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COMMISSIONING OF THE STORAGE RING FOR THE KHARKOV GENERATOR OF X-RAY RADIATION NESTOR

V. Androsov, S. Bazarov, V. Berezka, A. Bezdetko, A. Cherkashin, A. Dovbnya, A. Gevchuk, P. Gladkikh, S. Gokov, A. Gordienko, V. Grevtsev, A. Gvozd, V. Ivashenko, A. Kalamayko, I.I. Karnaukhov, I.M. Karnaukhov, V. Kozin, V. Lyashchenko, V. Margin, N. Mocheshnikov, M. Moisieienko, A. Mytsykov, F. Peev, A. Rezaev, V. Sergienko, A. Shcherbakov, V. Shpagina, N. Shul'ga, V. Skomorokhov, D.Tarasov, V. Trotsenko, V. Tsyats'ko, A. Zelinsky, A. Zolochevskiy, O. Zvonaryova, NSC KIPT, 61108, Kharkov, Ukraine
J.I.M. Botman, Eindhoven University of Technology, Netherlands

Abstract

During 2015-2017 the X-ray source NESTOR (New Electron STOrage Ring) based on a storage ring with low beam energy and Compton scattering of intense laser beam is under commissioning at the National Science Center "Kharkov Institute of Physics and Technology Institute" (NSC KIPT). The start-up of the injector and storage ring is one of the basic task for the facility commissioning.

In the paper, the results of the NESTOR X-ray source 200 MeV electron storage ring commissioning are described and further plans are discussed.

INTRODUCTION

Compton backscattering is the most efficient photon energy amplifier. The energy of the scattered photons can be describe by the formula:

$$\varepsilon_{\gamma CBS} \approx 4\gamma^2 \varepsilon_{\gamma 0}\,, \quad (1)$$

where $\varepsilon_{\gamma 0}$ is the energy of colliding photons and $\varepsilon_{\gamma \mathrm{CBS}}$ is the energy of scattered photons, $\gamma = E_0 / mc^2$, E_0 is the relativistic electron beam energy and mc^2 is the rest energy of the electron.

For example, using an electron beam with an energy of 50 MeV and a laser with a photon energy of 1 eV, one can obtain the hard X-ray radiation necessary for X-ray angiography.

The total intensity of scattered photons is:

$$N_{\gamma CBS} \approx \sigma_C \frac{N_e N_l}{4\pi\sigma_r^2} f_c\,, \quad (2)$$

where σ_C is the Compton cross section, N_e, N_l are the number of the particles on both bunches (electrons and photons), f_c is repetition frequency of the interaction and σ_r is the transverse spot size.

X-RAY GENERATOR NESTOR

The last several years the source of the X-rays NESTOR (New Electron STOrage Ring) based on a storage ring with low beam energy and Compton scattering of intense laser beam is under testing and commissioning at the National Science Center "Kharkov Institute of Physics and Technology Institute" (NSC KIPT) [1-3].

The facility consists of the compact 40-225 MeV storage ring, linear 35-90 MeV electron accelerator as an injector, beam transportation system, Nd:Yag laser system and optical cavity. It is expected that the facility will generate X-rays flux of about 10^{13} phot/s. The main facility design specifications are listed in Table 1.

Table 1: Design Specifications

Parameter	Value
Storage ring circumference, m	15.418
Electron beam energy range, MeV	40-225
Betatron horizontal tune, Qx	3.155
Betatron vertical tune, Qy	2.082
Amplitude functions βx , βz at IP, m	0.14, 0.12
Linear momentum compaction factor α1	0.01-0.08
RF acceptance, %	>5
RF frequency, MHz	700
Electron bunch current, mA	100
Number of circulating electron bunches	1,2,3,4, 36

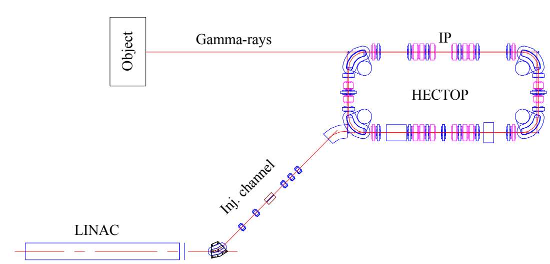

Figure 1: Scheme of the X-ray generator NESTOR.

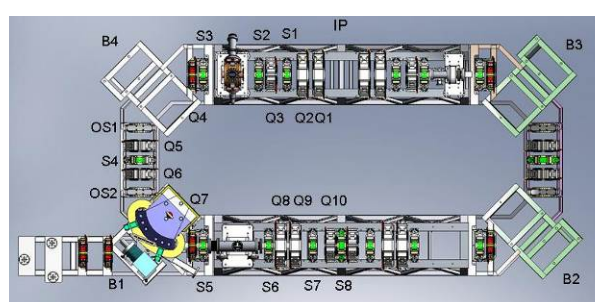

Figure 2:NESTOR storage ring lattice layout. B1-B4 are dipole magnets with combined focusing function, Q1-Q10 are quadrupole magnets, S1-S7 are sextupole magnets, OS1-OS2 are octupole magnets combined with sextupole magnets.

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The scheme of the X-ray generator NESTOR, which includes a linear electron accelerator, a beam transport channel and a storage ring, is shown in Fig. 1. The initial storage ring lattice and view of the assembled storage ring are shown in Fig. 2 and Fig. 3. The overall dimensions of the facility are about 15×10 m^2.

Figure 3: NESTOR storage ring.

NESTOR facility commissioning was divided at the following stages:

- Accelerator and transportation channel commissioning;
- electron beam injection system commissioning;
- storage ring commissioning;
- optical system design, development and testing;
- optical system implementation.

The commissioning of the NESTOR facility linear accelerator-injector, transportation channel and injection system have been carried out.

The measured parameters of the linear accelerator beam are the following:

- The output current of the electron gun is 140 mA.
- Current after the first accelerating section is 46 mA.
- Current after the second accelerating section is 33 mA.

All elements of the injector and transportation channel were aligned within ±200 μm transversal planes accuracy and electron beam of 60 MeV energy was focused and transported to the storage ring.

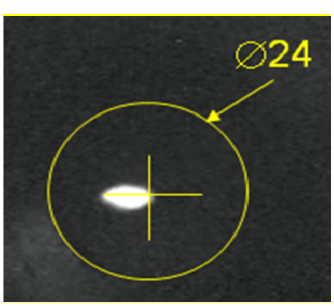

Figure 4: Electron beam shape behind the second bending magnet of the transporation channel.

The electron beam shape on the scintillating screen at the end of transportation channel is shown in Fig. 4. Beam sizes are in a good agreement with the design calculations. To determine the necessary forces of dipole correctors of the transport channel sensitivities of the beam gravity center to each corrector were calculated. The measurements showed good agreement between calculations and experimental data.

Electron beam current measured with current transformer detector in transportation channel is about 20 mA (66% of the current at the exit of the linear accelerator). Beam losses are in a good agreement with calculation results.

The injection system of the NESTOR facility was assembled and tested. After the injection system commissioning the injection experiments of the electron beam to the storage ring have been started. The results of the experiments showed the necessary of the storage ring lattice modification to increase storage dynamic aperture at the injection azimuth and increase injection efficiency.

At lattice modification the following factors were taken into account:

- interaction point (IP) straight section length should be increased to 0.75 m;
- the positions of all but IP triplet magnets should not be changed;
- the force of lenses could be changed within 20% from maximal magnet forces.

As a result of parameter calculations of modified NESTOR storage ring lattice were determined. First, the lattice parameters were determined in linear approximation. The lattice satisfied all requirements and in needed range of quadrupole magnet changes. In Fig. 3 the beta functions of modified lattice are shown. It is clear that theirs value is similar to the design project beta functions. The betatron oscillation frequencies values are Q_x=3.10, Q_z= 1.79 and momentum compaction factor α = 0.01. Second, the natural chromaticity was suppressed with sextupole magnets OS1-OS4 and S4-S12. Third, the dynamic aperture of the storage ring was corrected with sextupole magnets S1-S3, S17-S19. The value of the dynamic aperture at the injection point is about 42 mm in horizontal direction and about 26 mm in vertical direction. It is bigger then in initial design project and provides the effective injection in NESTOR storage ring.

Figure 5 shows the modified lattice dynamic aperture of the NESTOR storage ring at the injection azimuth. One can see that the aperture was increased that should provide injection efficiency increasing.

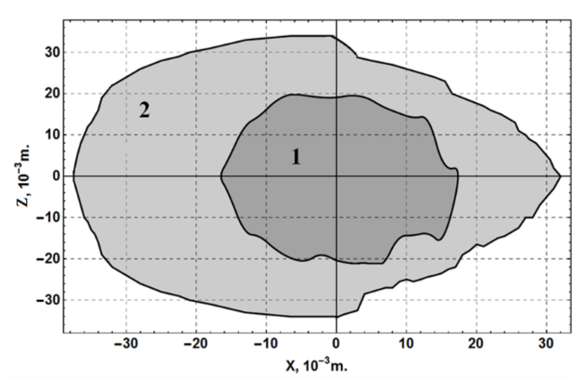

Figure 5: The dynamic aperture of the NESTOR storage ring (1- old, 2- new).

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LASER OPTICAL SYSTEM

The NSC KIPT NESTOR facility is going to use a laser with the following parameters: λ = 1.064 μ, f = 350 MHz (with tuning), power = 10 W and Fabri-Perot resonator with the parameters: L = 0.406 m, mirrors with R = 99.9%, waist ~ 100 μ, interaction angle ~ 10 °

Figure 6 shows a 3D model of the optical resonator for a laser beam x-ray source NESTOR.

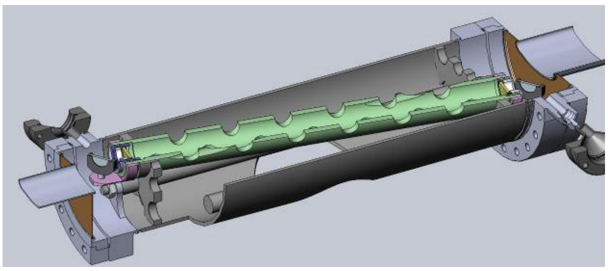

Figure 6: 3D model of the optical resonator for a laser beam x-ray source NESTOR.

Optical storage system of NESTOR generator consists of external optical enhancement cavity (OEC) resonantly driven by a mode-locked laser (Figs. 7 and 8).

Performance demands for OEC: low internal losses; a narrow transverse waist at the interaction point (IP); optical/mechanical stability.

Performance demands on the drive laser:

- efficient coupling to the cavity eigenmode by transverse mode-matching and alignment;
- tracking the central frequency of the cavity by maintaining an overall frequency stability within the cavity bandwidth.

One mutual requirement is to match the laser pulse repetition rate to the free spectral range of the cavity, where both also match the electron storage ring circulation frequency.

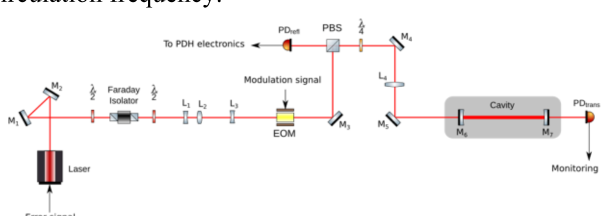

Figure 7: A schematic of the optical system.

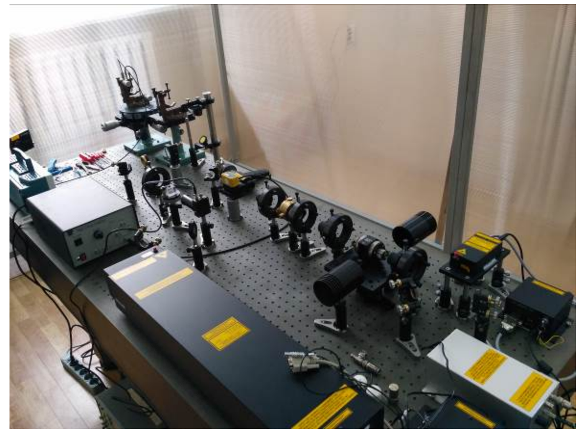

Figure 8: Optical bench of NESTOR generator

CONCLUSION

The assembling of the NESTOR X-ray generator facility technological systems has been done. The testing and commissioning of the accelerator-injector and transportation channel has been carried out. The test operation of the storage ring vacuum system shows the good performance of the accelerator and storage ring vacuum system (about 10^{-9} torr). Optical system of the facility was designed and test bench for the testing was developed. Bench tests of the system are in progress. The next steps of the commissioning are implementation of the optical system to the storage ring structure and design and development of the user output X-ray channel.

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