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STORAGE RING DESIGN AND BEAM INSTABILITIES INVESTIGATION FOR MEPhI's PHOTON SOURCE*

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Abstract

There is a design of a compact photon source based on inverse Compton scattering at NRNU MEPhI. Updated synchrotron lattice, electron dynamics simulation and beam instabilities studies are presented.

INTRODUCTION

Photons of 5-30 keV and flux of about 10^{10}-10^{12} γ/s are used for materials science, research of nano - and biosystems, medicine and pharmacology, physics and chemistry of fast-flowing processes. There are a few ways of 5-30 keV photon production. This project aims to development of a compact system for generating radiation in a next-generation light undulator in the photon energy range of 5-30 keV for ring and linear sources based on inverse Compton scattering.

A number of facilities based on inverse Compton scattering effect are under design or operation today: MuCLS [1], LyCLS [2], ThomX [3], ODU CLS [4], SLEGS [5], SPARC_LAB [6], LUCX [7], LESR [8], Daresbury Compton Backscattering X-ray Source [9]. Compton light source is supposed to be built on the NRNU MEPhI site. Two operating modes of the compact light source are possible: the storage ring Compton source design and the linac-based Compact-XFEL.

STORAGE RING

In order to generate 5-30 keV X-rays in light ondulator it is suggested that compact storage synchrotron will be used with top-up injection from normal conducting S-band linac with tuneable energy in the range of 20-60 MeV.

The use of a storage ring provides the following advantages: high intensity of the generated photon flux, high brightness, electron beam energy tuning in a wide range, high degree of monochromaticity and coherence of the generated photons.

In order to get horizontal rms beam size at interaction point (IP) with laser photons of 30 µm for electron horizontal emittance $\varepsilon_{x,\mathrm{rms}}$ of 100 nm the horizontal beta-function value should be equal to 30 cm in accordance with

$$\beta_x = \sigma^2_{x,\mathrm{rms}} \big/ \varepsilon_{x,\mathrm{rms}}.$$

The same value should have the vertical beta-function at IP. Dispersion function D_x should have a zero value at IP to minimize e-bunch size because

$$\sigma^2_{x,\mathrm{rms}} = \beta_x \varepsilon_{x,\mathrm{rms}} + D_x^2\left[(p-p_0)/p_0\right],$$

where $\sigma_{x,\mathrm{rms}}$ – horizontal rms beam size, β_x – horizontal beta-function, p – momentum of electron, p_0 – equilibrium momentum.

Furthermore, the length of storage ring straight section should be of 1.5 m to increase interaction efficiency between electron bunch and laser photons head-on collision as well as feasibility of laser positioning. The updated version of synchrotron magnetic lattice is presented in Fig. 1. Storage ring circumference is 10.661 m. The quadrupole gradients were calculated numerically by means of AT [10] to satisfy requirements above. Figure 2 shows obtained optic functions. From Fig. 2 it is seen that β_x is 24.12 cm and β_y is 14.62 cm at IP. Momentum compactification factor is equal to 0.0645 at 60 MeV, betatron horizontal and vertical tunes are 3.762 and 2.794 correspondingly. Also it was estimated dynamic aperture (DA) (Fig. 3). DA is equal to ±4.3 mm which is sufficient value for 30 µm beam-size.

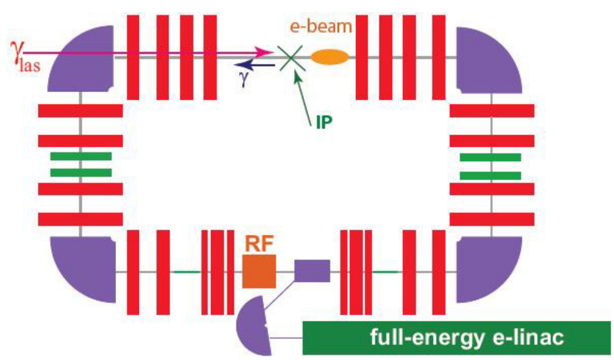

Figure 1: Basic magnet lattice of storage ring.

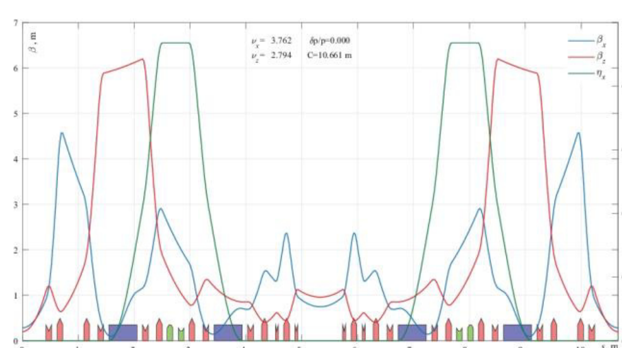

Figure 2: Twiss functions and dispersion.

Two families of sextupoles were arranged in the dispersion function maximum to correct chromaticities.

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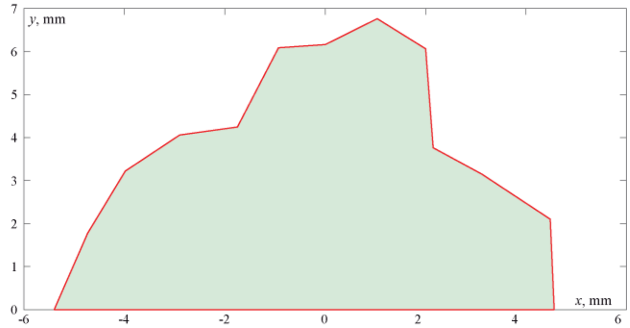

Figure 3: Dynamic aperture (for 1000 turns).

LIFE TIMES, INSTABILITIES, NON-LINEAR EFFECTS AND LIMIT CURRENTS

Following the study of different non-linear effects, instabilities and space charge limitations are started. It is necessary to define the final value of beam lifetime and the bunch current (charge). These parameters are crucially important to further design both injector and laser systems. First we estimate values of radiation integrals [11] for the lattice [12]: I_1=1.17, I_2=7.48 1/m, I_3=14.48 1/m^2, I_4=2.27 1/m. Such values of radiation integrals and small radiation energy losses (due to the low beam energy of 10-60 MeV losses are equal to $3\cdot10^{-1}$ eV/turn) give us very high value of the radiation times τ_x=3200 and τ_y=2230 s correspondently for horizontal and vertical motion. The calculation of the Touschek lifetime (TLT) give the representative value about 1-10 ms for the different beam energy, bunch charge, and the energy acceptance (see Figs. 4-7). We should estimate TLT and decide will it be the main factor limiting the lifetime for the low energy beam in small-circumference ring. It is obviously from our general suggestions for beam dynamics in low-energy rings and it was shown by simulation for MEPhI project.

It is clear the optimal bunch charge should be not greater than 300 pC and we have to increase the momentum acceptance up to 2-3 % to reach biger value of TLT.

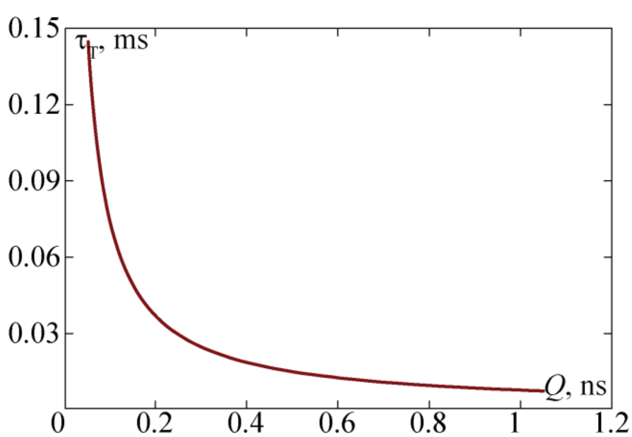

Figure 4: TLT vs bunch charge.

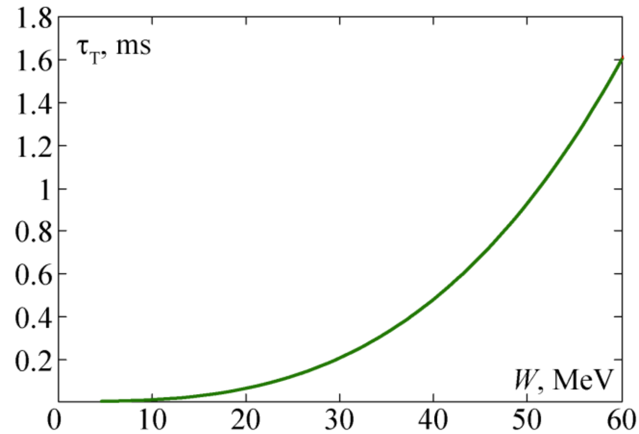

Figure 5: TLT vs beam energy.

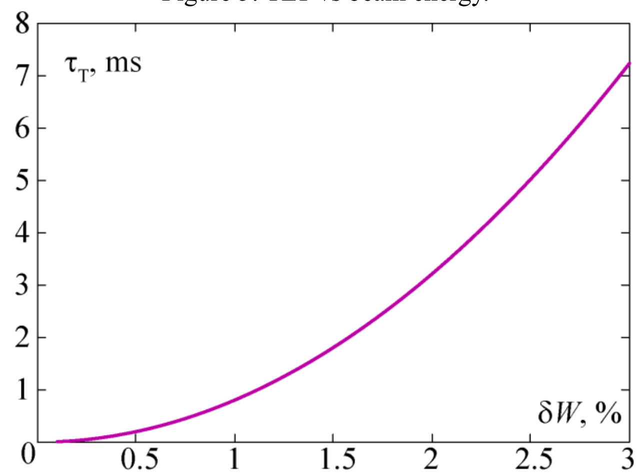

Figure 6: TLT vs energy acceptance (Q = 1 nC).

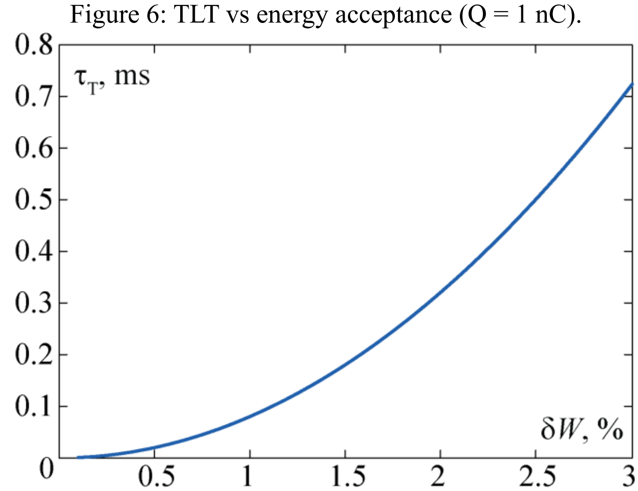

Figure 7: TLT vs energy acceptance (Q = 100 pC).

Following the intra-beam scattering (IBS) was simulated and the IBS time was defined [13]. It is equal to ~150 s for horizontal motion and is very high for vertical and longitudinal ones. The threshold bunch current calculated for longitudinal motion using the finite fine filament technique is equal to 630 A (or 600 nC in 1 ps bunch). The limit calculated for transverse motion (by uniformly charged ellipsoid technique and with the accelerating potential 300 kV and the vacuum chamber size 20×100 mm) is ~830 pC.

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As it was shown under such values (< 1 nC) of the bunch charge the batatron tune shift will very small $\Delta\nu_x$=-2.02·10^{-13} and $\Delta\nu_x$=−2.21·10^{-12} per turn.

Finaly the estimation of the microwave instability life times were done. It was chosen the accelerating cavity frequency about 3000 MHz (T_{turn}/T_{RF}=105) and energy acceptance 3 %. The vacuum chamber form was supposed to be similar to USSR4 (ESRF-EBS synchrotron vacuum chamber) project to define the vacuum chamber impedance. The beam current will be limited by ~400 A due to microwave instability. Characteristic times will be equal to 23 and 4.2 ms for horizontal and vertical motions correspondently.

CONCLUSION

Current activities on physical models design of a compact monochromatic radiation source in the x-ray range based on inverse Compton scattering are presented. A circumference of the storage ring is supposed to be about 11 m. Simulations were done to define the bunch life times and to study basic non- linearity effects. It was shown Touschek lifetime will the main limiting factor for the designed low-energy ring. Estimation gives us TLT is about 0.1-1.0 ms for different bunch charge, beam energy and energy acceptance values and it is the lowest from the set of key lifetimes. The bunch charge should be limited by 300-400 pC/bunch to have high TLT and weakly influence on the bunch dynamics.

REFERENCES

[1] M. Dierolf, “The Munich Compact Light Source – a laboratory-scale synchrotron facility for biomedical research”. http://www.e17.ph.tum.de

[2] J. Rifkin *et a1.*, “Apparatus, system and method for high flux, compact Compton X- ray source”, US patent 7277526 B2. Oct. 2, 2007.

[3] A. Variola *et al.,* “ThomX Technical Design Report”, France, Rep. SOLEIL/SOU-RA-3629, Mar. 2014. http://hal.in2p3.fr/in2p3-00971281

[4] K.E. Deitrick *et al.*, “High-brilliance, high-flux compact inverse Compton light source”, *Phy. Rev. Accel. Beams*, vol. 21, p. 080703, Aug. 2018. doi:10.1103/PhysRevAccelBeams.21.080703

[5] Q.Y. Pan *et al.*, “A Future Laser Compton Scattering (LCS) γ-Ray Source: SLEGS at SSRF”, *Synchr. Rad. News*, vol. 22, no. 3, p. 11, Jun. 2009. doi:10.1080/08940880902959759

[6] C.Vaccarezza *et al.*, "The SPARC_LAB Thomson source", *Nucl. Instrum. Meth. A*, vol. 829, no. 1, p. 237, Sep. 2016. doi:10.1016/j.nima.2016.01.089

[7] K. Sakaue *et al.*, “Development of a compact X-ray source based on laser-Compton scattering with a pulsed-laser super-cavity”, in. *Proc. 11th Eur. Particle Accelerator Conf. (EPAC'08)*, Genova, Italy, Jun. 2008, paper TUPP156, pp. 1872-1874.

[8] P. Gladkikh, “Lattice and beam parameters of compact intense x-ray sources based on Compton scattering*”, Phy. Rev. Accel. Beams*, vol. 8, p. 050702, May 2005. doi:10.1103/PhysRevSTAB.8.050702

[9] D. Laundy *et al.*, “Results from the Daresbury Compton backscattering X-ray source”, *Nucl. Instrum. Meth. A*, vol. 689, p. 108, Oct. 2012. doi:10.1016/j.nima.2012.05.054

[10] AT, http://atcollab.sourceforge.net/docs.html

[11] E.B. Levichev, “Low emittance electron storage rings”, *Phy.-Uspekhi*, vol. 61, no. 1, pp. 29-51, 2018. doi:10.3367/ufne.2016.12.038014

[12] V.S. Dyubkov *et al.*, “Beam Dynamics Investigation for a New Project of Compton Back Scattering Photon Source at NRNU MEPhI”, in *Proc. IPAC'21*, Campinas, SP, Brazil, May 2021, pp.186-188. doi:10.18429/JACoW-IPAC2021-MOPAB042

[13] J.D. Bjorken and S.K. Mtingwa, “Intrabeam Scattering”, *Part. Accel.*, vol. 13, pp. 115-143, 1983.