LASER ELECTRON STORAGE RING FOR TTX*

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Abstract

Tsinghua Thomson scattering X-ray (TTX) source, proposed by Tsinghua University, is a hard x-ray source with multi-application in condensed matter physics and other applications. The TTX is composed of an S-band photocathode RF gun and a SLAC type 3m travelling wave Linac, and a femto-second tera-watt laser system. The TTX source is in operation. To extend the capability of TTX, we plan to design a ring based system to increase the average photon flux. In this paper, we report the design of the 4.8 m electron storage ring and optical cavity, expected performance, and future prospects.

INTRODUCTION

Inverse Compton Scattering is a physical effect which can transfer energy from electrons to photons. Hard x-ray, which is in dozens of keV range, can be generated by head-on collision between low energy photons and MeV electrons. Tsinghua Thomson scattering X-ray source was started in 2001, which consists of an S-band photocathode RF gun, an S-band 3m SLAC type travelling wave linac, and a tera-watt laser system [1]. In previous experiments, the number of generated X-ray photons, which is measured with MCP, is about 1×10^6photons/pulse [2]. The repetition frequency is 10 Hz.

For generating stable x-ray output and increasing the photon flux, a compact electron storage ring and an optical cavity are proposed. In this scheme, the electron beam is stored in a small ring while laser pulses are stored and enhanced in an optical cavity. The repetition frequency is the same as the revolution frequency of the electron beam in the ring of the order of magnitude of tens of MHz.

In this paper, we present the current design of the compact electron storage ring and optical cavity.

THE ELECTRON STORAGE RING DESIGN

Lattice

We propose to use a 4-dipole scheme in the design of this 4.8 m ring. The bending radius of dipoles is 0.25 m. Two quadrupoles are put opposite to each other to change the damping partition number. As shown in Fig. 1 and Fig. 2, both betatron tune and horizontal damping partition number can be varied by adjusting the strength of the quadrupoles and the edge angle of dipoles. Tune should be chosen carefully in order to avoid the harmful linear and nonlinear resonances.

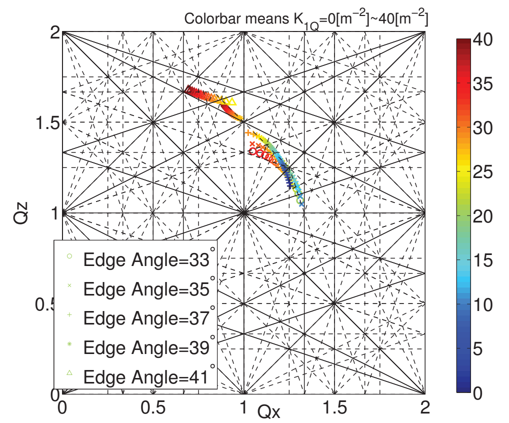

Figure 1: Tune diagram by changing the edge angle of bending magnets and focusing strength of quadrupoles.

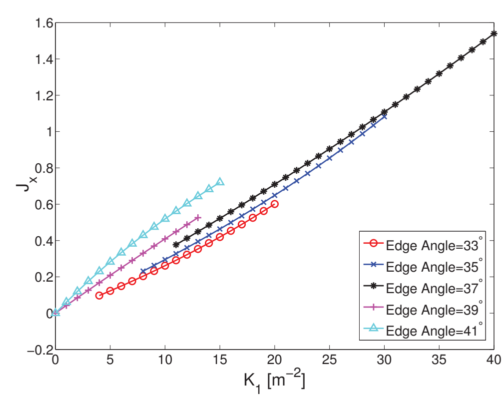

Figure 2: Horizontal damping partition number by changing the strength of quadrupoles at different edge angle.

With 4 bending magnets and 2 quadrupoles, the momentum compaction factor is tunable by changing the strength of quadrupoles. We choose the edge angle of bending magnets as 37°. The momentum compaction factor can be changed from -0.45 to 1.12 by adjusting the strength of quadrupoles. The accelerator can be used to study the dynamics and collective instabilities under isochronous condition.

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The baseline design with edge angle of dipoles as 37° and strength of quadrupoles as $30m^{-2}$ is shown in Fig. 3. The calculation of betatron amplitude functions and dispersion function are carried out with Elegant [3].

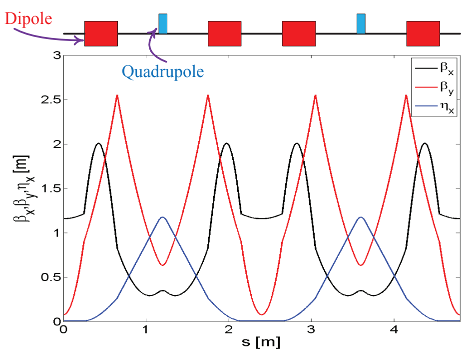

Figure 3: The layout and betatron amplitude function and dispersion function.

Injection System

The interaction point between electron bunches and laser pulses locates at the center of one of the short straight sections. Take this into consideration, an on-axis injection scheme, which is shown in Fig. 4, is proposed. Only one kicker is required in this scheme. An electron bunch from linac is delivered to the fringe field of a bending magnet (B1) firstly, and then passes through the quadrupole (Q1, 5[T/m]), arriving at the entry of kicker. A travelling wave kicker, which is optimized at 300 millimeters in length, is proposed to afford a kick angle about 30 mrad.

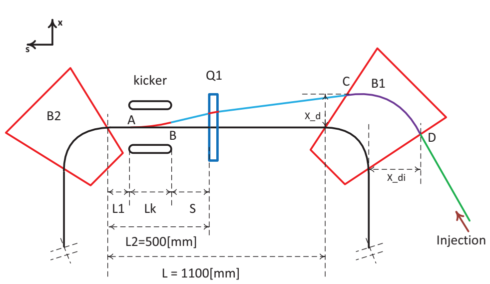

Figure 4: Schematic drawing of the injection process.

Dynamic Aperture

The horizontal and vertical chromaticities are -2.139 and -0.991, respectively. Therefore, we prefer not to correct them if Dynamic Aperture (DA) is large enough automatically. As shown in Fig. 5, the DA for particles with momentum deviation up to $\pm3.0\%$ are still larger than the vacuum chamber. In this calculation, particles are tracked 20000 turns by Elegant code [3]. Fringe field of bending magnets and small bending radius effect are all included in the tracking.

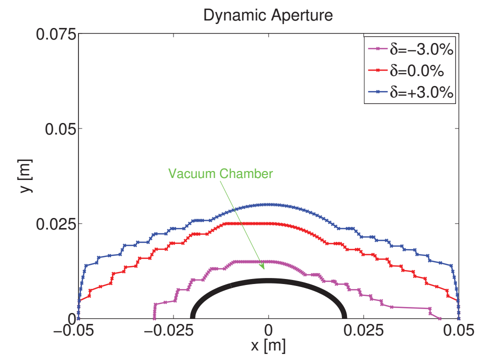

Figure 5: The dynamic aperture for $\delta = -3.0\%$ (magenta), $\delta = 0.0\%$ (red), $\delta = +3.0\%$ (blue). The black half-ellipse is the designed vacuum chamber.

THE OPTICAL CAVITY DESIGN

The optical cavity system can be divided into the following parts, as shown in Fig. 6: Laser, Optical cavity, Optical setup, Electro-optical setup, Feedback and the Electron Storage Ring locking.

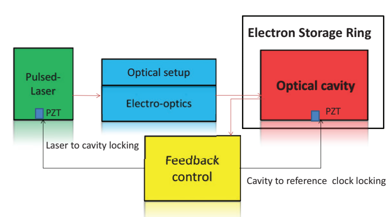

Figure 6: Block diagram of the optical cavity system.

Stacking the laser pulses inside the cavity requires the following features: laser source should have small phase noise and stable pointing instability, the repetition rate of the laser is locked to the cavity free space range (FSR), and the FSR locked to the electron storage ring circulation frequency.

The free running mode-locked laser cavity flucturates by several nano-meters because of the noises: pump light, mirror position, beam axis fluctuations and so on. The resonance of the Fabry-Perot cavity cannot be maintained without using the feedback, which keeps permanently Frep matched with FSR. In order to adjust the laser Frep, a piezo actuator is installed inside the laser, which changes the laser cavity length. We plan to use tilt-locking [4] technique to provide an error signal suitable to lock the laser to the cavity.

The structure of the high finesse optical cavity is a key factor for pulse stacking, because the resonance condition is very sensitive to the environment noise and fluctuations.

The constraints imposed on the optical cavity design by the designed x-ray flux are the following: good intra-cavity stacking power stability, small laser beam waist at the IP. The design of the cavity must also include an electron beam pipe, and the distance between the spherical mirrors must be long enough in order to reduce the scattering angle. Therefore, the designing of a cavity with a minimum sensitivity to the vibrations induced by the noisy environment of an electron accelerator is required.

We have studied numerically the mechanical stability of various optical resonator geometries. The 2M geometry is simpler but it is known to be mechanically unstable when small laser waists are reached. The 4M resonators are mechanically more stable and widely used in laser oscillator technology but the round-trip power loss is higher than in the 2M case. Specially, 2D 4M optical cavity is suitable for Thomson X-rays with an electron storage ring of several meters or tens of meters [5]. This kind of optical cavity has been used in LAL ThomX project [6], and KEK Quantum Beam project [7].

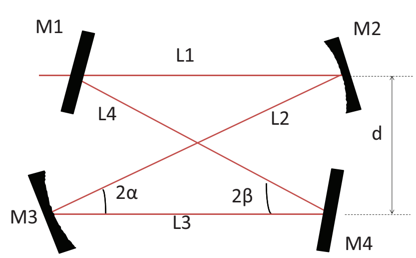

Figure 7: Schematic drawing of the 2D crossed 4-mirror cavity.

Figure 7 shows the schematic drawing of the 2D 4M crossed cavity. M1 and M4 are plane mirrors; M2 and M3 are spherical mirrors with a curvature ρ. L2 and L4 are the distances between the two spherical mirrors and two plane mirrors, respectively. L1 and L3 are the longitudinal distances between plane and spherical mirrors. M1 and M4 are plane mirrors; M2 and M3 are spherical mirrors with a curvature ρ. And d is the distance between the two parallel lines connecting the center of mirrors, M1, M2 and M3, M4. The round-trip cavity length is L, i.e. $L = L1 + L2 + L3 + L4$. The incident angle on the spherical mirrors is α and β on plane mirrors.

In order to combine the optical cavity with the electron storage ring and match the repetition rate of electron beams, the optical cavity round-trip length is chosen to be 4.8m. The spherical mirror with a curvature of $\rho = 1.2$m and $d = 60$mm. Table 1 gives the designed optical cavity parameters.

Table 1: Designed Optical Cavity Parameters

Parameters	Value
L1 [mm]	1199.25
L2 [mm]	1250.00
L3 [mm]	1199.25
L4 [mm]	1151.50
d [mm]	60.00
Beam Waist in Sagittal Plane (2σ) [μm]	170
Beam Waist Tangential (2σ) [μm]	170
Scattering Angle [°]	2.75
FSR [MHz]	62.5
Gain Factor	10000
Power Inside the Cavity [kW]	10-100

PROPERTY OF X-RAY

In this kind of low energy ring, Intra-Beam Scattering (IBS) play a dominant role in the process of getting to an equilibrium. Therefore, IBS, synchrotron radiation damping, quantum excitation, etc. should be taken into account in the calculation of equilibrium parameters. Using the equilibrium emittance, one can get the expected photon flux of this design to be about 5×10^{10}photons/s. The details are shown in another paper [8] in this proceeding.

DISCUSSION

We present the design of a 4.8m electron storage ring and an optical cavity for TTX in this paper. We have a preliminary design of the injection system of the electron ring. Studies of a 4-mirror, high finesse Fabry-Perot cavity are also presented.

REFERENCES

[1] Chuanxiang Tang *et.al.*, Nucl. Instr. Meth. Phys. Res. A 608 (2009) S70-S74.

[2] Yingchao Du *et.al.*, "Hard X-ray Generation Experiment at Tsinghua Thomson Scattering X-ray Source," MOPPP008, IPAC12.

[3] M. Borland, "Elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation," Advanced Photon Source LS-287, Sep. 2000.

[4] D.J. Ottaway *et.al.*, IEEE Journal of Quantum Electronics, Vol. 37, No. 5, May 2001.

[5] F. Zomer *et.al.*, Appl. Opt. 48 (35), 6651-6661 (2009).

[6] A. Variola *et.al.*, "THOMX Conceptual Design Report," LAL RT 09/28, SOLEIL/SOU-RA-2678 (2009).

[7] Junji Urakawa, "Overview for Quantum Beam Project at KEK," talk at Tomsk Polytechnic University, Aug. 2012.

[8] Haisheng Xu *et.al.*, "Calculation of the equilibrium parameters for the compact ring of TTX," TUPME025, in these proceedings.

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