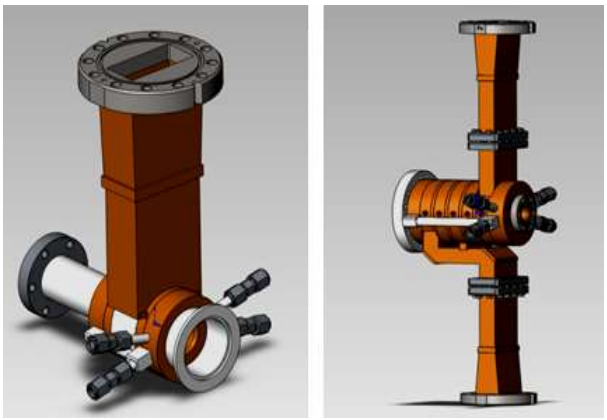


Fig. 6. Pre-buncher cavity (left) and Buncher (right)

Figs. 3, 4 show layout of the vacuum equipment allocation of the accelerator injection part.

The vacuum system of the NSC KIPT mainly consists of the sequence of tubes, volumes and holes (diaphragms) (Figs. 5–8). Sizes of pre-buncher are 50.8/25.4 mm.

The buncher has diameter of 83.92 mm and sickness of 5.84 mm. The diaphragm iris diameter is of 22.616 mm.

The accelerating section parameters are:

Number of cells	34 + 2 coupler cells	
Section length	1260 (36 cells)	mm
Cell length	34.989783	mm
Disk thickness	5.84	mm
Iris diameter	27.887…23.726	mm
Cell diameter	83.968…82.776	mm

Fig. 7. Accelerating section of the accelerator (general view)

Fig. 8. Accelerating section of the accelerator (model)

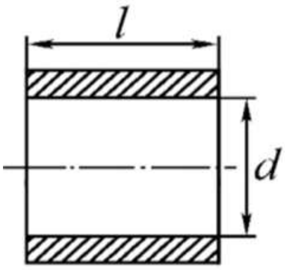


Fig. 9. The diagram of the straight pipe section.

For the straight pipe section (Fig. 9) The following expression can be used:

$$U = 3.64F\left(T/_M\right)^{1/_2}, \tag{4}$$

where F is a square of the hall, cm^2; M is a gas molecular mass; T is a temperature in K.

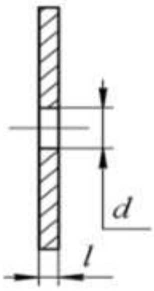


Fig. 10. The diagram of the straight pipe section

For the diaphragm (Fig. 10) the following formula can be used:

$$U = U = 3.81d^3\left(T/_M\right)^{1/_2}, \tag{5}$$

where d is diaphragm iris, cm^2; l is the diaphragm thickness, cm^2.

The total volume of the accelerator injection part is 145 l. The length of the first section is 8 m, and together with electron gun is 9 m.

Vacuum chambers are made of 316 LN stainless still and pre-buncher, buncher, accelerating sections and RF wave guides are made of pure oxygen free cooper. The forms of the chambers and wave guides, structural materials allow to fabricate high vacuum after vacuum-thermal processing.

Taking into account the vacuum conditions for the successful accelerator operation without electron beam losses (Table 1) and all mentioned above allow to specify the pumping equipment for the Subcritical Assembly Neutron source.

Required conditions for the stable electron beam operation in the accelerator are provided by the magnetic-discharge pumps PS series with different pumping speed.

At electron gun 200 l/s diode-type ion pumps is installed. 70 l/s triode-type ion pumps are installed at the beginning of the accelerating section A0 (see Figs. 3, 4).

In the chicane scheme (Fig. 11) the vacuum system also includes a cold cathode gauge, two 100 l/s diode-type ion pumps, two tri-port vacuum chambers, a collimator, a by-pass vacuum chamber and some bellows. The collimator will be heated by the beam. According to the simulation result the highest temperature in the collimator is less than 65 °C under the water-cooling condition. Considering the limited space the vacuum chambers of CB1 and CB2, CB3 and CB4 are integrated to save the space. A schematic diagram of the chicane without BPM (beam position monitor) and bellows is shown in Fig. 11.

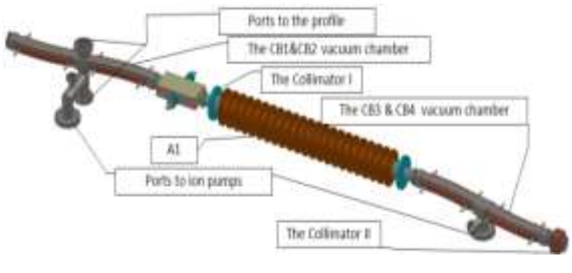


Fig. 11. Chicane vacuum chamber layout

Table 2 shows ion pump types and positions of the accelerator vacuum system pumping units.

As the first step of the vacuum fabrication the necessary residual gas pressure should be provided to start magnetic-discharge pumps. The start of the magnetic-discharge pump with low vacuum value leads to the decreasing of the pumping speed and deterioration of the “limit” pressure.

Table 1

Required parameters of the accelerator vacuum system

Position	Ultimate pressure, mbar	Working pressure, mbar
Triode gun	$1 \cdot 10^{-9}$	$7 \cdot 10^{-9}$
Accelerating structures	$3 \cdot 10^{-8}$	$1.5 \cdot 10^{-7}$ (after beam aging)
Section measure	$3 \cdot 10^{-8}$	$5 \cdot 10^{-8}$

Table 2

Ion pump types and positions of the pumping units of the accelerator vacuum system

No.	Place of installation	Pump type	Place at the accelerator layout (see Figs. 1, 2)	Power supply
1	E-gun	200 l Triode Ion Pump	E-gun	Diode Ion Pump PS, 6 kV/600 W/200 mA
2	Pre-buncher	70 l Triode Ion Pump	PB 01	Triode Ion Pump PS, 6 kV/600 W/200 mA
3		150 l Diode Ion Pump	PB 02	Triode Ion Pump PS, 6 kV/600 W/200 mA
4	Buncher	70 l Triode Ion Pump	B 01	Triode Ion Pump PS, 6 kV/600 W/200 mA
5		70 l Triode Ion Pump	B 02	Diode Ion Pump PS, 6 kV/600 W/200 mA
6	Chicane	100 l Diode Ion Pump	CH 1	Diode Ion Pump PS, 6 kV/600 W/200 mA
7		100 l Diode Ion Pump	CH 2	Triode Ion Pump PS, 6 kV/600 W/200 mA
8	Collimator	100 l Diode Ion Pump	COLL	Triode Ion Pump PS, 6 kV/600 W/200 mA
9	Accelerating sections	70 l Triode Ion Pump	A 0	Triode Ion Pump PS, 6 kV/600 W/200 mA
10		70 l Triode Ion Pump	A 1	Triode Ion Pump PS, 6 kV/600 W/200 mA
11	Klystrons	150 l Diode Ion Pump	K1 - 1	Triode Ion Pump PS, 6 kV/600 W/200 mA
12		150 l Diode Ion Pump	K1 - 2	Triode Ion Pump PS, 6 kV/600 W/200 mA
13		150 l Diode Ion Pump	K2 - 1	Triode Ion Pump PS, 6 kV/600 W/200 mA
14		150 l Diode Ion Pump	K2 - 2	Triode Ion Pump PS, 6 kV/600 W/200 mA

To get low level outgassing from inside accelerator vacuum chamber walls the ultrasonic cleaning with further heating were maid [6, 7]. Step by step ultrasonic cleaning and bake out was adopted. To analyze residual gas of the accelerating structure, the quadruple mass spectrometer (RGA) with sensitivity down to 10^{-12} mbar partial pressures was used. The visual result of the surface cleaning quality is that after full vacuum chamber connections and vacuum equipment installation the design, operation residual gas pressure was obtained and optimal composition of the residual gas with minimal content of heavy hydrocarbon was obtained. It provided stable accelerator operation during facility physical start-up.

To measure and monitor the vacuum system, the cold cathode gauges are used. All vacuum equipment units are monitored and supervised by the accelerator control system. A fast-closing valve was installed at the entrance of the dump to protect the vacuum system from the film break suddenly. The ceramic vacuum chamber installed in the beam scanning area. An additional requirement is the pneumatically operated all-metal vacuum gate valve is used in the accelerator sections to isolate the atmospheric and the total vacuum system to avoid leakage.

The parameters of the power supplies of the accelerator, that are voltage, power and current are equal for each ion pump and are 4 kV/600 W/200 mA.

Power supply sources and control units SP-D/T (*Shanghai SanJing Vacuum Equipment Company*) for all pumps of PS series and are connected with ion pumps with high voltage cable (Fig. 12). Control of the power supply source is realized with micro-controllers “Mini 2440”.

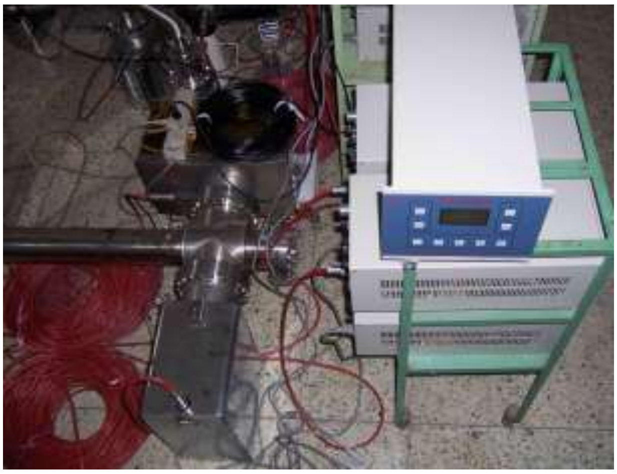


Fig. 12. Power supply source and control unit SP-D/T with ion pump

All power supplies and controllers of the vacuum system are installed in the Racks, as it shown in Fig. 13.

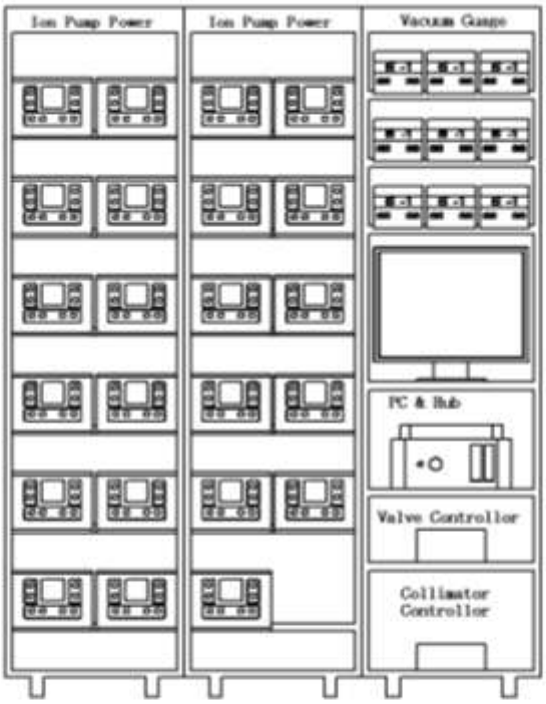


Fig. 13. Racks for the power supply and vacuum system control units

PRELIMINARY PUMPING

To obtain the design vacuum operation conditions for the functioning of the magnetic discharge pumps it is necessary to provide preliminary pumping with oil free mechanical turbo-molecular pump and fore vacuum pump. Such set of pumps can provide limit pressure up to ~ 10^{-9} Torr [7]. For such purposes, the fore vacuum pump ScrollVac SC 15D and turbo-molecular pump TURBOVAC SL 300 with power supply source and control block TURBO.DRIVE 400 (Oerlicon Leybold Vacuum) were used.

Pressure was measured with vacuum meter of ITP 90 series that is combination of ion probe with incandescent cathode for the pressure measurement up to $2 \cdot 10^{-2}$ Torr and Pirani probe that works with a range $5.5 \cdot 10^{-3}$ Torr and lower.

Residual gas was measured with a vacuum gauge with a cold cathode pressure sensor of the IKR - 050 type is used (Fig. 14).

Fig. 14. Pressure probe with cold cathode (IKR - 050)

Such equipment was incorporated in a single mobile unit for the preliminary pumping (Fig. 18). The connection of the unit to the accelerator body is determined by the technological necessity.

Connection of the preliminary pumping unit with the accelerator vacuum volume was made with manual right-angle valve series 540 DN 40 through flexible metal bellows adapter (Fig. 15).

To divide vacuum volume of the accelerator during pumping process and in the case of some accident or failure in the vacuum system automatic metal, pneumatic, fast gate valve of DN 16 – 40 (Fig. 16) and DN 63 – 160 (Fig. 17) is used. It can be used in both manual and remote mode.

Fig. 15. Right angle valve

Fig. 16. Fast gate valve DN 16 – 40

Fig. 17. Fast gate valve DN 63 – 160

Fig. 18. Preliminary pumping mobile unit

During preliminary pumping all valves are closed and turbo pumps unit is connected to the one of the sections of the accelerator vacuum section. When the vacuum value reaches the necessary value for the magnetic discharge pumps operation the magnetic discharge pumps are switch on, turbo pumps unit is connected to the next accelerator vacuum section. When the accelerator vacuum volume is pumped accelerator is ready for operation.

When accelerator is not operated the valves are closed but ion pumps are in operation. Before accelerator operation vacuum valves are opened one by one. Fig. 19 show the dynamic of the vacuum value changes during the pumping of the injection part of the accelerator. During pumping the E-gun was pumped and vacuum valve was closed. The valve of the accelerating section was closed too. As one can see in the Fig. 19 after more than 500 h (21 days) the vacuum value became stable that means the limit value of the vacuum was reached. The long process of vacuum pumping of the accelerating section was carried out step by step in four stages. This allows to reduce the load on the pumps and extend their service life.

During the facility physical start-up, the pressure of the residual gas in the accelerator vacuum chamber reached the value that is higher than $5 \cdot 10^{-9}$ Torr.

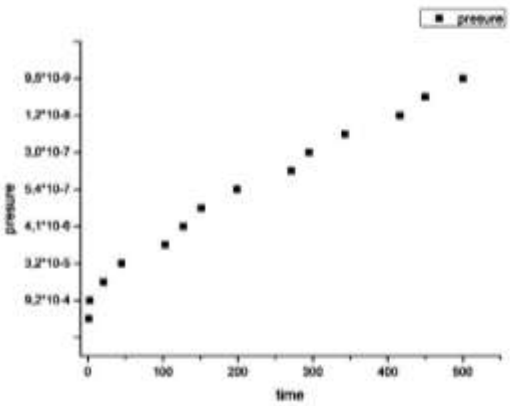


Fig. 19. The dynamic of the vacuum value changes during the pumping of the injection part of the accelerator

Fig. 20 shows the panel of vacuum monitors after pumping completion. As one can see the highest vacuum value is about $5.5 \cdot 10^{-9}$ Torr.

EG	PB	A0
A1	B	CB3
A5	A6	ST
A2	A9	-
K1	K3	K5
K2	K4	K6

Fig. 20. Vacuum monitor panels in the klystron gallery cabinet after accelerator pumping completion

CONCLUSIONS

The vacuum system of the 100 MeV/100 kW electron linear accelerator – driver of the NSC KIPT Neutron Source was designed and developed in accordance with original design. The system is oil free. All connections and vacuum equipment units are made of metal. The system was tested and after preliminary pumping put in operation.

During the tests the high vacuum value up to $2 \cdot 10^{-9}$ Torr was provided. Such value of the vacuum was reached during several days from atmosphere till the highest value and further was stable without deviations. It means that vacuum chamber inside walls are clean, without outgassing and vacuum chambers do not have leakages.

The operating vacuum system provided successful physical start-up of the NSC KIPT SCA “Neutron Source”.

REFERENCES

1. A. Zelinsky, O. Bezditko, P. Demchenko, et al. NSC KIPT neutron source on the base of subcritical assembly driven with electron linear accelerator // *Proceedings of IPAC 2013*. 2013, p. 3481-3483.

2. I.M. Karnaukhov, O.P. Bezditko, B.V. Borts, et al. Reactivity measurement methods and the first results of the physical start-up for the nuclear subcritical facility “Neutron Source // *Ukr. J. Phys.* 2023, v. 68, p. 147-161.

3. I.M. Karnaukhov, O.P. Bezditko, B.V. Borts, et al. Research of neutron-physical characteristics of the

Subcritical Nuclear Facility "Neutron Source" of NSC KIPT during the physical start-up // *Dopov. Nac. akad. nauk Ukr*. 2024, N 3.

4. O. Bezditko et al. Electron gun for 100 MeV/100 kW linear accelerator of electrons as a driver of nuclear subcritical assembly neutron source // *Proc. of LINAC'2018,* 16-21, September, 2018. Beijing, China, TUPO002; http://www.JACoW.org

5. I.M. Karnaukhov et al. Linear Accelerator Magnetic System of the NSC KIPT Subcritical Assembly "Neutron Source" // *Problems of Atomic Science and Technology*. 2024, N 3, p. 92-100.

6. B.D. Ershov et al. *Synchrotron accelerator vacuum systems and accelerator storage complexes,* Revie OA-49. L.: NIIEFA, 1982, 101 p.

7. A. Gordienko, V. Gretsev, O. Zvonareva. Problems to fabricate and keeping the ultra-high vacuum in the storage ring N-100 M – the source of on Compton radiation NESTOR // *Problems of Atomic Science and Technology*, 2009, N 6 (64), p. 56-59.

Article received 04.03.2025

ВАКУУМНА СИСТЕМА ПКЗ «ДЖЕРЕЛО НЕЙТРОНІВ» ННЦ ХФТІ. ПЕРША ПРИСКОРЮЮЧА СЕКЦІЯ ЛІНІЙНОГО ПРИСКОРЮВАЧА

О.М. Гордієнко, В.Г. Грєвцев, І.М. Карнаухов, А.О. Мициков, А.Ю. Зелінський

Наведені загальна структура та детальний опис вакуумної системи інжекційної частини 100 МеВ/100 кВт лінійного прискорювача електронів, який є драйвером підкритичного «Джерела нейтронів» ННЦ ХФТІ. Обгрунтовано використання обладнання, яке встановлене у вакуумній системі. Визначені умови що до досягнення проектного значення тиску у вакуумних камерах прискорювача. Наведені результати вимірювань тиску в період фізичного пуску джерела нейтронів.