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# NEW VACUUM CHAMBER OF THE BENDING PART OF THE INJECTION CHANNEL OF THE NSC KIPT SCA "NEUTRON SOURCE"

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The Subcritical Assembly "Neutron Source" of the National Science Center "Kharkiv Institute of Physics and Technology" is an Accelerator Driven System facility with 100 MeV/100 kW electron linear accelerator as a driver and tungsten neutron generating target as a source of the primary neutrons. To provide 100 MeV/100 kW electron beam delivery from the exit of the linear accelerator to the neutron generating target without electron beam losses it is necessary to provide the residual gas pressure in the vacuum chamber of the transportation channel of about $10^{-8}$…$10^{-9}$ Torr and set the electron beam at the center of the target. The possibility to install and operate electron beam parameters and position monitoring equipment in the chamber should be realized. In the article the reasons and technical solutions for the vacuum chamber of the second 45 degree bending magnet of the electron beam transportation channel for National Science Center "Kharkiv Institute of Physics and Technology" Subcritical assembly "Neutron Source" redesign are described. The methods and conditions for providing the residual gas pressure, which were included in the original design, are presented. The diagnostic equipment should be operated under hard radiation conditions. The developed bending magnet vacuum chamber design, manufacturing and vacuum test results before and after the chamber implementation in the accelerator vacuum system are presented. The results of the new chamber installation and operation provided the successful physical start-up and further pilot operation of the National Science Center "Kharkiv Institute of Physics and Technology" Subcritical Assembly "Neutron Source" facility.

## INTRODUCTION

Since 2012-year Neutron Source on the base of Subcritical Assembly (SCA) driven with 100 MeV/100 kW electron linear accelerator [1, 2] is under construction, assembling, tests, commissioning and physical start-up (Figs. 1–3) at National Science Center "Kharkiv Institute of Physics and Technology" (NSC KIPT) [3]. According to the original design, the facility should generate the neutron flux of about $10^{14}$ neutrons/s. NSC KIPT SCA "Neutron Source" is the facility of Accelerator Driven System (ADS) type were the intensity of $^{235}$U isotope fission and, therefore, the intensity of neutron flux generation, depends on intensity of driving accelerator beam. Driver of the NSC KIPT facility is 100 MeV/100 kW electron linear accelerator (see Fig. 2) [2]. The process of obtaining an intense neutron flux in the NSC KIPT SCA "Neutron Source" facility is based on the multiplication of primary photo-neutrons in an environment of fissile nuclear material. The primary photo-neutrons are generated with electron linear accelerator by electron beam interaction with heavy metal neutron generating target (NGT) [4–6] (tungsten or uranium in the case of NSC KIPT SCA "Neutron Source"). It is supposed that generated neutrons will be used for various applied and fundamental scientific researches, medical isotope productions, as well as to train specialists in the field of nuclear physics and nuclear energy. NGT is necessary element of the ADS-type facility and is the source of the primary neutrons and hard X-rays with wide spectrum due to photo-neutron reactions [7].

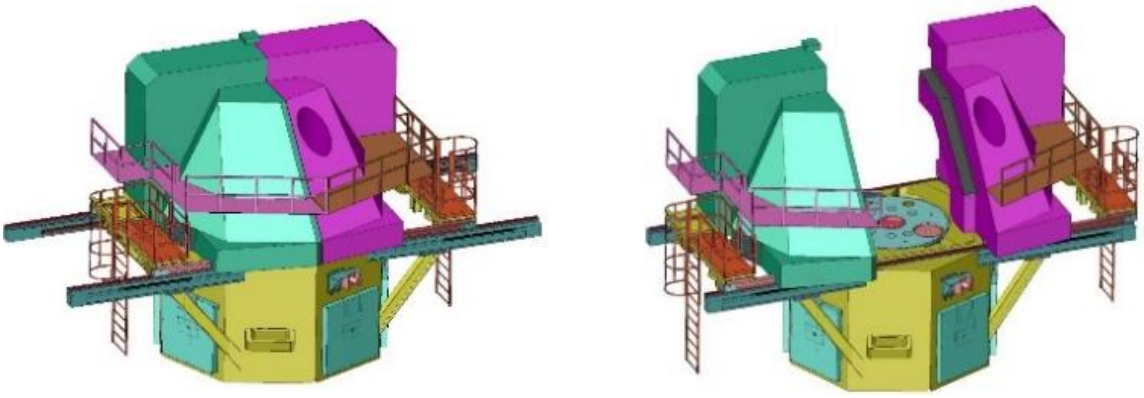


*Fig. 1. The view of the SCA "Neutron Source" NSC KIPT (scheme)*



*Fig. 2. The view of the SCA "Neutron Source" NSC KIPT*



*Fig. 3. NSC KIPT SCA "Neutron Source" electron linear accelerator*

## 1. ADS VACUUM CHAMBER PECULIARITIES

The development of modern nuclear physics facilities, such as subcritical assemblies and ADS [8], requires the design and implementation of high-precision beam transport systems. One of the key subsystem of such facilities is the vacuum system, which should provide the stability of beam parameters and minimize scattering losses during interaction with residual gas. An analysis of existing vacuum chamber designs shows that the main challenge is achieving an ultra-high vacuum of $\sim 10^{-9}$ Torr under conditions of intense radiation exposure [9]. When operating with a high-power electron beam of up to 100 kW, additional gas-outgassing effects occur under the influence of the beam, necessitating effective heat removal. Furthermore, to ensure control over the position and dimensions of the charged-particle beam, it is necessary to provide space for diagnostic equipment such as pickups, striplines [10], strip screens [11], or beam-profile sensors based on CCD cameras [12].

Despite a detail investigation and engineering design of the general principles of vacuum technology for accelerators and nuclear physics facilities [13], the literature does not sufficiently address the design and implementation of injection channel vacuum chambers of

dipole magnets for facilities such as MYRRHA [14], Ci-ADS [15], and JAEA-ADS [16] for specific conditions requiring a combination of a specific geometry (a 90° turn of an intense charged-particle beam with a power of up to 1 MW) and high reliability during long-term operation.

Although the beam power of the NSC KIPT SCA "Neutron Source" is significantly lower than that of the aforementioned facilities, at 100 kW the inability to monitor and adjust the parameters and position of the electron beam, as well as the inability to adjust the position of the NGT, can lead to the beam striking the walls of the vacuum chamber and, as a result, to a deterioration of vacuum conditions and a vacuum failure with destroy of the vacuum chamber. During preliminary tests and tuning of the NSC KIPT SCA "Neutron Source" accelerator, it was found that the aforementioned capabilities and means for the electron beam parameters monitoring were absent.

Thus, the need arose to develop a new chamber for the second transportation channel 45 degree bending magnet. Moreover, the same task is existing for the all facilities of the similar specialization.

The design of the new chamber should provide the following:

1. The ability to monitor the electron beam parameters.
2. Flexible connection of the chamber to the NGT vacuum chamber housing.
3. Achieving and maintaining a vacuum residual gas pressure of approximately $10^{-9}$ Torr during operation of the NGM and the 45 degree bending magnet chamber.
4. Geometric matching with the existing magnetic equipment of the transportation channel.

Resolving this issue is a necessary step toward ensuring the successful physical startup and transition to pilot operation of the NSC KIPT SCA "Neutron Source" facility.

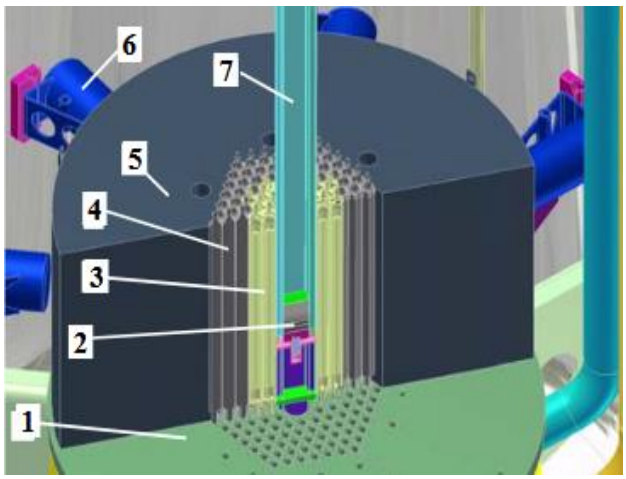



*Fig. 4. 3D model of the NSC KIPT SCA "Neutron Source" core: 1 is installation plate; 2 is NGT; 3 is fuel elements; 4 is beryllium reflector elements; 5 is graphite reflector; 6 is neutron channel; 7 is NGT vacuum pipe*

### 2.2. NSC KIPT SCA "NEUTRON SOURCE" VACUUM SYSTEM

It is clear that facility like SCA driver requires complicated and up to date vacuum system for continuous providing residual gas pressure of about $5.0 \cdot 10^{-8}$ Torr under condition of high electron beam current NGT bombarding [1, 2]. The layout of the

## 2. THE COMPONENTS OF THE NEW VACUUM CHAMBER DESIGN

### 2.1. NEUTRON GENERATION TARGET (NGT)

The target itself consists of the square plate set of $65.8 \times 65.8$ mm transverse sizes and total thickness of 80 with 2 mm gaps between target plates to provide target cooling. The thicknesses of the separate plates were chosen taking into account distribution of the heat release density volume at electron slowing-down in the target. To provide delivery of the electron beam to the plate set, the aluminum extruded pipe of 2624 mm length with target cooling channels was welded with high vertical direction accuracy. The pipe is equipped with special flange to provide vacuum sealed target connection with accelerator transportation channel (Figs. 4, 5).

As it can be seen from Fig. 4 the NGT is installed in vertical position in parallel with fuel assemblies (TVS VVR - M2). The installation accuracy should be no worse than 1.7 mrad (gap is about ± 5 mm). With such installation accuracy all core elements will be free and can be inserted and removed in the core without any interferences.

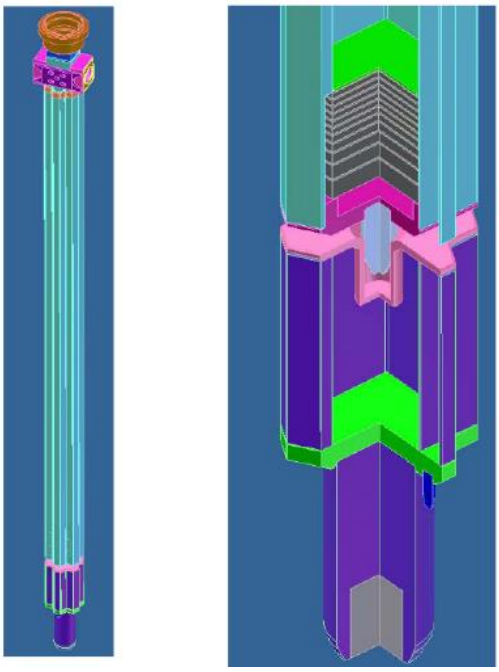


*Fig. 5. Layout of the NSC KIPT tungsten NGT*

NSC KIPT facility vacuum system and vacuum system components are shown in Fig. 6.

To deliver intense electron beam from the accelerator exit to the NGT with minimal beam losses, necessary beam geometrical parameters and to provide uniform electron beam distribution on the surface of the NGT the vacuum sealed transportation channel with necessary

electromagnetic elements for the beam focusing and formation of uniform beam density distribution is used (Fig. 7). Two 45° bending magnets TB 1 and TB 2 provide 90° bend from horizontal direction to the NGT and two scanning magnets provide uniform electron beam distribution on the target surface [17].

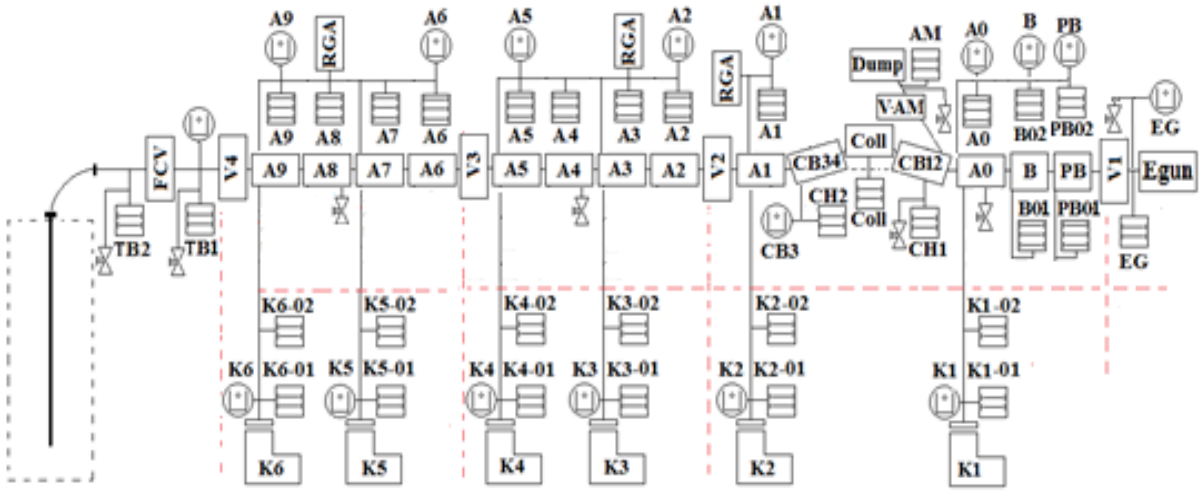



*Fig 6. NSC KIPT SCA "Neutron Source" vacuum system layout*

Vacuum equipment of the NSC KIPT SCA "Neutron source"

| | | | |
|---|---|---|---|
| Egun | – electron gun | | – diode pump |
| PB B | – pre-buncher and buncher | | – triode pump |
| CB... | – electromagnetic chicane | | – vacuum measurement probe |
| Coll | – collimator | V... | – angular manual probe |
| A ... | – accelerating sections | FCV | – Fast closing valve |
| K ... | – klystrons | | – Neutron generating target (NGT) in subcritical assembly |
| | – angular manual valve | | – special quick flange |
| RGA | – Quadrupole mass spectrometer | | |

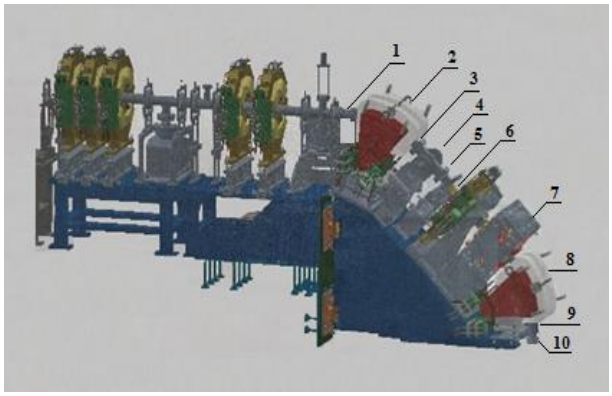



*Fig. 7. Layout of the bending part transportation channel: 1 is input of the vacuum chamber; 2 is the first bending magnet TB 1 vacuum chamber; 3 is output of the first bending magnet TB 1 vacuum chamber; 4 are pick-ups; 5 are screen lame monitors; 6 is quadrupole magnet; 7 are scanning magnets; 8 is second bending magnet TB 2; 9 is output of the second bending magnet TB 2 vacuum chamber; 10 is output flange*

### 2.3. NEW BENDING MAGNET VACUUM CHAMBER

As follows from the foregoing, for the successful operation of the NSC KIPT SCA "Neutron Source" facility the second bending magnet vacuum chamber should provide reliable vacuum sealing of the facility electron beam transportation channel in combine with the following functions:

- flexible connection of the TB 2 chamber with scanning magnet chamber to avoid ceramic of scanning magnet chamber from demage durung assembling, operation and maintenace;
- flexible connection of the bending magnet chamber with the NGT vacuum chamber to provide NGT chamber adjustment in the facility core;
- fast and remote connection of the magnet chamber with the NGT vacuum chamber;
- possibility of electron beam postion monitoring at the NGT surface.

During the facility assembling, commissioning and tests it was clarified that designed, developed and delivered by IHEP, Beijing, China to NSC KIPT TB 2 vacuum chamber not meet the two very important requirements, namely:

- the chamber does not provide possibility to monitor electron beam position at the NGT (Fig. 8);
- the connection of the TB 2 vacuum chamber and the NGT vacuum chamber is rigid (Fig. 9).

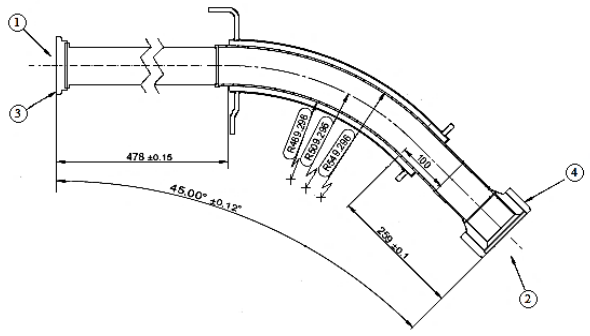



*Fig. 8. Drawing of the vacuum chamber developed by IHEP, Beijing, China:*
*1 is electron beam input channel; 2 is electron beam output channel; 3 is input pipe; 4 is output pipe for connection with the NGT*



*Fig. 9. TB 2 vacuum chamber developed by IHEP, Beijing, China after installation*

Such vacuum chamber could be used during tests with low level of the electron beam power and during the facility physical start-up, but not during the pilot operation and regular full power operation.

For these reasons, the new vacuum chamber should be designed, developed and installed by NSC KIPT. The new technical solution should allow electron beam parameter monitoring, minimize electron beam losses, decrease the radiation background at the exit of the accelerator during accelerator adjustment, tuning and regular operation. The new flexible mechanical connection of the new vacuum chamber and the NGT vacuum chamber should decrease the mechanical tension of the construction and allow to adjust the NGT vacuum chamber with target in the facility core.

The drawing of the new vacuum chamber designed by NSC KIPT is shown in Fig. 10. As one can see, the chamber equipped with addition pipes (specification 3 and 4 in Fig. 10) to provide monitoring of the electron beam and with bellows (see specification 2 and 5 in Fig. 10) to provide flexible connection of the chamber with scanning magnet vacuum chamber and NGT vacuum pipe. Monitoring pipes provide possibilities for installation of the video camera and diagnostic equipment like screen monitor at the chamber. The end face of the pipes is equipped with vacuum sealed flanges. Both items should be installed along with vertical axis that coincides with NGT axis.

Realization of the chamber allows to optimize accelerator modes during the facility start-up and further with full power operation. The new vacuum chamber is complicated vacuum unit and required careful and step by step approach. Figs. 11, 12 shows the view of bellows connection before installation.

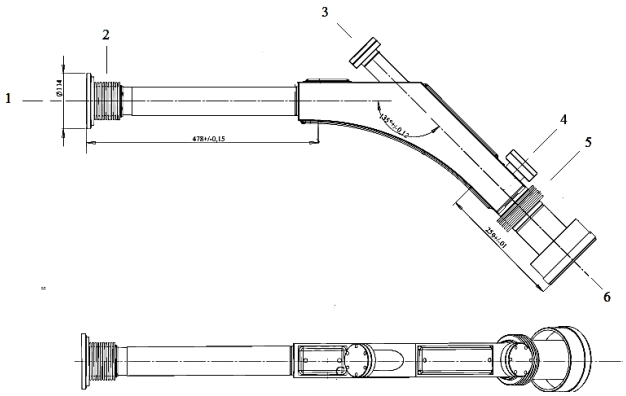



*Fig. 10. TB 2 vacuum chamber drawing designed by NSC KIPT:*
*1 is electron beam input channel; 2 is enter bellows connection; 3 is beam parameter monitoring pipe; 4 is pipe for lame monitor; 5 is exit bellows NGT connection; 6 is electron beam output channel*

One can understand, that bellows connections (1, 4) provide flexible connections of the TB 2 vacuum chamber with bending part of the electron beam transportation channel and with NGT, electron beam monitoring pipe (2) provides possibilities of the electron beam position and sizes monitoring at the NGT, lame monitor installation pipe (3) can provide possibility for lame monitor installation.

The new TB 2 vacuum chamber is made of high-quality austenitic steel 316 LN of 5 mm thickness, with high weldability and low value of magnetic permeability. The steel is purified, that allows to get specific gas release coefficient in vacuum of about $\sim 10^{-12}$ Torr × l × $s^{-1}$ × $cm^{-2}$.

The quality of weld seams is a factor of great importance in realization of complicated vacuum chambers and should provide long term residual gas pressure of about $10^{-10}$ Torr. In addition, the welding seams should have high radiation resistance that should be provided with metal thickness and depends on type of radiation and time of exposition. To provide weld quality the austenitic steel wire ER 308L (classification AWS A5.9) was used. Such type of wire is used to connect the stainless steel with low carbon content. Because of high radiation resistance, wire of ER 308L type is in widespread use in nuclear industry for components welding that are under neutron irradiation.



*Fig. 11. TB 2 vacuum chamber end part bellows connection*

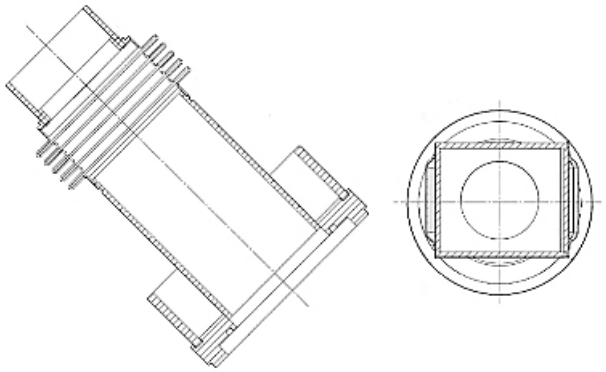


*Fig. 12. TB 2 vacuum chamber end part bellows connection (scheme)*

The welded joints of ER 308L keep their mechanical properties even after irradiation dose of about ~ 20 dpa (displacements per atom), 1 dpa is corresponded up to neutron flux value of about $10^{21}$ neutrons/cm² (neutron energy > 1 MeV) and are stable at 280…350 °C (at the temperature higher than 400 °C the thermal aging effect is possible with radiation defects).

As it was already mentioned, the TB 2 vacuum chamber was assembled step by step with vacuum tests with leak detector ASM 142 (ADIXEN company) after each step of the welding. Fig. 13 shows one of the stage of the TB 2 vacuum chamber test.

Fig. 14 shows the TB 2 vacuum chamber after final welding and vacuum tests.

To provide low level of outgassing from the inside walls of the TB 2 vacuum chamber the parts of the chamber were under vacuum cleaning procedure [15]:

- degreasing using organic solvents such as acetone, benzene, and perchloroethylene at a temperature of 120 ºC;
- ultrasonic cleaning in alkaline solutions at a temperature of 60 ºC during 4 h;
- rinsing in tap water, then in distilled water to remove carbon contaminants and ensure a low gas release coefficient;
- vacuum chamber heating in situ.

As a result, the minimal outgassing out of chamber walls was provided and required residual gas pressure was reached.



*Fig. 13. TB 2 vacuum chamber test*



*Fig. 14. TB 2 vacuum chamber with welded bellows at the each end*

## 3. RESULTS AND DISCUSSIONS

The results of the of the NSC KIPT SCA "Neutron Source" TB 2 bending magnet vacuum chamber modernization are the following:

1. A new vacuum chamber of the second bending magnet TB 2 of the NSC KIPT SCA "Neutron Source" transportation channel was design, manufactured and integrated into the facility transportation channel. The chamber geometry is optimized for the electron beam's trajectory, minimizing beam interaction with the chamber walls and thereby reducing the thermal load on the vacuum system.

2. Tests confirmed that, following degassing and vacuum pumping procedures, a chamber residual gas pressure of approximately $5.0 \cdot 10^{-8}$ Torr was achieved. This value meets design specifications and provides the necessary conditions for transporting a beam with a power of up to 100 kW.

3. The installation of the new camera made it possible to complete the commissioning phase of the accelerator operation and to perform a physical startup of the facility and proceed with pilot operation.

The data obtained during testing indicate that the upgraded chamber fully meets the design requirements. The design of the vacuum chamber for the second bending magnet, TB 2, resolved a critical issue that had arisen prior to the accelerator's operation at high power levels. The chamber was equipped with additional ports to enable

electron beam parameter monitoring, allowing for the installation of a video camera and diagnostic equipment, as well as bellows to provide a flexible connection for the chamber at the electron beam inlet and outlet.

A comparison of the measured vacuum characteristics – with a residual pressure of approximately $5.0 \cdot 10^{-8}$ Torr – with the operational results of similar vacuum systems at world-class facilities (such as those at Argonne or CERN) confirms that the achieved performance meets the requirements for ADS-class facilities.

The successful physical startup of the "Neutron Source" Vacuum Chamber served as practical confirmation of the accuracy of the engineering and physical solutions underlying the modernization of the second bending magnet vacuum chamber. The stability of the vacuum during the physical start-up confirmed the successful implementation of the upgrade and allowed for the transition to the next stage of pilot-scale operation, which requires further vacuum value and electron beam parameter monitoring during operation.

## CONCLUSIONS

The study and further activity on the design and modernization of the vacuum system in the beam transport channel of the NSC SCA "Neutron Source" facility yielded the following results:

1. The need to modify the design of the vacuum chamber of the second bending magnet of the NSC KIPT SCA "Neutron Source" transportation channel has been demonstrated. Issues with rigid connection to other components of the vacuum line have been identified, along with the need to eliminate structural loads and the advisability of installing equipment to monitor charged particle beam parameters.

2. A new design for the vacuum chamber of the 45-degree bending magnet was developed and manufactured using specialized welding and surface treatment methods, which minimized the material's outgassing rate.

3. During testing and the facility physical start-up, a stable residual pressure of approximately $5.0 \cdot 10^{-8}$ Torr was achieved and registered, which fully meets the design requirements for handling an electron beam with a power of up to 100 kW. It allows to proceed to the next phase of the facility pilot operation.

## 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. A. Zelinsky, Y. Chi, S. Pei, et al. Design studies on 100 MeV/100 kW electron linac for NSC KIPT neutron source on the base of subcritical assembly driven by linac // *Proceedings of IPAC11*. 2011, p. 1075-1077, TUPC034.

3. 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.

4. Graiciany P. Barros. Neutron Production Evaluation from a ADS Target Utilizing the MCNPX 2.6.0 code // *Brazilian Journal of Physics*. December, 2010, v. 40, N 4.

5. Yutaka Yamagata, Katsuya Hirota, et al. Development of a neutron generating target for compact neutron sources using low energy proton beams // *Journal of Radioanalytical and Nuclear Chemistry*. March 2015, v. 305(3).

6. I.M. Karnaukhov, B.V. Borts, A. Zelinsky, et al. A tungsten neutron – generating target of a Neutron source based on a subcritical assembly driven with an electron accelerator // *Proc. of IPAC 23*, Venezia, 2023, 07 – 12 May, p. 1046-1049.

7. H. Naik et al. Photo-neutron reaction cross-sections for natMo in the bremsstrahlung end-point energies of 12-16 and 45 - 70 MeV // *The European Physical Journal A*. 2016, v. 52, issue 7, article id.195, 14 p.

8. B. Yee-Rendon. Overview of ads projects in the world // *Proc. of the LINAC 2022*, Liverpool, UK, p. 310-313.

9. C.R. Ader, M. Alvarez, et al. Accelerator vacuum windows: a review of past research and a strategy for the development of a new design for improved safety and longevity for particle accelerators // *IPAC 2019 Melbourne*, Australia. 2019, p. 2237-2239.

10. P. Forck, P. Kowina, and D. Liakin. Beam position monitors: *CERN accel school*, 2008-2009.

11. Y. Hashimoto et al. Multi-ribbon profile monitor using carbon graphite foil for J-PARC // *Proceedings of HB2010*, Morschach, Switzerland, p. 429-433.

12. W.S. Graves, E.D. Johnson. A high resolution electron beam profile monitor // *Proceedings of the 1997 Particle Accelerator Conference* (Cat. No.97CH36167), 16 May – 16 May 1997, Vancouver, BC, Canada, v. 2, id. 217, p. 1993-1996.

13. Proc. of CERN accelerator school vacuum technology Scanticon Conference Centre, Snekersten, Denmark 28 May – 3 June 1999.

14. D. De Bruyn, R. Fernandez, J. Engelen. Recent Developments in the Design of the Belgian MYRRHA ADS Facility // *Proceedings of ICAPP 2016*, 2016 (International Congress on Advances in Nuclear Power Plants).

15. F. Yan et al. Physics design for the C-ADS main linac basing on two injector schemes // *Nuclear Instruments and Methods*. 2013 / arXiv (2013)

16. T. Sugawara et al. Research and Development Activities for Accelerator-Driven System in Jaea // *Prog. Nucl. Energy*. 2018, v. 106, p. 27.

17. A.Yu. Zelinsky et al. Linear accelerator magnetic system of the NSC KIPT subcritical assembly "Neutron source" // *Problems of Atomic Science and Technology*. 2024, N 3 (151), p. 92-100.


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# НОВА ВАКУУМНА КАМЕРА ПОВОРОТНОЇ ДІЛЯНКИ ІНЖЕКЦІЙННОГО КАНАЛУ УСТАНОВКИ «ДЖЕРЕЛО НЕЙТРОНІВ» ННЦ ХФТІ

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Для транспортування електронного пучка (100 МеВ/100 кВт) від виходу лінійного прискорювача до мішені без втрат необхідно забезпечити тиск залишкових газів у вакуумній камері каналу транспортування на рівні $10^{-8}…10^{-9}$ Торр і спрямувати пучок точно в центр мішені. Також необхідно передбачити можливість встановлення та експлуатації в камері обладнання для моніторингу параметрів і положення електронного пучка. Описано обґрунтування та технічні рішення щодо модернізації вакуумної камери другого поворотного магніту (на кут 45°) у каналі транспортування електронів для підкритичної збірки «Джерело нейтронів» ННЦ ХФТІ. Наведено методи й умови забезпечення необхідного тиску залишкових газів, передбачені в початковому проєкті. Діагностичне обладнання має працювати в умовах жорсткого радіаційного випромінювання. Представлено результати розробки конструкції вакуумної камери поворотного магніту, її виготовлення та вакуумних випробувань (як до, так і після встановлення камери у вакуумну систему прискорювача). Результати монтажу та експлуатації нової камери забезпечили успішний фізичний пуск і подальшу дослідну експлуатацію установки «Джерело нейтронів» ННЦ ХФТІ.