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GEODESIC NETWORK OF THE NSC KIPT SUBCRITICAL ASSEMBLY "NEUTRON SOURCE" FACILITY

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To provide uniform irradiation of the neutron generating target of the NSC KIPT Subcritical Assembly "Neutron Source" facility with driving electron beam it is necessary to provide accurate targeting of the electron beam at neutron generating target center and formation of the design beam parameters at the target. To achieve these goals, it is necessary to develop the facility geodesic network, to determine the position of the beam reference orbit in the developed network and to install all elements of the subcritical facility in design position relative to the reference orbit in the developed geodesic network. The RMS accuracy of the element alignment should be about 100…200 μm in transverse (horizontal, vertical) coordinates and about 200…300 μrad in longitudinal and transverse planes. To provide such accuracy of the facility element installations relative to the accelerator axis it is necessary to find axe of all accelerator elements (fiducialization with geodesic targets) and to match the element axis with the accelerator reference orbit. For the network development level LEICA NA2, theodolite 3T2KP, laser tracker LEICA AT401 and supporting devices were used. In the paper the activity results on development of the NSC KIPT Subcritical Assembly "Neutron Source" facility geodesic network are presented.

INTRODUCTION

In NSC KIPT the Subcritical Assembly (SCA) "Neutron Source" with 100 MeV/100 kW electron linear accelerator-driver [1, 2] is putting into pilot operation. The SCA "Neutron Source" is the complex of many various technological and engineering systems and subsystems, such as facility core with fuel elements (subcritical assembly), electron linear accelerator, electron beam transportation channel, biological shield, neutron flux measurement system, cooling systems, ventilation systems etc.

To assemble and correctly, with required accuracy, install all facility equipment in accordance with original design it is necessary to develop geodesic network and to set accelerator electron beam reference orbit in the developed geodesic coordinate network. The accuracy of all SCA and linear accelerator element alignments relative to the reference orbit of the electron beam in the developed geodesic network of the NSC KIPT SCA "Neutron Source" should be of about 100…200 μm in transverse (horizontal, vertical) coordinates and about 200…300 μrad of longitudinal and transvers element slopes [3].

The electromagnetic system of the 100 MeV/100 kW electron linear accelerator-driver consists of quadrupole lenses, quadrupole triplets, bending magnets of the transportation channel, bending magnets of the chicane, scanning magnets [4]. The accelerating sections and electron gun [5] provide generating and acceleration of the electron beam. To relate coordinate targets or marks at the facility elements with accelerator reference orbit the procedure of element fiducialization should be done with proper accuracy [6].

To provide required accuracy of the facility unit installations with metrological measurements the set of up-to-date geodesic devices and supporting devices are used. The most important devices of the geodesic equipment are the following:

- LEICA NA2 precise optical level [7] (Fig. 1) with the following characteristics:

Image – direct;
Magnification – 32x;
Minimal focal length – 1.6 m;
Field of view – 2.2 m;
Accuracy standard deviation per km double run – 0.7/0.3 mm (with micrometer attachment);
Compensator (type) – air;
Compensator accuracy – 0.3″.

- Theodolite 3T2KP [8] with the following characteristics (Fig. 2):

Magnification (multiplisity) 30x;
Error (accuracy) 2";
Operation temperature range -40… +50 °C.

Fig. 1. LEICA NA2 precise optical level

Laser Tracker Leica AT401 [9] (Fig. 3) is used as precise metrological measuring device at the final stage of the NSC KIPT SCA "Neutron Source" geodesic network development, accelerator element fiducializations and installation of the facility elements in design position. The laser tracker is portable coordinate-measuring system with possibilities to fulfill the precise measuring on long up to 320 m distances. For measurements the geodesic optical target-reflectors are used (Fig. 4). The target-reflector is installed at the measured object holder or another target place holder.

Fig. 2. Theodolite 3T2KP

Laser tracker Leica AT401 has the following characteristics:

Angular characteristics:
Resolution: 0.07″;
Error (maximal permitted error): ±(15+6) μm/m;
Accuracy of the slope installation (2σ): ± 1″.
Distance meter characteristics:
Resolution: 0.1 μm;
Error (maximal permitted error): ± 10 μm;
Repeatability (maximal permitted error): ± 5 μm.
Reflector-target characteristics:
Radius (ball): (19.05 ± 0.0025) mm;
Shifting on distance: (0.00 ±0.006) mm.

Fig. 3. Laser tracker Leica AT401

Fig. 4. Target-reflector (Red-Ring Reflector 1.5”)

A few target-reflector holder types are used to fix target-reflector at place for the facility geodesic network formation and to install accelerator elements in design position relative to the electron beam reference orbit. Figs. 5, 6 show the holders that help to develop geodesic network of the SCA facility. The target-reflector holders are fixed at the experimental hall walls and at the beginning of the accelerator (Fig. 9) (EGun, Base 1, Base 2, Base 3). The target-reflector can be shifted in the holder in horizontal direction for the geodesic network adjustment. As one can see the target reflector in the accelerator tunnel is different from the other three at the experimental hall. Three target-reflectors of the experimental hall are identical.

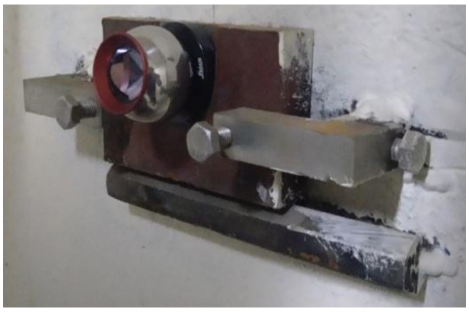

Fig. 5. Target-reflector holder at the beginning of the accelerator tunnel (Egun)

Fig. 6. Target-reflector holder at the wall of the SCA facility at the experimental hall (Base 1, Base 2, Base 3)

Fig. 7. Accelerator tunnel wall target-reflector holder of the NSC KIPT SCA “Neutron Source”

Fig. 8. Accelerator tunnel floor target-reflector holder of the NSC KIPT SCA "Neutron Source"

In the accelerator tunnel the target-reflector holders are installed in the floor and walls for the accelerator survey and alignment coordinate system development and element adjustments. Figs. 7, 8 show wall and floor target-reflector holders for the accelerator tunnel.

GEODESIC NETWORK OF NSC KIPT SUBCRITICAL ASSEMLY "NEUTRON SOURCE"

To install electromagnetic equipment of the 100 MeV/100 kW electron linear accelerator and other facility equipment relative to electron beam reference orbit with required accuracy and to provide coordinate monitoring of the element positions the facility geodesic network was developed (see Fig. 9). The development of the geodesic network involves the following stages:

1. Preliminary development of the plane geodesic coordinate network:

Geodesic network of the NSC KIPT SCA "Neutron Source" is Deckard coordinate system with X axis, which set along axis of the linear accelerator longitudinal axis at 1.2 m height from the accelerator tunnel floor. Axis Y is set as perpendicular to the axis X and cross it at the point where Neutron Generating Target (NGT) center is set. So, axis Z is directed vertically up (see Fig. 9) from the point of X and Y a[e intersection. Axis X is formed with the target-reflectors EGUN and Base 1, which put at the beginning of the accelerator tunnel and at the opposite wall of the experimental hall (see Figs. 5, 6). Axis Y is formed with two target-reflectors Base 2, Base 3, which are installed at the side walls of the experimental hall in the direction that are perpendicular to the X axis. As one can see, the used target holders allow to shift each target-reflector to adjust coordinate axe.

Because the facility configuration does not allow to adjust geodesic target-reflector positions at the side walls with assembled movable biological shielding at the top of the assembly core (the direct optical path is blocked) (Fig. 10), the preliminary formation of the geodesic network was made before installation of the top movable lid-parts и (see Figs. 10, 11).

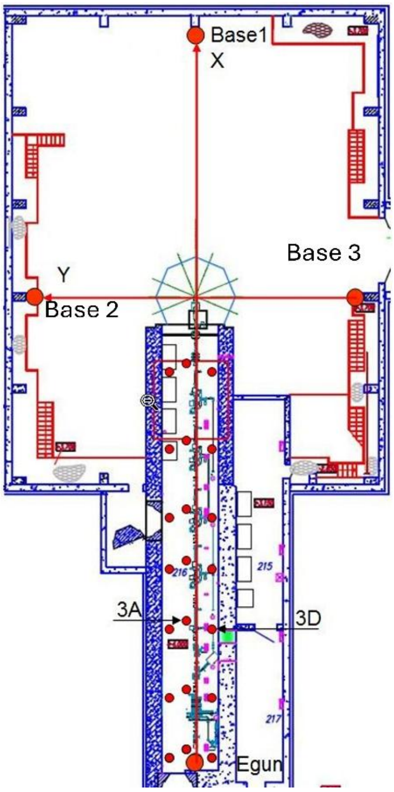

Fig. 9. Layout of the allocation of the basic geodesic target-reflectors in accelerator tunnel and experimental hall of the NSC KIPT SCA "Neutron Source" facility

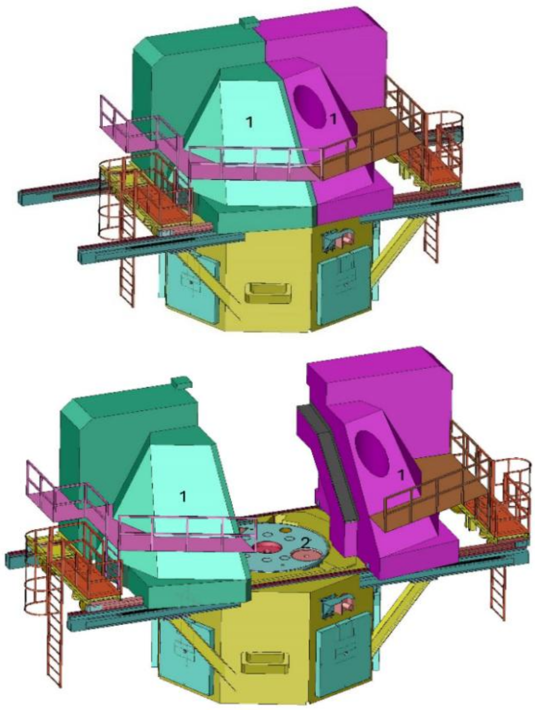

Fig. 10. Layout of the NSC KIPT SCA "Neutron Source" biological shield with closed and open top movable lid-parts: 1 – top movable side lids; 2 – top flat rotating lid

For mounting of the base wall target-reflector holders theodolite 3T2KP was «leveled» and «centered» above the design construction mark, which matches with the center of the facility core tank and to the center of the NGT.

Fig. 11. Biological shield of the NSC KIPT SCA "Neutron Source" core without top movable lid-parts

Further, in accordance with design drawings, the position of the target-reflector EGun holder was marked. After that, with two separate measurements of the horizontal 180º angle «through the zenith» the position of the Base 1 target-reflector holder was marked. In such way, the axis X is formed with base points EGun - Base 1. Measuring horizontal angle in 90º relative to EGun - Base 1 axis the position of the base holders for the Y axis is determined. So, the facility coordinate system is preliminary formed with theodolite accuracy of about 2″, that on the 0…30 m distance matches the error value in target-reflector position Base 1 in horizontal plane equal to $\pm\ 0…3.0\cdot10^{-4}$ m. The center of the developed coordinate system is the axis of the theodolite vertical rotation. Because the target-reflector holders do not have possibilities for vertical adjustment the level, which was marked with level LEICA NA2 for the target-reflector EGun determined the height for the holders relative to EGun height level with RMS level accuracy of abou $\pm 4\cdot10^{-5}$ m.

2. Laser tracker Leica AT401 coordinate system formation [10, 11].

After formation of the facility geodesic network with theodolite 3T2KP it was necessary to relate "mechanical" coordinate center of the theodolite with "virtual" laser tracker Leica AT401 coordinate system. Before the start of the accelerator equipment mounting and assembling, and before installation of the top, movable side lids of the core (see Fig. 10) the top flat rotating lid of the core biological shield was mounted (see Fig. 10). Setting the laser tracker at the rotating flat lid in direct view of all coordinate system basic target-reflector holders the "real" position in the horizontal plane of the vertical coordinate axis Z was determined as intersection of projection X and Y axe at horizontal plane of EGun target-reflector level. Because the laser tracker has better angle accuracy (0.07″) in comparison with theodolite angle accuracy (2″), positions of Y axis target-reflectors were adjusted a little bit to correct the intersection angle of X and Y axe closer to 90º. The data of target-reflector position coordinates were put to the laser tracker and formed the facility geodesic network.

In addition, the "real" center of the top flat rotating lid of the core biological shield was determined. According to the original design the top lid of the core biological shielding should be rotated around vertical coordinate system axis Z and its center is matched with NGT and core center. "Real" X, Y coordinates of the rotating axis Z for the top flat lid were determined by setting the laser tracker at any point of the top rotating flat lid with direct view of basic network target-reflectors and with use of laser tracker function of circle formation with two tangent lines and radius. Fig. 12 shows the sketch of the top rotating lid of the core biological shield with pressing rollers and coordinate network. Radius of the rotating flat lid is 1365.65 mm.

In parallel with all measurements described above the coordinates of the pressing rollers were measured.

Tabel 1 shows the results of the base target-reflector coordinate measurements for the geodesic network of NSC KIPT SCA "Neutron source" facility. The values of measurement RMS errors are generated automatically with standard tracker AT401 algorithm on the base of series of measured data. As one can see from Table 1 the maximal errors in target-reflector coordinates are in the range ± 120…200 μm.

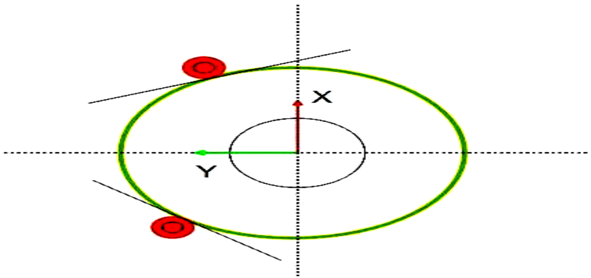

Fig. 12. Sketch of the coordinate measurements of the rotating center of the top lid of the core biological shielding

Table 1

Coordinates of the basic target-reflectors along the facility X and Y axe of NSC KIPT SCA "Neutron Source"

X, mm	Δ X max, μm	Y, mm	Δ Y max, μm	Name of the basic target-reflector
-30788.295	± 10	-0.024	199.79977	Egun
0	± 20	0	± 20	«0»
17450.462	± 10	0.0125	119.702772	Base 1
-0.012	199.79977	11026.25	± 10	Base 2
0.012	119.702772	-11030.37	± 10	Base 3

So, the basic target-reflectors "EGun", "Base 1" and virtual "0" of the facility geodesic network (axis X), which form the accelerator reference orbit are at one straight line with accuracy equal to 0.024 ± 0.2 (3σ) mm, on the base of 48 m.

The basic target-reflectors "Base 2", "Base 3" and virtual "0", which are the Y axis of the facility geodesic network and together with axis X form the accelerator horizontal plane, are at one straight line with accuracy equal to 0.012 ± 0.2 (3σ) mm, on the base of 22 m.

RMS accuracy of the laser tracker Leica AT401 center is 67 μm, that with NGT sizes of 64×64 mm is about 0.2% deviation from the NGT center.

Fig. 13 shows the scheme of the geodesic network center in the vertical plane with elements of electron accelerator beam transportation channel. Q9, Q10, Q11 are quadrupole magnets, B1, B2 are 45º dipole magnets, ScM_H, ScM_V are horizontal and vertical scanning dipole magnets, NGT is neutron generating target. So, setting laser tracker at any point of the facility experimental hall and have at least one target-reflector in direct view, one can determined the laser tracker position measuring distance and angle to the target-reflector. With laser tracker position one can start to install and adjust equipment in design position with closed top movable lids of the core biological shielding.

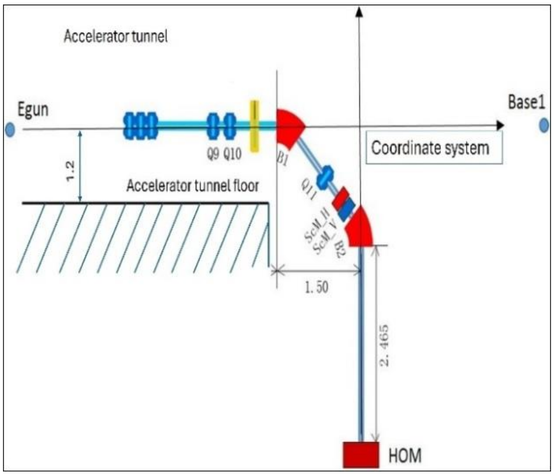

Fig. 13. The scheme of the geodesic network center determination in vertical plane

Fig. 14. The view of the accelerator equipment allocation in the facility 100 MeV/100 kW accelerator tunnel and target-reflectors of the accelerator tunnel geodesic network

In the same way the position of the accelerator elements in the accelerator tunnel can be determined and elements can be adjusted and aligned. However, the simultaneous direct view of "EGun" and accelerator elements is impossible (Fig. 14) and the procedure of accelerator element alignments in the accelerator tunnel requires addition geodesic (survey and alignment) network in the tunnel.

To have possibility to align each accelerator element independently without direct view of the basic target-reflector EGun and with closed top side movable lids of the core biological shield (see Fig. 10) the addition geodesic (survey and alignment) coordinate network of the accelerator tunnel was developed. Accelerator geodesic coordinate network of the NSC SCA "Neutron Source" facility is formed with 23 target-reflectors which installed in the floor and walls of the accelerator tunnel (see Fig. 9, red circles, Fig. 14, general view). Geodesic points are the target-reflector holders with magnetization for the tracker target-reflector. Such holders provide accurate, repeatable installation of a reflector at the holder (see Figs. 7, 8).

To develop accelerator tunnel coordinate system, it is necessary to determine coordinates of each target-reflector holder out of 23 along the tunnel. The coordinates should be determined for geodesic network of the facility, namely, relative to basic target-reflector EGun, center of the facility geodesic network and its X axis. At the first step of the accelerator coordinate system development the laser tracker is set in direct view of the target-reflector EGun. Measuring distances and angles from the laser tracker to the geodesic network center and to the target-reflector EGun, the position of the laser tracker and all target-reflectors, which are in direct view of the tracker are determined. The measured coordinates, which initially were measured for the intrinsic laser tracker coordinate system, are transferred to the facility geodesic network. According to the laser tracker data the error in determination of the target-reflector position coordinates is about ~ 20 μm. Further the procedure of the target-reflector coordinate determinations is step by step coordinate measurements of certain groups of the target-reflectors (3-4 target-reflector measurements at one position). Laser tracker is set in the way, that the direct view of 2 next target group and 2 previous target group target-reflectors (measurable and measured) was possible. The layout of target-reflector holders in the accelerator tunnel of NSC KIPT SCA "Neutron Source" is shown in Fig. 9. Measurement of 3 target reflector coordinates is necessary and sufficient condition to transfer laser tracker to the next position and next target-reflector group. The procedure of the target-reflector coordinate determination is shown in Fig. 15, where A, B, C, D are geodesic target-reflectors. The target-reflector holders of the accelerator tunnel were divided on 7 groups. After measurements of the target-reflector coordinates for all 7 groups the cloud of the target coordinates in the tunnel in the geodesic network of the NSC KIPT SCA "Neutron Source" facility was obtained.

In Table 2 the coordinates of one out of 23 measured target-reflector group are presented.

Table 2

*Measured coordinates of the target-reflectors for the 3rd target group of the accelerator tunnel**

X, mm	Y, mm	Z, mm	Base target mark
-21123.436	376.205	-1339.686	03A
-21204.759	2035.347	-1337.724	03B
-21216.597	2163.859	610.502	03C
-20968.805	-1489.168	225.767	03D

*According to laser tracker AT401 data the accuracy in each target-reflector position determination is about ± 0.020 mm.

To align the elements of the accelerator in design position it is necessary to install the laser tracker in a view of one of the working target holder groups of the accelerator geodesic network. The accuracy of the laser tracker positioning for all three coordinates of the network $\Delta x_{tr\ target}$, $\Delta y_{tr\ target}$, $\Delta z_{tr\ target}$ are ± 0.020 mm relative to all target-reflectors of the certain working group. Taking into account the absolute accuracy of each target reflector position measurement themselves Δx_{target}, Δy_{target}, Δz_{target} are ± 0.020 mm, the absolute accuracies for the laser tracker position determination on each coordinate axis of the geodesic network are:

$$\Delta x_{tr\ i} = (\Delta x_{tr\ target\ i}^2 + \Delta x_{target\ i}^2)^{1/2} = 0.028\ \text{mm};$$
$$\Delta y_{tr\ i} = (\Delta y_{tr\ target\ i}^2 + \Delta y_{target\ i}^2)^{1/2} = 0.028\ \text{mm};$$
$$\Delta z_{tr\ i} = (\Delta z_{tr\ target\ i}^2 + \Delta z_{target\ i}^2)^{1/2} = 0.028\ \text{mm}.$$

To relate laser tracker coordinates with accelerator element target-reflector holder coordinates with one more coordinate measurement with the same accuracy $\Delta x_{tr\text{-}el}$, $\Delta y_{tr\text{-}el}$, $\Delta z_{tr\text{-}el}$, which are ± 0.020 mm and add the value of the accuracy to the previous one:

$$\Delta x_{el\ i} = (\Delta x_{tr\ target\ i}^2 + \Delta x_{target\ i}^2 + \Delta x_{tr\text{-}el\ i}^2)^{1/2} = 0.035\ \text{mm};$$
$$\Delta y_{el\ i} = (\Delta y_{tr\ target\ i}^2 + \Delta y_{target\ i}^2 + \Delta y_{tr\text{-}el\ i}^2)^{1/2} = 0.035\ \text{mm};$$
$$\Delta z_{el\ i} = (\Delta z_{tr\ target\ i}^2 + \Delta z_{target\ i}^2 + \Delta y_{tr\text{-}el\ i}^2)^{1/2} = 0.035\ \text{mm}.$$

So, the total measurement error budget for the accelerator alignment target coordinate measurements is about 0.035 mm. Such accuracy satisfied the requirements for the accelerator element alignment at the reference orbit. The final stage of the accelerator element alignments is adjustment of each element with the accelerator reference electron beam orbit with accuracy Δx_{fid}, Δy_{fid}, Δz_{fid}. After this procedure the accelerator alignment will be completed and its final accuracy will be:

$$\Delta x_{el\ I\ ref} = (\Delta x_{tr\ target\ i}^2 + \Delta x_{target\ i}^2 + \Delta x_{tr\ el\ i}^2 + \Delta x_{fid})^{1/2};$$
$$\Delta y_{el\ I\ ref} = (\Delta y_{tr\ target\ i}^2 + \Delta y_{target\ i}^2 + \Delta y_{tr\ el\ i}^2 + \Delta y_{fid})^{1/2};$$
$$\Delta z_{el\ I\ ref} = (\Delta z_{tr\ target\ i}^2 + \Delta z_{target\ i}^2 + \Delta y_{tr\ el\ i}^2 + \Delta z_{fid})^{1/2}.$$

Considering the requirements to the accelerator element alignments (0.15…0.2 mm) the accuracy of the elements fiducialization should be in a range 0.1…0.2 mm.

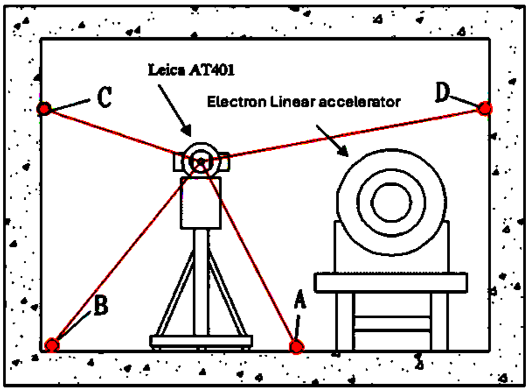

Fig. 15. View of accelerator tunnel geodesic target-reflector coordinate determination, where A, B, C, D are geodesic target reflectors

CONCLUSIONS

The geodesic coordinate network was designed and developed for NSC KIPT SCA "Neutron Source". To provide necessary alignment accuracy which is about 100…200 µm in transverse (horizontal, vertical) coordinates and about 200…300 µrad of longitudinal and transvers planes slope, level LEICA NA2, theodolite 3T2KP, laser tracker LEICA AT401 with target-reflectors and supporting devices were used.

The network is formed with 4 base target-reflectors at the walls of the experimental hall and accelerator tunnel with "virtual" center at the position of NGT. Addition 23 target-reflectors allocated in the accelerator tunnel provide possibility to align accelerator equipment independently and in the accelerator tunnel.

The absolute accuracies of the geodesic target-reflector installations are between 0.1…0.2 mm for the base targets and 0.02 mm relatively base target for the 23 accelerator tunnel targets.

The absolute accuracy of the coordinate measurements is 0.035 mm plus accuracy of the element fiducializations. The geodesic coordinate network satisfies to necessary accuracy requirements but the final accuracy is depended from the fiducialization accuracies of accelerator elements.

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ГЕОДЕЗИЧНА СИСТЕМА КООРДИНАТ ПІДКРИТИЧНОЇ ЗБІРКИ «ДЖЕРЕЛО НЕЙТРОНІВ» ННЦ ХФТІ

О. Бездітко, А. Мициков, А. Зелінський

Для забезпечення рівномірного опромінення електронним пучком нейтронно-генеруючої мішені підкритичної установки «Джерело нейтронів» ННЦ ХФТІ необхідно забезпечити точне наведення електронного пучка на центр мішені та формування проєктних геометричних розмірів пучка на мішені. Для досягнення цих цілей необхідно сформувати геодезичну сітку установки, визначити положення рівноважної орбіти електронного пучка і встановити всі елементи підкритичної збірки і лінійного прискорювача електронів у проєктне положення відносно рівноважної орбіти в системі координат геодезичної мережі ЯПУ «Джерело нейтронів» ННЦ ХФТІ з точністю порядку 100…200 мкм у поперечних координатах, 100…200 мкм у поздовжньому напрямку і порядку 200…300 мкрад у поздовжньому нахилі елементів. Для забезпечення даної точності установки елементів необхідно вирішити три завдання: побудувати планову геодезичну сітку установки ЯПУ «Джерело нейтронів» ННЦ ХФТІ, зв'язати координати геодезичних мішеней на електромагнітних елементах лінійного прискорювача з рівноважною орбітою електронного пучка (фідуціалізація електромагнітних елементів), встановити геометричну вісь електромагнітних елементів у проєктне положення з необхідною точністю. Наведено результати роботи зі створення геодезичної сітки установки ЯПУ «Джерело нейтронів» ННЦ ХФТІ. При створенні геодезичної сітки установки використовувався нівелір LEICA NA2, теодоліт 3Т2КП, лазерний трекер LEICA AT401 і допоміжні геодезичні прилади.