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VACUUM SYSTEM OF THE NSC KIPT SCA "NEUTRON SOURCE". BENDING PART OF THE LINER ACCELERATOR TRANSPORTATION CHANNEL

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In NSC KIPT (Kharkiv, Ukraine) department of nuclear and accelerating systems the subcritical assembly "Neutron Source" is under pilot operation. The driver of the facility is electron linear accelerator of 100 MeV/100 kW. In the paper the vacuum system of the bending part of the accelerator transportation channel is described. The features, characteristics and equipment layout of the system are described too. The chois of the equipment specifications are explained and the conditions of the design vacuum parameters for design vacuum pressure obtaining are justified.

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INTRODUCTION

After put in regular operation the nuclear NSC KIPT Subcritical Assembly (SCA) facility with 100 MeV/100 kW linear electron accelerator [1 - 4] will solve several important scientific and technical tasks such as neutron physics, high current electron beam dynamics, solid state physics, medical isotope production, nuclear and radiation safety etc. The facility will play the key role in investigations of Ukrainian power plant neutron physics and construction materials.

One of the most important facility supporting systems of the accelerator is vacuum system which should provide electron beam formation, acceleration and transportation without losses and beam delivery to the neutron generating target (NGT) [5]. To provide the performance of all tasks mentioned above the vacuum system should satisfy the conditions of ultra-high vacuum (UHV).

Vacuum system of 100 MeV/100 kW linear electron accelerator that is driver of the3 NSC KIPT SCA "Neutron Source" was developed and put in operation in accordance with original design [2, 6]. The system is oil free. All vacuum chambers are made of 316 LN stainless steel, and NGT chamber of aluminum deformable alloy SAV-1 [5]. The vacuum chamber of the electron gun has ceramic cylinder to separate high voltage part from system [7, 8]. Vacuum chamber of the scanning magnets has ceramic insertion [9] to provide functioning of the transportation channel scan above the top of the NGT to provide uniform electron beam distribution density at the NGT [10]. Input of the electron beam to the target from the bending part of the electron beam transportation channel is made with vacuum sealed aluminum window.

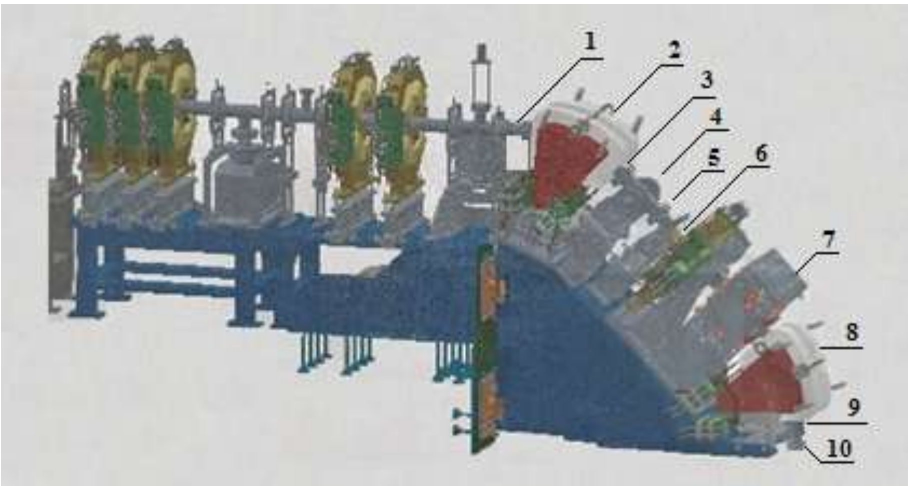


Fig. 1. Layout of the bending part transportation channel:
1 – Input vacuum chamber; 2 – the first bending magnet TB-1 chamber; 3 – output first bending magnet TB-1 vacuum chamber; 4 – Pick-ups; 5 – screen lame monitors; 6 – Quadrupole magnet; 7 – Scanning magnets; 8 – Second bending magnet TB-2; 9 – Output second bending magnet TB-2 vacuum chamber; 10 – Output flange

LAYOUT OF THE VACUUM SYSTEM BENDING PART

Bending part of the NSC KIPT SCA “Neutron Source” electron beam transportation channel (Fig. 1) roughly can be divided on three parts (Fig. 2):

1. From fast pneumatics valve at the beginning of the bending part till the first bending magnet (TB-1) [9].
2. From the entrance to the first bending magnet TB-1 till the exit from the second bending magnet TB-2.
3. From the exit from the second bending magnet TB-2 till the vacuum window of NGT.

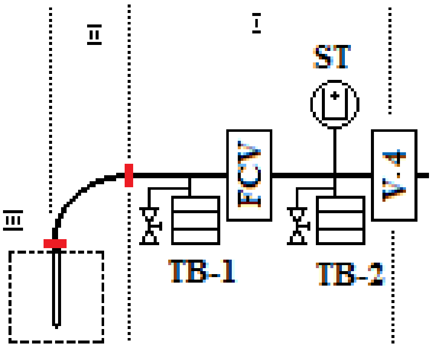


Fig. 2. Layout of the bending part vacuum system equipment location

Fig. 2 shows the division into three and location of the vacuum equipment of the bending part. Table 1 shows the list of vacuum equipment.

Fig. 1 shows the layout the transportation channel bending part. The total length of the vacuum system of the bending part of the electron beam transportation channel is 6.7 m with inside volume of about 63 l. Fig. 3 shows the layout of the final part of the vacuum system of the transportation channel.

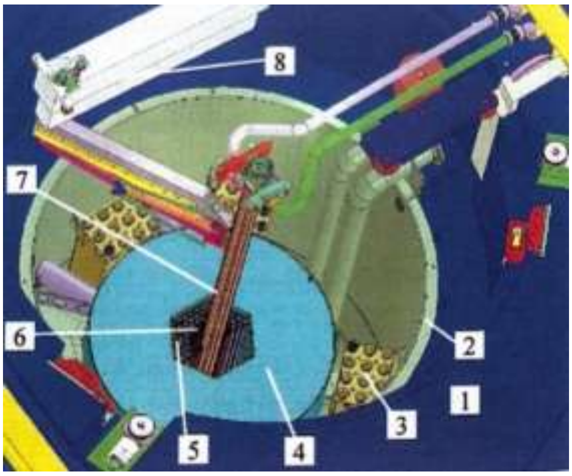


Fig. 3. Layout of the SCA with final part of the transportation channel vacuum system:
1 – core bioshielding; 2 – SCA core tank; 3 – shelf for fuel loading; 4 – ring graphite reflector; 5 – berilium reflector; 6 – fuel elements; 7 – NGT; 8 – fueling machine

After passing of the horizontal part of the accelerator the electron beam should be bend on 90° in vertical plane to the NGT. This is provided with two 45° dipole magnets and one quadrupole magnet between them. The view of the bending magnet is showed in Fig. 4.

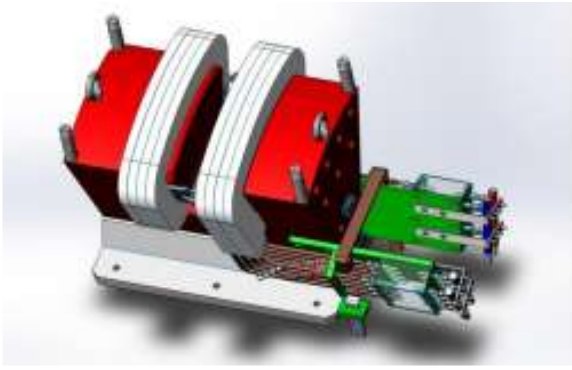


Fig. 4. 3D mechanical model of transportation channel bending magnet

View of the input and output flanges of the bending part vacuum system are shown in Figs. 5, 7.

The input flange of the bending part (see Fig. 5) by VARIAN production is tightened with fast released vacuum clamp (Fig. 6). To seal the connection vacuum gasket EVAC CF-80 type is used.

The connection of output bending part with NGT vacuum chamber is made with originally designed and developed vacuum flange (see Figs. 7, 16) which is clamped with originally designed fast released vacuum clamp (Fig. 8) with vacuum gasket of EVAC CF-100 type.

Fig. 5. Connection unit of the horizontal and bending part of the accelerator vacuum system

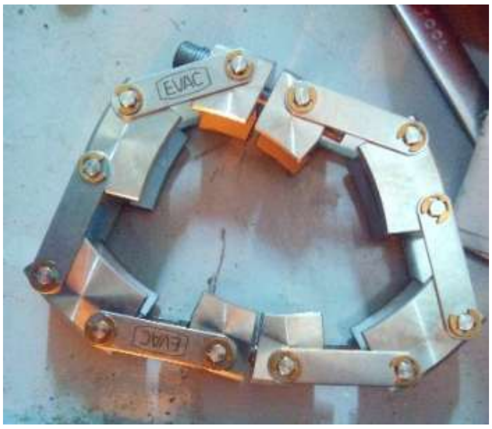


Fig. 6. Fast released vacuum clamp to connect horizontal and bending part of the accelerator transportation channel vacuum system

Fig. 7. Connection unit of the bending part and NGT vacuum chamber

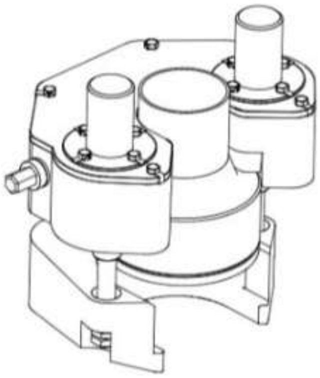


Fig. 8. Fast released vacuum clamp of the NGT vacuum pipe

PUMPING EQUIPMENT AND SYSTEM PUMPING

Vacuum system of the NSC KIPT "Neutron Source" linear accelerator should provide UHV of about $5.0 \cdot 10^{-9}$ Torr in the electron beam transportation channel.

The preliminary under pressure in the accelerator vacuum system that is necessary for operation of high vacuum ion pumps is provided with oil free mechanical (fore vacuum) and turbomolecular pumps [6]. Ion (magnetic discharge) pumps of PS series are the main operation pumps of the linear accelerator vacuum system.

One can to determine the necessary capacity of the pumps which are necessary to produce the residual gas pressure in the transportation channel (about $5.0 \cdot 10^{-9}$ Torr) with the use of the fundamental equation in vacuum technology for the gas flux in the system [11]:

$$U = {}^{Q}\!\big/_{(P - P_p)} \qquad (1)$$

or

$$ {}^{1}\!/_{U} = {}^{1}\!/_{S} + {}^{1}\!/_{S_p}, \qquad (2)$$

where U is gas flow; P is pressure at the exit of the vacuum chamber; P_P is the pressure at the entrance of the vacuum chamber; Q is the volume of the gas that passes through the system in time unit; S is pump capacity; S_P is pumping speed.

Considering all necessary parameters for the accelerator bending part vacuum system and number of pumps as two the capacity of the pumps was estimated as 200 l.

Parameters of the pump power supplies for the bending part of the vacuum system are shown in Table 2.

Power supplies for the pumps and controllers of the vacuum probes are installed in control cabinets which are set in the klystron gallery. Controllers are operated with Mini controllers of "Mini 2440" type.

To divide vacuum volumes of the regular accelerator part and bending part of the transportation channel during the pumping and prevent the system from damages in the case of vacuum failure the automatic, metal, pneumatic quick valve of DN 16-40 (V-4) with closing time of 1 s (Fig. 9) by VAT production.

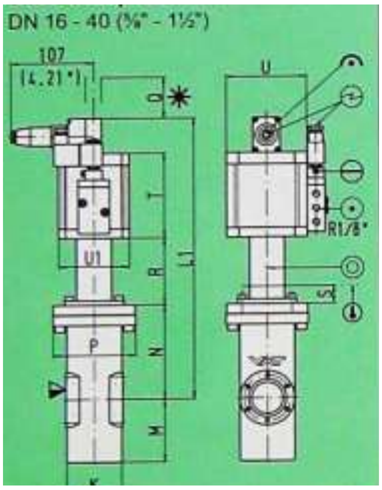


Fig. 9. Valve with pneumatic actuator
▼ – valve seat side; ✳ – required for dismantling; ⊙ – compressed air connection; ⊖ – electrical connection; ⊖ – emergency operation; ◎ – leak detection hole; ⏀ – bake-out area; – mechanical position indication

Addition defense device that is installed in the very end of the horizontal part of the accelerator is fast shut-off vacuum valve of DN 63-200 type with response time of 15…20 ms. It defenses bending part and NGT from the sudden rupture of the vacuum system wall or flange in the regular part of the accelerator and opposite to defend the accelerator from the damage in the bending part. The view of the fast valve is shown in Fig. 10.

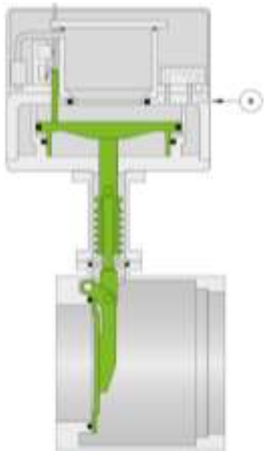


Fig. 10. UHV Fast Closing Valve (Closed)

The main requirement to the fast valve is fast and reliable response on the sudden atmosphere rupture to the vacuum chamber. The lid of the device has a metal seal and weld metal bellows seals the vacuum chamber. The valve is operated under control of individual control unit with posibility to set the parameters for operation. and monitoring the status of the system, vacuume probes and connections (Fig. 11). Other pumping devices.are operated under control of the accelerator control system.

Fig. 11. Fast valve control unit

PRELIMINARY PUMPING

At the first stage of the necessary residual gas pressure providing in the accelerator vacuum chamber it is necessary to provide the residual gas pressure value less than $\le 1 \cdot 10^{-6}$ or $\le 0.75 \cdot 10^{-6}$ Torr. The start of the magnetic charging pumps with residual gas pressure value that is more than mentioned above leads to the decreasing of the pumping speed and the value of "limit" pressure. In addition, it leads to the decreasing of the pump operation time [12].

Preliminary pumping of the SCA "Neutron Source" accelerator vacuum volume is done with oil free fore vacuum and turbomolecular pumps. This set of the pumps, composed as a movable unit of preliminary pumping (Fig. 12) allows to reach the limit residual gas pressure of about ~ $1 \cdot 10^{-7}$ Torr.

Fig. 12. The preliminary pumping unit in operation

Connection with the accelerator vacuum volume is done with manual 90° vacuum valve 540 DN 63-160 by VAT production (Fig. 13).

During preliminary pumping all intermediate vacuum section are closed with valves and preliminary pumping unit is connected to the bending part of the accelerator.

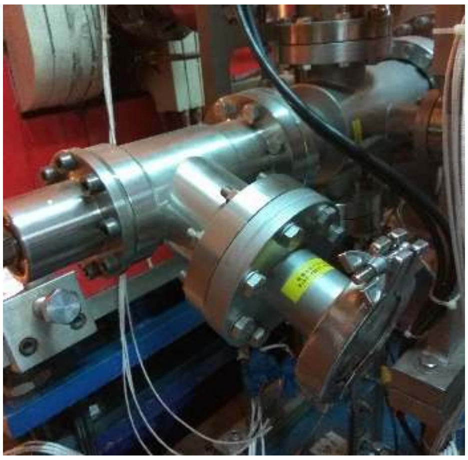


Fig. 13. UHV all metal angle valve

Fig. 14. Pressure probe IKR - 050

Fig. 15. Vacuum monitor panel in the klystron gallery cabinet

Table 1

Vacuum equipment of the bending part

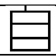
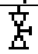
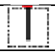
	– diode pump	V.4	– angular manual probe
	– vacuum measurement probe	FCV	– Fast closing valve
	– angular manual valve		– special quick flange
	– NGT	–	–

Table 2

Ion pump types and positions of the pumping units of the beam part

No.	Place of installation	Pump type	Power supply
1	TB-1	200 l Diode Ion Pump	Diode Ion Pump PS, 4 kV/600 W/200 mA
2	TB-2	200 l Diode Ion Pump	Diode Ion Pump PS, 4 kV/600 W/200 mA

When residual gas pressure reaches the value that satisfies the magnetic charging pump operation conditions the preliminary pump unit is shut off and disconnected. When residual gas pressure reaches the design value the accelerator is ready for operation and should be under permanent pumping of the magnetic charging pumps [13].

Monitoring of the residual gas pressure in the bending part of the accelerator vacuum chamber is realized with vacuum meter with cold cathode pressure probe IKR-050 (Fig. 14) and measuring block (Fig. 15).

NEUTRON GENERATING TARGET

Fig. 16. NGT under testing

NSC KIPT SCA "Neutron Source" was design to use two types of NGT [5]. One is used tungsten (W) plates. The other one is used uranium plates (^{235}U) covered with tantalum. During SCA facility physical start-up the tungsten NGT was used that was provided by the facility physical start-up program and by the program of the facility pilot operation.

Technically, the construction of the NGT consists of two units (Fig. 17). These are NGT itself and vacuum pipe which provides delivery of the electron beam to the surface of NGT and delivery of the cooling water to the NGT. Both parts are connected to each other with welding. The housing of NGT with NGT itself inside is filled with demineralized water. Both units are divided with vacuum window. The tungsten NGT has 138×144×2624 mm and mass of about 14 kg.

Unlike accelerator vacuum chamber which made of stainless steel NGT units are made of aluminum alloy SAV-1 (Al-Mg-Si), which is strengthened by heat treatment and natural aging (limit strength at stretching is 217…233 MPa at 20…25 °C). The content of the aluminum in the alloy is 97.5…98.5%.

Before NGT installation and vacuum part vacuum sealing the tests for vacuum tightness were carried out (see Fig. 16). After some mechanical troubles the valve was successfully sealed and designed value of the residual gas pressure was provided.

To have possibility to change or remove NGT the bending part can be disconnected from each other with fast vacuum (see Fig. 8) and water valve and turned at 45 in horizontal plane (Fig. 18).

After technical operations bending part of the transportation channel can be returned back in the design position and sealed as for the vacuum as well for the cooling water.

In addition, the new type of vacuum gasket made of led (Pb) of 5 mm thickness and with stainless steel rim was successfully tested (Fig. 19).

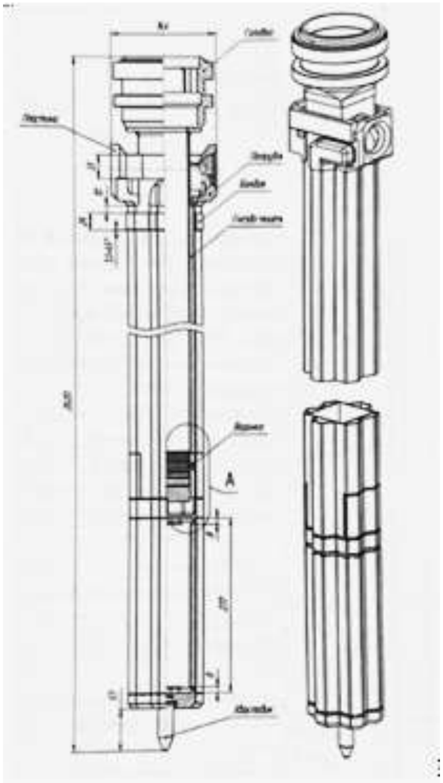


Fig. 17. Vacuum chamber of NGT with originally designed flange and NGT

Fig. 18. View of the bending part of the transportation channel that is ready for the NGT installation (turned at 45°)

This gasket was designed and manufactured for the test activity to make the tests cheaper and to safe spare regular gaskets. Plasticity of the led and high outgassing increased the pumping time to the limit residual gas pressure. The test pumping was carried out in a few steps that decreased the loading on the pumps. The satisfactory results of the tests allow to continue further works on NGT installation, and vacuum tests and physical start up.

During the facility start up with high voltage at pump power supply equal to 4 кV and magnetic charging pump currents equal of about 3.8 μA in TB-1 pump and 0.5 μA in TB-2, the residual gas pressure in the bending part of the accelerator vacuum system was of about ~ $5.8 \cdot 10^{-9}$ Torr.

Fig. 19. Lead vacuum gadget

The power units of the pumps during vacuum pumping are shown in the Fig. 20.

Fig. 20. TB-1 and TB-2 in operation

After accelerator vacuum chamber final pumping till the limit value and accelerator stable mode turning with low electron beam current (up to 40 mA) the activity on physical start with fuel elements loading in the facility core was started (Fig. 21) [3]. In addition, the monitoring of the vacuum value with high electron beam current (up to 2 A) was done. It showed, that vacuum value was not spoiled with increasing of the electron beam current.

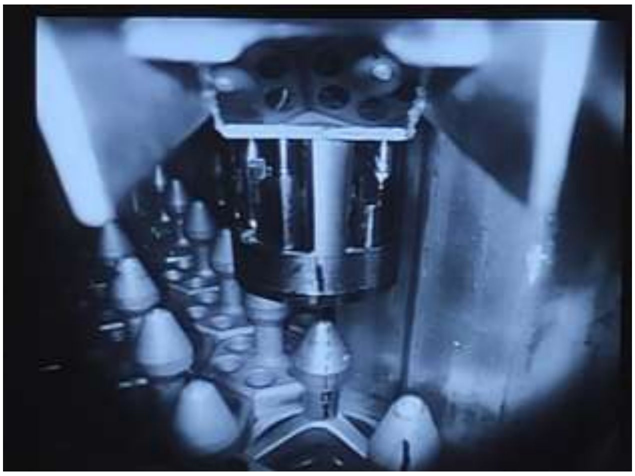


Fig. 21. Fuel elements loading in the SCA facility core

CONCLUSIONS

The vacuum system of the 100 MeV/100 kW electron linear accelerator – driver of the NSC KIPT SCA “Neutron Source” facility was designed, developed and put in operation at NSC KIPT together with IHEP, Beijing, China and with support of Argon

National Laboratory, Chicago, USA. The system was successfully tested and passed through the State individual tests. During the system adjustment and preparation to the State individual and comprehensive tests the residual gas pressure in the accelerator vacuum chamber reached the value of ~ $5.8 \cdot 10^{-9}$ Torr. It allows to carry out the stage of the facility physical start-up. During tests and physical start-up the residual gas pressure was stable and any vacuum failure happened. The accelerator system is ready for pilot operation, has high cleanness of the intrinsic vacuum chamber walls, low value of outgassing and tight vacuum sealing between accelerator vacuum sections. During pilot operation the SCA facility should provide design electron beam power of 100 kW.

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ВАКУУМНА СИСТЕМА ПКЗ «ДЖЕРЕЛО НЕЙТРОНІВ» ННЦ ХФТІ. ПОВОРОТНА ЧАСТИНА ЛІНІЙНОГО ПРИСКОРЮВАЧА

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

У Відділі ядерних та прискорювальних систем ННЦ ХФТІ (Харків, Україна) ведуться роботи з введення в експлуатацію Підкритичного складання «Джерело нейтронів». Основою установки є лінійний прискорювач електронів 100 МеВ/100 кВт. Описано вакуумну систему поворотної частини лінійного прискорювача електронів – драйвера підкритичної збірки, її особливості, характеристики та детальне компонування. Обґрунтовано вибір вакуумного обладнання прискорювача, описано умови досягнення робочого тиску та представлено результати роботи вакуумної системи при фізичному пуску установки.