MAGNETS OF THE INJECTION CHANNEL FOR THE X-RAY GENERATOR "NESTOR"

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In recent years in NSC KIPT the X-ray generator "NESTOR" are under design and development. In the paper the parameters of the magnetic elements of the facility injection channel are presented. The magnetization curves, effective lengths of dipole magnets have been measured and the results are in a good agreement with project parameters. The produced dates allow to control the magnetic field of the dipole magnets with absolute accuracy equal to 2 Gs at 60 MeV injection electron beam energy and to demagnetize the magnets down to ± 2 Gs . For quadrupole magnets magnetization curves, magnet forces and magnetic axis positions were measured. The parameters of the corrector magnets were measured too.

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1. INTRODUCTION

In NSC KIPT a project of an X-ray generator on the base of Compton back scattering of laser photons with relativistic electrons of 225 MeV energy has design and now is under development [1]. The generator allows to produce X-ray with photon energy from 5 to 900 keV. The project realization are carried out with support NATO SfP grant. A magnetic latice of "NESTOR" facility injection channel [2] is shown in Fig.1. It consists of 7 quadrupole magnets, 2 dipole magnets and 5 dipole correctors.

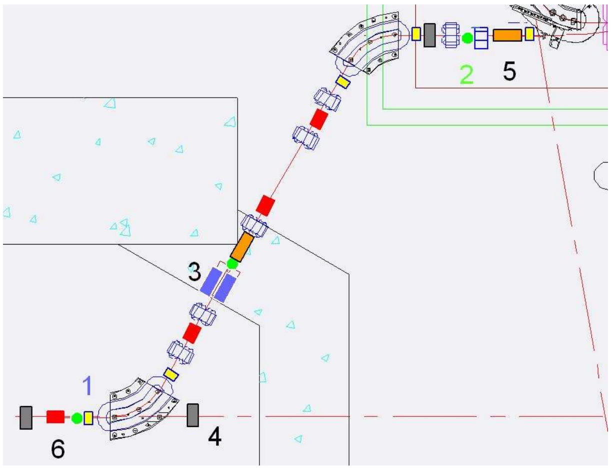

Fig.1. *"NESTOR" injection channel layout: 1 - bellows joint, 2 - pumping points, 3 - collimator, 4 - vacuum valve, 5 - beam position monitor, 6 - beam correctors*

Also it involves electrical pulse inflector as a final element of the injection system to put electron beam to the storage ring reference orbit. The design parameters of the lattice magnetic elements are presented in Table 1.

Table 1. *Parameters of "NESTOR" facility injection channel magnetic elements*

Element	Max Magnet Field	Mag. axis accur.	Powers supply stab.
Quadrupole $IQ1-IQ7$	$6\ T/m$	$0.1mm$	10^{-3}
Dipole magnet $IB1, IB2$	$0.4\ T$	$0.1mm$	10^{-4}
Dipole corrector $C1-C5$	$0.0140\ T$	–	10^{-3}

Despite that the lattice has quite a big number of correctors it has specific requirements to the accuracy of the injection channel magnetic elements manufacture and installation. The installation tolerances are 100 μm in vertical and horizontal planes and 500 μm in longitudinal direction. Angular installation tolerance is 1 mrad in all three directions. Power supply stability should be not worse then 10^{-3}. Such quite strict requirements are caused by the fact that injection of the electron beam to the storage ring is made through the fringe fields of the first storage ring dipole magnet and quadrupole magnet of the ring lattice [3],[4]. These fields are non uniform and defocus the beam in horizontal plane. In addition, the electron beam injection is made with running wave electrical inflector with non uniform distribution of the field. To satisfy the requirements to magnetic element parameters of the "NESTOR" injection channel a specialized magnetic benches for passportization and fiducialization of the elements has been designed and developed. Dipole magnets

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with uniform magnetic field distribution were measured with Hall probes and quadrupole magnets were tested rotated integral wire coil.

2. QUADRUPOLE LENSES

In "NESTOR" design project, on the base of Table 1, two types of the quadrupole magnets designed and manufactured. The technical parameters of the quadrupoles are presented in Table 2. Magnetic and geometrical characteristics of the quadrupole magnets were investigated at magnetic measurement bench with rotated integral wire coil. The bench allows to measure magnetization curve of a quadrupole magnet (see, for example, Fig.2 were magnetization curve of one of the quadrupoles is shown) and element magnetic axis out from geometrical axis displacement (Table 3).

Table 2. *Quadrupole lens parameters*

Parameter	Type1	Type2
Aperture radius,mm	26	26
Maximal Gradient,T/m	4	6
Iron Length,mm	70	70
Effective Length,mm	100	100
Gabarite,mm^3	360× 360× 70	360× 360× 70
Numbers	3	4
Max current,A	5	5
Resistance,Ω	2.5	3.2

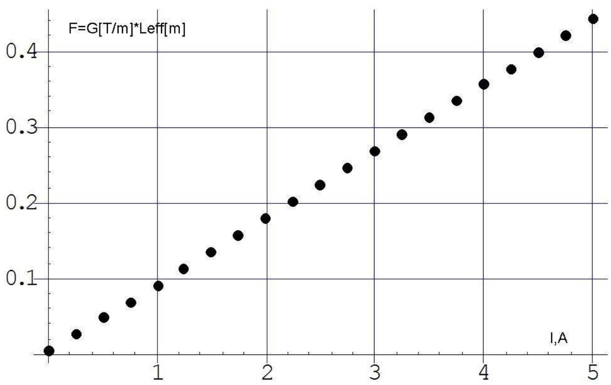

Fig.2. *Exitation curve of quadrupole lense IQ2*

In Table 3 approximated magnetization curves and magnetic axis displacements are presented. In addition, on the bench one can connect coordinates of magnetic axis of a magnet with position of survey targets installed at the top of an element (Fig.3). At the bench the methodology of the quadrupole magnet installation in project position has been developed, tested and verified. Expressions for quadrupole force dependence on excitation current calculations (see Table 3) were produced after three-time magnetization of each lens with maximal value of excitation current equal to 5 A. Such development of a magnetic element histories helps to improve the repetition of the magnetic element parameters during further magnetization cycles. During regular facility operation the set of qadrupoles operation regime parameters will be installed after three-time magnetization cycles.

Fig.3. *Installation of the injection channel quadrupoles in the project position with survey targets on the top of the elements after foducialization at the magnetic bench*

As one can see from Table 3, the result of injection quadrupole measurements are in a good agreement with project requirements presented in Table 1.

Table 3. *Measured quadrupole lens parameters*

Name	Max Force, T	misalighment, μm	Fit formulae for Force; F[T]=
IQ1	0.434	dy=-93; dx=-89	$0.0267 + 0.0794 \times I$
IQ2	0.444	dy=-14; dx=7	$0.00367 + 0.0880 \times I$
IQ3	0.580	dy=-5; dx=-39	$0.00626 + 0.1148 \times I$
IQ4	0.569	dy=31; dx=94	$0.0043 + 0.113 \times I$
IQ5	0.580	dy=-76; dx=120	$0.0057 + 0.115 \times I$
IQ6	0.589	dy=-27; dx=60	$0.0048 + 0.117 \times I$
IQ7	0.441	dy=36; dx=51	$0.0049 + 0.0888 \times I$

Accuracy and methodology of the magnetic elements magnetic axis determination and installation in the project position allow to satisfy the project requirements mentioned above. So injection channel quadrupole magnets provide the "NESTOR" project electron beam parameters.

3. DIPOLE CORRECTORS

Dipole correctors of the "NESTOR" injection channel are two-coordinates and make correction of the injection electron beam position in horizontal and vertical plane (Fig.4) To provide orbit correction procedure designed in the facility project the correctors field value should be.equal to 138 ± 1.5 Gs (see Table 1). The corrector magnetic measurements were carried out at the same magnetic bench with rotated integral coil. Magnetization curves of all five correctors were measured (Fig.5). [2].

Fig.4. *2-th coordinate dipole corrector*

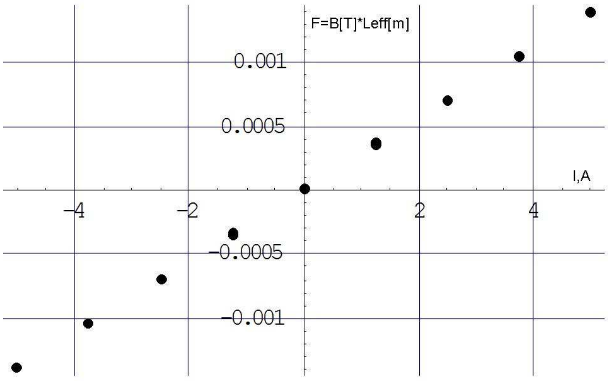

Fig.5. *Excitation curve of dipole corrector*

Since all corrector have identical shape, are manufactured from the same material and excitation coils have the equal number of ampere turns the magnetization curves of all correctors can be described with one expression $F = 0.00278 \times I[T \times m]$. All five two-coordinate correctors completely satisfy the project requirements (see Table 1) and can provide project beam orbit correction procedure described in [2].

4. DIPOLE MAGNETS

Dipole magnets of the "NESTOR" injection channel provide parallel transportation of the injected electron beam from electron linear accelerator to the storage ring. They have 0.5 m bending radius and magnetic field equal to 0.4 T in the magnet gaps at injection electron beam energy equal to 60 MeV (see Table 1). The of the injection channel magnet with removed top cover is shown in Fig.6. The magnet coils are supplied with high current supply source in series with current equal to 300 A. For this purpose in the "NESTOR" power supply system there is separate motor-generator. Each magnet has additional low current coil to match the forces of the injection magnets and for magnet demagnetizations.

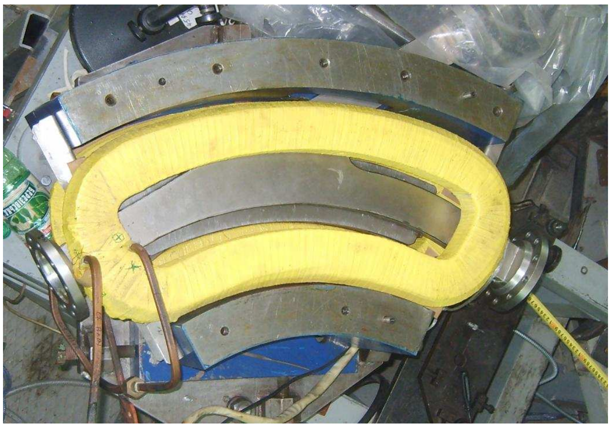

Fig.6. *"NESTOR" injection channel dipole magnet with removed top cover*

Magnetic measurements have been carried out with Hall probe matrix that was moved along special guide positioned in gap between dipole magnet poles as it is shown in Fig.7

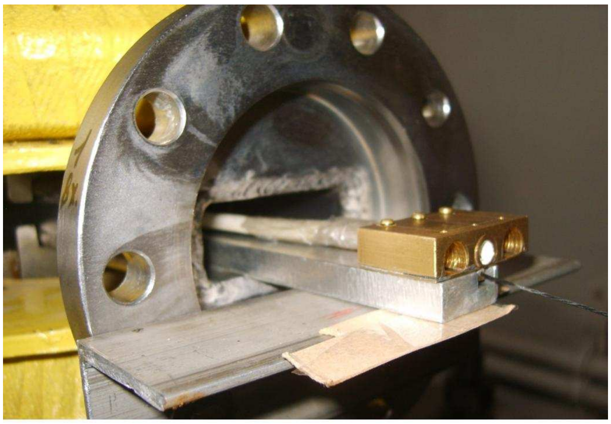

Fig.7. *Hall probe matrix in the edge of dipole magnet gap with installed vacuum chamber*

The measurements were carried out in some stages and involved the following. The measurements of dipole magnet effective length (Fig.8). The magnetic field was measured along six different, parallel to each other trajectories. It was provided by the matrix construction were two Hall probes can be set at different 3 radiuses (Fig.9). The measurements have shown that angular effective length of the first injection dipole magnet is $60.0° \pm 0.03°$ and effective angular effective length of the second injection dipole magnet is $60.3° \pm 0.3°$. It means that magnet parameters are in a strict agreement with design project and small mismatching can be eliminated with correction coils. The measured longitudinal magnetic field distributions at different radiuses were identical with accuracy 10^{-4} within ± 10 mm out from reference orbit. It means that both injection channel dipole magnets are sector magnets.

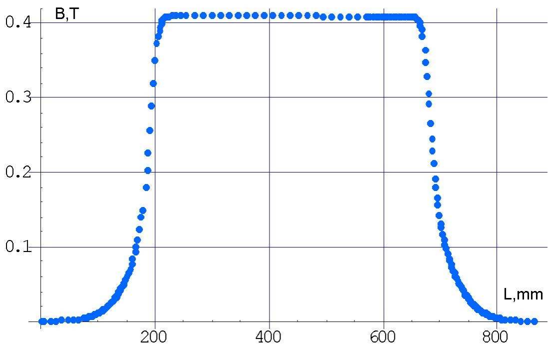

Fig.8. *Magnetic field distribution along reference orbit of the "NESTOR" facility injection channel dipole magnet*

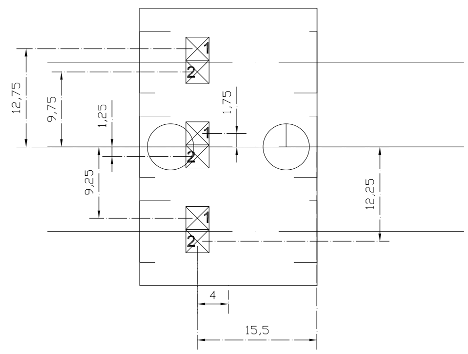

Fig.9. *Positioning of the Hall probes at the moved probe matrix*

The magnetization curves of the magnets have been measured with supply of the main current supply source (Fig.10).

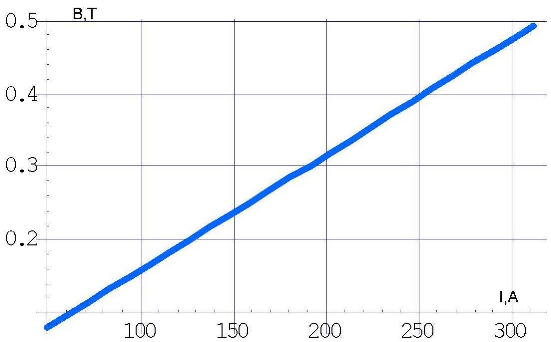

Fig.10. *Magnetization curve of the "NESTOR" injection channel dipole magnets*

As for the case of the quadrupole magnet measurements this characteristics was registered after three-time preliminary magnets magnetization with constant speed of excitation current increasing and decreasing equal to about ($\approx 1.2\ A/s$). For the first dipole magnet the approximation magnetic field expression is $B[T] = 0.00157 + 0.00157 \times I\ [A]$. The difference between approximation formula results and experimental results are within 0.2% and is shown in Fig.11. The second dipole magnet the approximation magnetic field expression is $B[T] = 0.00195 + 0.00156834 \times I\ [A]$. The difference between approximation formula results and experimental results are within 0.2% and is shown in Fig.12. For the exact matching of the fields in the first and second "NESTOR" injection dipole magnets one can use Fig.13 where difference of the magnetic field in the first and second injection dipole magnets in dependence on excitation current are shown.

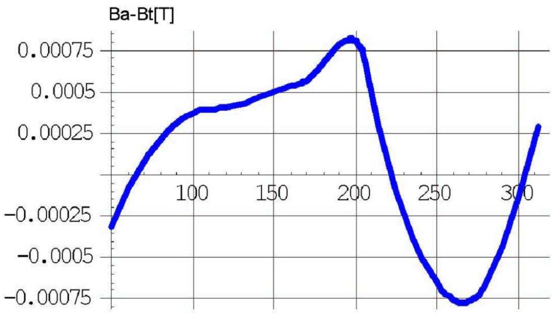

Fig.11. *Difference between magnetic field of the first "NESTOR" injection channel dipole magnet IB1 calculated with approximation formula $Ba[T] = 0.00157 + 0.00157 \times I\ [A]$ and experimentally measured field Bt*

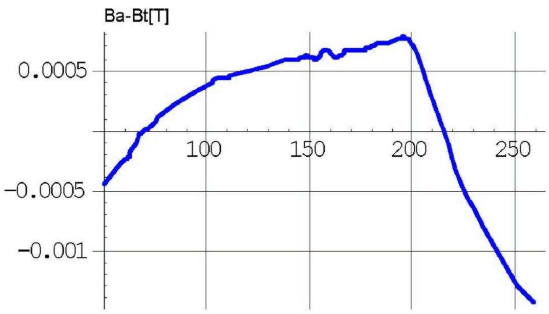

Fig.12. *Difference between magnetic field of the second "NESTOR" injection channel dipole magnet IB1 calculated with approximation formula $B[T] = 0.00195 + 0.00157 \times I[A]$ and experimentally measured field Bt*

Fig.13. *Dependence of magnetic field difference in the first and second "NESTOR" injection channel dipole magnets on magnet excitation current*

To accurate tuning and agreement of the bending magnet magnetic fields the magnetization curve of the additional excitation coils for both injection dipole magnets have been investigated. The measurements were carried out in the range of injection electron energy (60 $MeV - 0.4\,T$ magnetic field) and near the zero current. The results of the measurements are shown in Table 4.

Table 4. *Magnetization "NESTOR" injection channel dipole magnet parameters due to additional excitation coils*

Parameter	Mag1	Mag2
$\Delta B_{ing}[Gs]$	$63. \times I$	$24. \times I$
$B_{B0=0}[Gs]$	$42 - 68 \times I$	$46 - 26 \times I$
$Demag\ Curr_{B=0}$	$0.623[A]$	$1.785[A]$

5. CONCLUSIONS

In accordance with "NESTOR" injection channel conception and design project of the "NESTOR" X-ray source the magnetic elements of the transportation channel were manufactured. The set of the transportation channel elements involves 2 injection dipole magnets, 7 focusing quadrupole magnets and 5 two-coordinate dipole correctors. To test magnetic properties of the manufactured magnetic elements and verify their agreement with project requirements two magnetic measurement benches were designed and developed. One was designed for the quadrupole magnet and corrector testing. The second was used for dipole magnet testing. The magnetic property measurement methodology that involves fiducialization procedure of the magnetic element survey targets has been developed and tested. The results of the measurements show that parameters of all "NESTOR" transportation channel magnetic elements are in a good agreement with design project. The injection channel magnetic elements will provide project parameters of the electron beam at entrance of a traveling wave electrical inflector.

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МАГНИТЫ ИНЖЕКЦИОННОГО КАНАЛА ДЛЯ РЕНТГЕНОВСКОГО ГЕНЕРАТОРА "НЕСТОР"

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В ННЦ ХФТИ в последнее время идут работы по изготовлению рентгеновского источника "НЕСТОР". В работе представлены параметры магнитов для канала инжекции установки "НЕСТОР". Для дипольных магнитов получены характеристики: кривая намагничивания, эффективная длина, которые согласуются с расчетными. Измеренные параметры позволяют управлять магнитным полем с абсолютной точностью 2 Гс при энергии инжекции 60 МэВ и размагничивать магнит до ±2 Гс. Для квадрупольных линз получены кривые намагничивания, силы и положения магнитной оси. Измерены параметры 2-х координатних корректоров.

МАГНІТИ ІНЖЕКЦІЙНОГО КАНАЛУ ДЛЯ РЕНТГЕНІВСЬКОГО ГЕНЕРАТОРА "НЕСТОР"

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В ННЦ ХФТІ протягом останніх років ведуться роботи з виготовлення генератора рентгенівського випромінювання "НЕСТОР". У статті представлено параметри магнітів для каналу інжекції установки "НЕСТОР". Для дипольних магнітів отримані характеристики: крива намагнічування, ефективна довжина, які співпадають з попередньо розрахованими. Виміряні параметри дозволяють задавати магнітне поле з абсолютною точністю 2 Гс при енергії інжекції 60 МеВ та розмагнічувати магніти до ±2 Гс. Для квадрупольних лінз отримані криві намагнічування, сили та положення магнітної осі. Виміряні параметри 2-х координатних коректорів.