DESIGN OF A COMPACT STORAGE RING FOR THE TTX*

Haisheng Xu†, Wenhui Huang, Chuanxiang Tang,
Department of Engineering Physics, Tsinghua University, Beijing 100084, China
Shyh-Yuan Lee, IUCEEM, Indiana University, USA

Abstract

We study a compact storage ring with circumference 3-m, 4 dipoles, and 2 quadrupoles for the Tsinghua Thomson scattering X-ray (TTX) source. The effects of Touschek lifetime, RF system requirement, the Intra-Beam Scattering (IBS) and Coherent Synchrotron Radiation (CSR) are addressed. A top-up injection system is designed to maximize the photon flux. A conceptual laser cavity to enhance photon flux is discussed. The expected performance of the compact X-ray source is presented.

INTRODUCTION

Hard X-ray photon source can easily be obtained by the inverse Compton Scattering of eV laser photons with MeV electrons. Therefore, the hard X-ray light source based on ICS can be made very compact. Using an electron storage ring can further increase the repetition frequency of the scattering and increase the photon flux [1].

In the past few years,we have designed a compact ring for Tsinghua Thomson scattering X-ray source (TTX) [2] [3] [4]. Here, we propose a compact storage ring of which the circumference is 3m. We use a photocathode RF gun and a 3m SLAC-type Linac as the injector. The electrons are accelerated to 50MeV and injected into a compact storage ring. The electron beam is stored in the ring while the laser is stored in a Fabry-Perot cavity. The repetition frequency of the ICS increases from 10 Hz to 100 MHz. In this article, we present the lattice optics of the ring, some dynamic effects and the present status of the ring.

THE RING

The 3-m storage ring includes four bending magnets and two quadrupole magnets. There is no sextupoles in the ring. However, if needed, we will design sextupole field into quadrupoles. The preliminary design of the lattice optics, the injection system and the RF system is presented in this section.

Lattice

The lattice is tunable from double bend achromat (DBA) to nearly isochronous by adjusting the quadrupole strength. The injection Lambertson locates on one of the long straight sections while the RF cavity locates on the other. The schematic drawing of the ring is shown in Fig. 1.

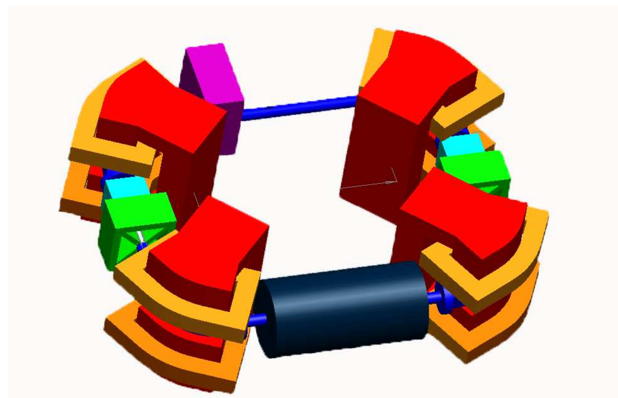


Figure 1: The schematic drawing of the ring.

The lattice optics shown in the Fig. 2 corresponds to DBA condition. In the present design, the two focusing quadrupole magnets provide major modification to the dispersion function without changing much the betatron tunes because the values of the betatron functions are small. The focusing in the horizontal direction and the focusing in the vertical direction are provided by the bending radius and the edge angle of the bending magnets. Some basic parameters of the lattice are shown in the Table. 1.

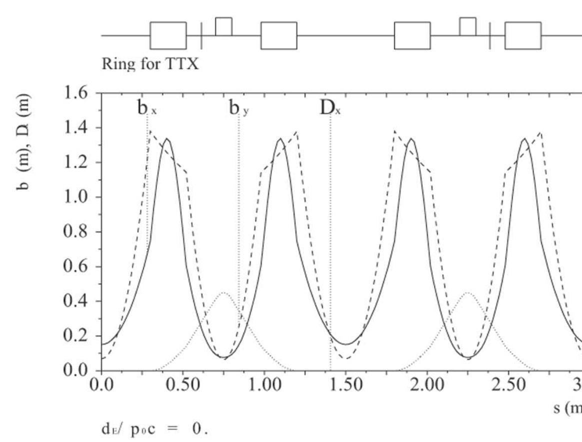


Figure 2: The lattice of the ring.

The Injection System

For the purpose of top-up injection, we intend to use two horizontal kickers to generate a local horizontal closed or-

* Work supported by the National Natural Science Foundation of China (NSFC) under Grant Nos. 10975088, 10735050, 10704087 and 10805031 and by the National Basic Research Program of China (973 Program) under Grant No. 2007CB815102.
† haishengxu@gmail.com

Table 1: Basic Parameters of the Ring

Parameters	Value
Circumference	3 m
Beam energy	50MeV
Bunch charge	1nC
Energy spread	0.23%
Bending radius	0.15m
Bunch length	23ps
Tunes	ν_x=1.7662, ν_y=1.7006
Synchrotron tune	0.0096
Natural chromaticity	$\xi_x = -4.44$, $\xi_y = -5.49$
MCF	α_c=0.059014
Damping partition	J_x=0.7988, J_y=1.0, J_e=2.2012
β function at the IP	$\beta_y^* = 0.7467\,\mathrm{m}$, $\beta_y^* = 1.3796\,\mathrm{m}$
Dispersion at the IP	$D_x^* = 0\,\mathrm{m}$, $D'^*_x = 0$
Radiation loss / turn	U_0=4.11eV/turn
Kicker arm	0.1868 m
Decay time τ	40ns
Max closed orbit	7mm
Max kicker angle θ_k	37.5mrad
RF frequency	499.65MHz
Harmonic number	5
peak RF voltage	100kV
Shunt impedance	$5M\Omega$
Power dissipation	1kW
RF acceptance	6.54%
Type	re-entrant, normal conducting
$\tau_{Touschek}$	19h

bit bump at the position of the Lambertson septum, which is shown in the Fig. 3. The horizontal betatron oscillation phase difference between the two kickers is π. We have calculated the required parameters of the kickers, which are shown in Table. 1. The falling time of the kicker is about 40 ns because the circumference of the ring is only 3m (10ns) and the horizontal tune is very closed to $\pi/2$. We intend to design the kickers with ferrite blocks as the magnetic yoke. Meanwhile, we choose to use the ceramic vacuum chamber for avoiding the eddy current. We will design the Lambertson septum and the kicker in details in the near future.

The RF System

We plan to use a single cell normal conducting re-entrant type RF cavity in the ring. The beam loading of the cavity won't be very heavy because the energy loss per turn is small in this ring (shown in the Table. 1). But the length of the longest straight section is only 0.6m, which requires the whole RF system to be very compact.

Meanwhile, Touschek lifetime is usually considered important for the low energy electron storage ring [5]. Thus we estimate the Touschek lifetime $\tau_{Touschek}$ by equation. 1 [6]. The Touschek lifetime of 19 h is long and considered not very important in this ring.

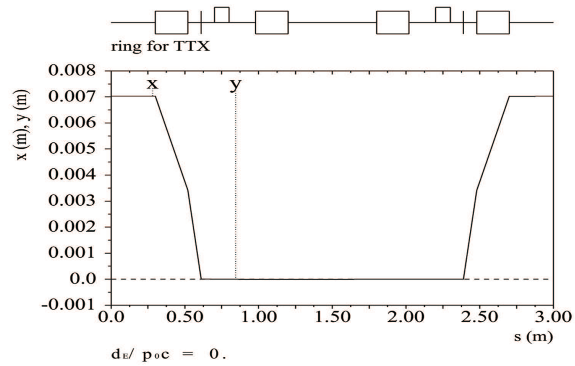


Figure 3: The closed orbit at the beam injection.

$$\tau_{Touschek} \approx \frac{48\gamma^2\pi\sigma_x\sigma_z\sigma_s}{Nr_0^2c}\left(\frac{\Delta p}{p}\right)^3 \qquad (1)$$

BEAM DYNAMICS

There are many important dynamic effects in the compact ring. In this section, we will present the research on the chromaticity, IBS and CSR in this ring.

Chromaticity

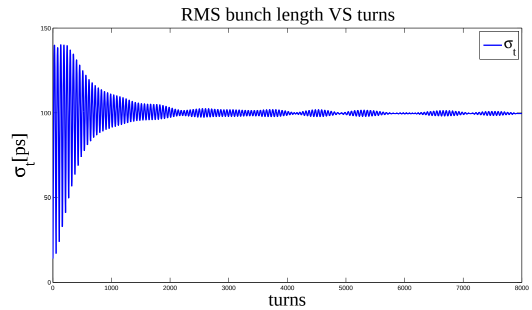
We prefer to not correct the chromaticity in the ring for the limited longitudinal space. But unfortunately, that may cause a large tune spread. Using the parameters in the Table. 1, we can estimate the maximum tune shift by $\Delta\nu_x = \nu_x \cdot \xi_x \cdot \delta \approx 0.018$ and $\Delta\nu_y = \nu_y \cdot \xi_y \cdot \delta \approx 0.022$. We can roughly account that there won't be any integer and half-integer resonances, at the same time, the higher order resonance lines are not important because there isn't any nonlinear elements in the ring. The more accurate results can be calculated with the Frequency Map Analysis (FMA) technology [7] in the future.

However, we find that a serious problem arises in the beam injection if the chromaticity is not corrected. Fortunately, it appears in the preliminary research that the problem can be solved by carefully designing the parameters of the injection system. Single beam head-tail instability will be studied in the future to understand the need of sextupoles in the ring.

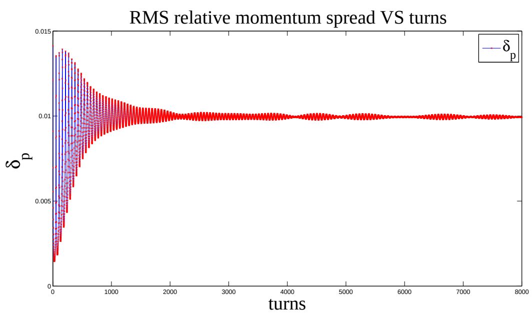
Intra-Beam Scattering (IBS)

Intra-Beam Scattering (IBS), which increases the emittance and reduces the beam lifetime, is considered as an important effect in low energy, low emittance storage rings. We use the IBS command of the MAD 8 to calculate this effect, using the formula first derived by J.D. Bjorken and S.K.Mtingwa [8]. A self-consistent calculation technology is employed to evaluate the change of the emittance [9].

Fig. 4(a) and Fig. 4(b) show that the change of bunch length σ_t and the momentum spread δ_p when we consider only the basic synchrotron motion.



(a)



(b)

Figure 4: (a) The RMS bunch length VS turns and (b) the RMS relative momentum spread VS turns.

Similarly, we calculate the evolution and the equilibrium values of emittances. Both the bunch length and the energy spread of the beam injected into the ring are better than the values determined by the RF parameters of the ring. Fortunately, both the bunch length and the momentum spread will reach the 'equilibrium' in about 2000 turns, meanwhile, the transverse emittances don't change much in such a short time. Therefore, it is reasonable to use the 'equilibrium' values of σ_t and δ_p as the initial values in the calculation. The gas scattering, synchrotron radiation damping and fluctuation will also be considered in the calculation. In each step of the calculation, we can obtain the new horizontal and vertical emittance, the bunch length and the energy spread which will be the initial values in the next step. The change of emittance shows in the Fig. 5, while the final equilibrium parameters are shown in the Table. 1.

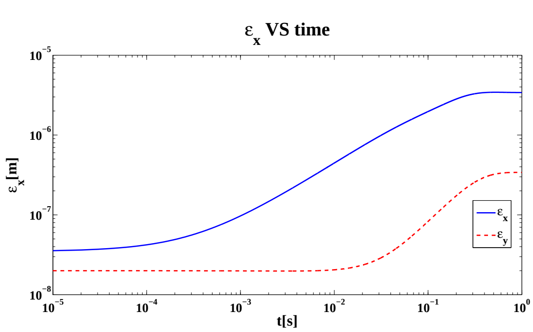


Figure 5: The transverse emittance VS time.

Coherent Synchrotron Radiation (CSR)

The CSR might account for instability in this ring for the equilibrium bunch length is about 23 ps and the bunch charge is 1 nC, and the bending radius is only 0.15 m. We use the parallel-plate model to estimate the impedance [10] and the method of Venturini [11] to obtain the CSR threshold with the parameters presented in the Table. 1. Fig. 6 shows that the current design is below the CSR threshold.

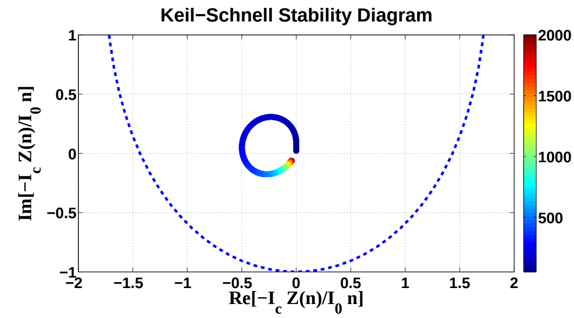


Figure 6: The Keil-Schnell stability diagram.

THE LASER CAVITY

We plan to use a Fabry-Perot (FP) cavity to store the laser. In the present design of the ring, the Interaction Point (IP) locates inside the RF cavity. We have to consider this carefully when we design the FP cavity. The design value of the photon flux is about 2×10^{10} photons per second. One of our colleagues is designing the FP cavity in detail.

CONCLUSION

In this article, we present a basic design of a compact ring for the TTX. We have a preliminary design of the injection and RF systems. Some important dynamic effects such as the IBS, CSR and so on were also considered. The Laser cavity is being designed.

REFERENCES

[1] Zhirong Huang and Ronald D. Ruth, Phys. Rev. Lett. 80, 976 (1998).
[2] Peicheng Yu et.al, Phys. Rev. ST AB 12, 061301 (2009).
[3] Peicheng Yu et.al, Chinese Phys. C, 33(S2), 151-153, 2009.
[4] DD Yang and Wenhui Huang, Chinese Phys. C, 35(8): 784-790, 2011.
[5] S. Y. Lee et.al, Rev. Sci. Instrum 78, 075107 (2007).
[6] S. Y. Lee, Accelerator Physics (2nd).
[7] L. Nadolski and J. Laskar, Phys. Rev. ST AB 6, 114801 (2003).
[8] J. D. Bjorken and S. K. Mtingwa, Part. Accel., Vol. 13, 1983.
[9] T. Luo, Ph.D. Thesis, Indiana University, 2011.
[10] R. L. Warnock, SLAC-PUB-5375. Stanford Linear Accelerator Center, Menlo Park, CA, USA, 1990.
[11] M. Venturini et.al, Phys. Rev. ST AB 8, 014202 (2005).