Preliminary Engineering Design of SSMB Laser Modulator

Zhou Yang

Department of Engineering Physics, Tsinghua University

Abstract

Storage ring light source based on the principle of Steady-State Microbunching (SSMB) is a new advanced light source, which can generate coherent radiation with high average power from THz to EUV, and has broad scientific research prospects and great industrial value. The core component of SSMB storage ring is the laser modulator. Under the longitudinal bunching effect of the laser modulator, combined with the Lattice design with ultra-low longitudinal emittance of the whole ring, the microbunches running in the whole ring can be realized. Laser modulator is the first time to combine undulator, optical cavity and storage ring, and it is innovative in physical design and engineering design. Based on the dynamic process of the interaction between laser and electron, the important parameters of laser and undulator are optimized, and the engineering design of laser modulator is completed, including the structure of optical cavity, undulator and vacuum system.

Energy modulation of Gaussian laser

Under the modulation of Gaussian laser, electrons continue to gain or lose energy, and the modulation wavelength is in the order of um. Compared with the traditional storage ring, the laser modulator is used to replace the microwave RF cavity, and with the careful design of R56, the longitudinal length of the electron bunches is compressed to tens of nm.

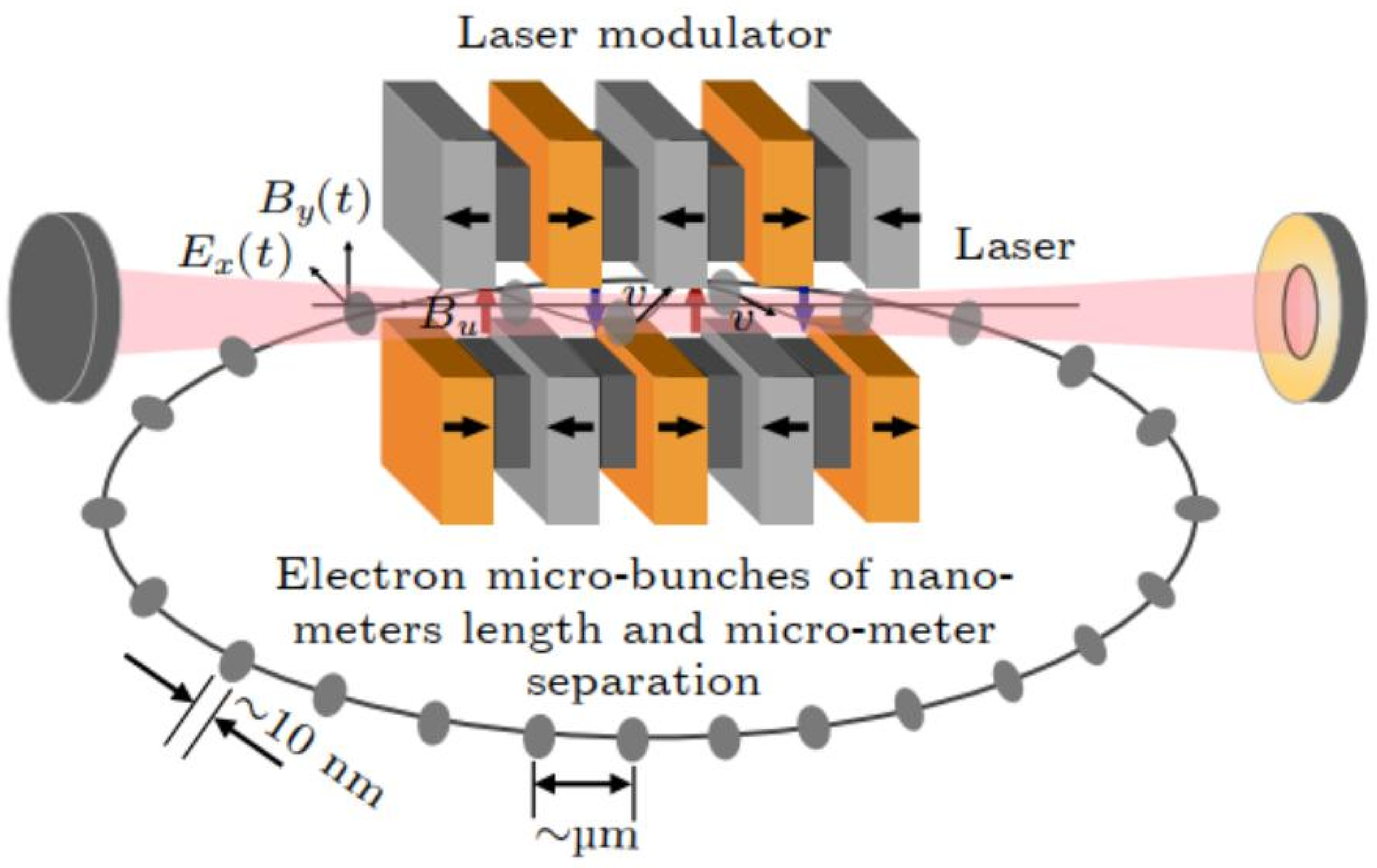
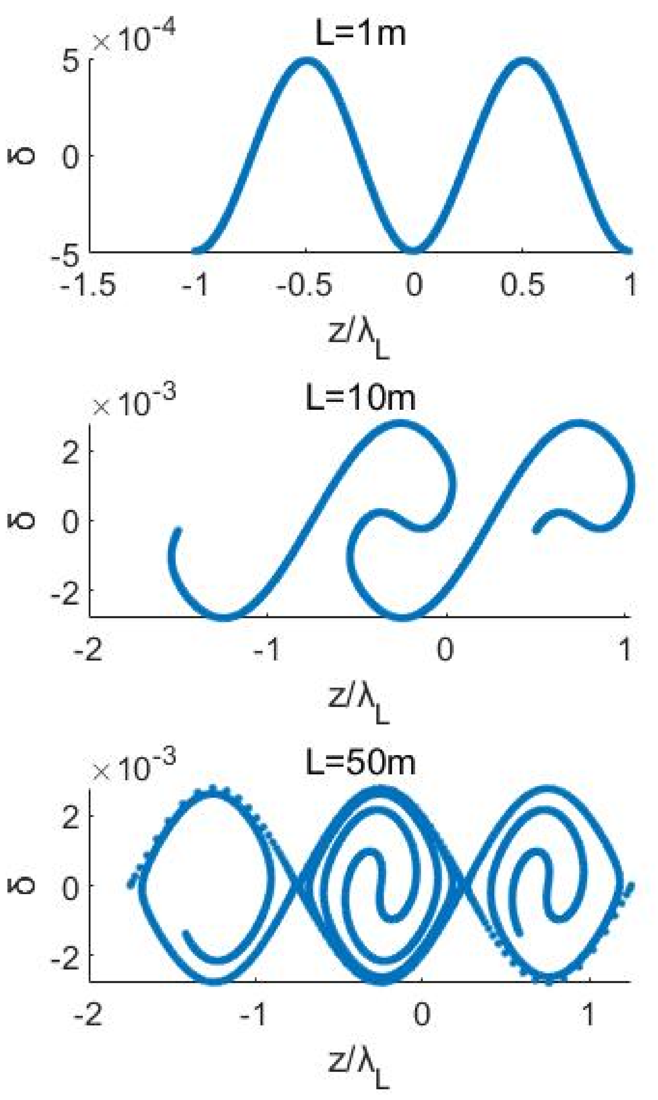


Fig. 1 Schematic diagram of laser modulator



$$M = \begin{bmatrix} \cos(AL) & \frac{2k_u}{Ak_l}\sin(AL) \\ -\frac{Ak_l}{2k_u}\sin(AL) & \cos(AL) \end{bmatrix}$$

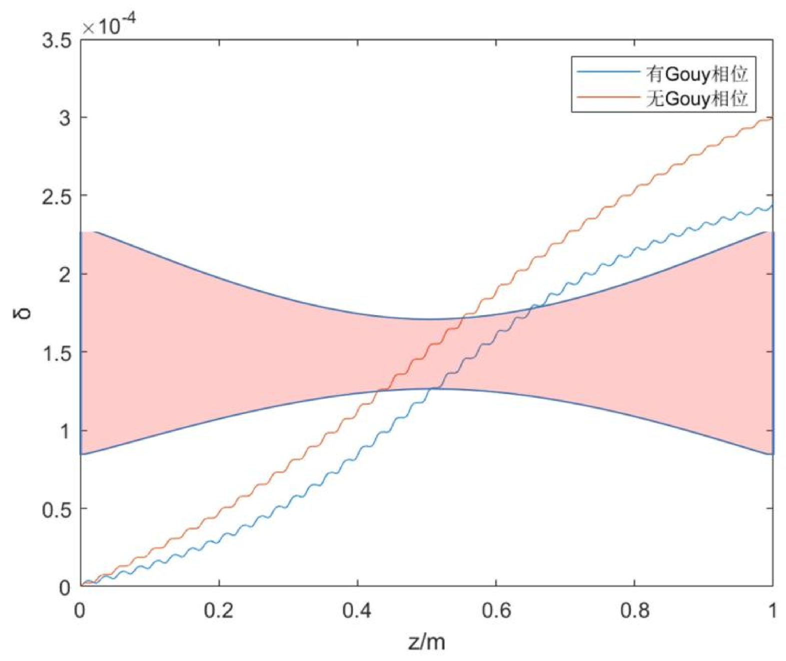


Fig. 2 Evolution of longitudinal phase space of electron beam

Fig. 3 Electron energy increasing process

Fig. 2 shows the evolution process of the longitudinal phase space of the electron beam, forming microbuckets with um length. Fig. 3 describes the process of electron energy increase, and the existence of Gouy phase causes phase mismatch, which leads to the weakening of modulation intensity.

Physical parameters of SSMB laser modulator

Table. 1 Physical parameters of SSMB laser modulator

Parameter	Symbol / Units	Value
Beam Energy	E/MeV	250
Undulator Length	L/m	1
Undulator Period	λ_u/mm	50
Undulator Magnetic Field	B/T	0.917
Undulator Parameter	K	4.28
Modulation Laser Wavelength	λ_m/nm	1064
Rayleigh Length	R_z/m	0.36
Modulation Laser Peak Power	P_L/kW	200
Energy Chirp	h/m^{-1}	1452.3

Through numerical calculation, it is found that when the length of the undulator and the Rayleigh length of the laser satisfy the relationship of L≈2.76Rz, the modulation intensity of Gaussian laser on electron energy is the largest. Under this set of parameters, the energy chirp of 1452 is realized, which meets the requirements of SSMB longitudinal focusing.

Lattice of SSMB laser modulator

In the undulator, the electron beam coincides with the laser path, so dipoles are needed to deflect the electron beam. The deflection angle is limited by the longitudinal emittance and the length of optical cavity, and the angle can not be too large or too small. The design adopts two DBA structures in symmetrical positions.

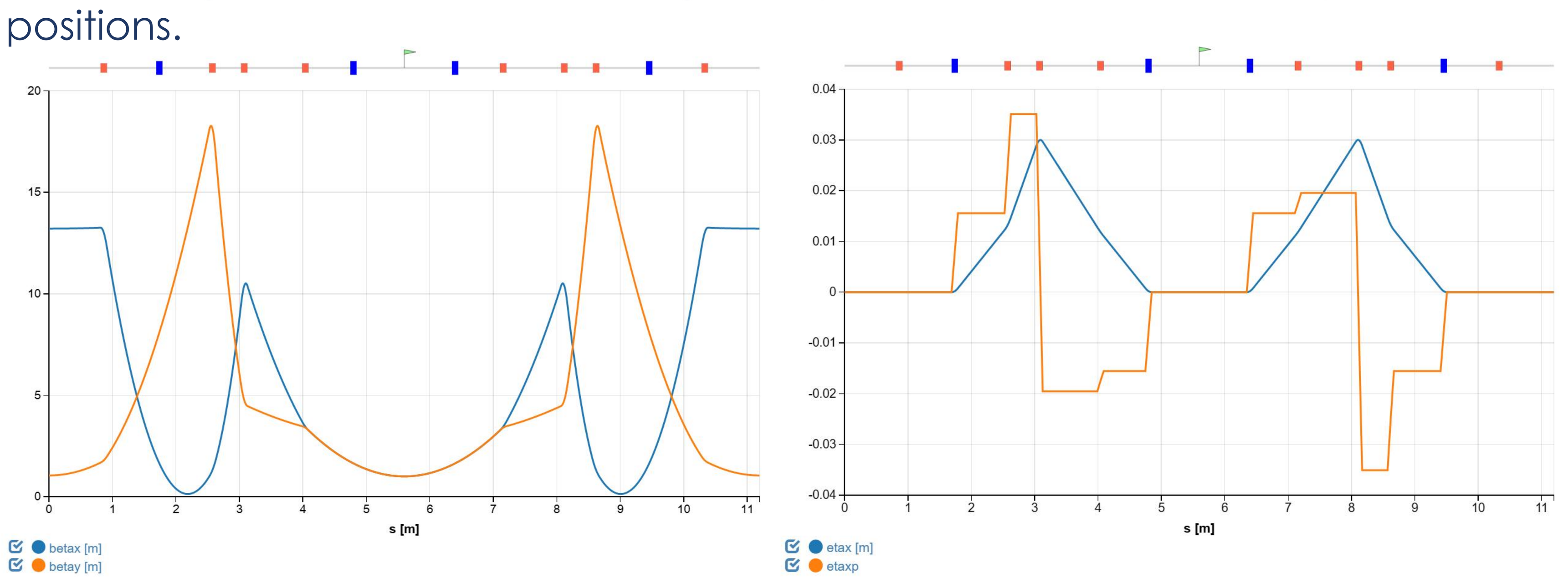
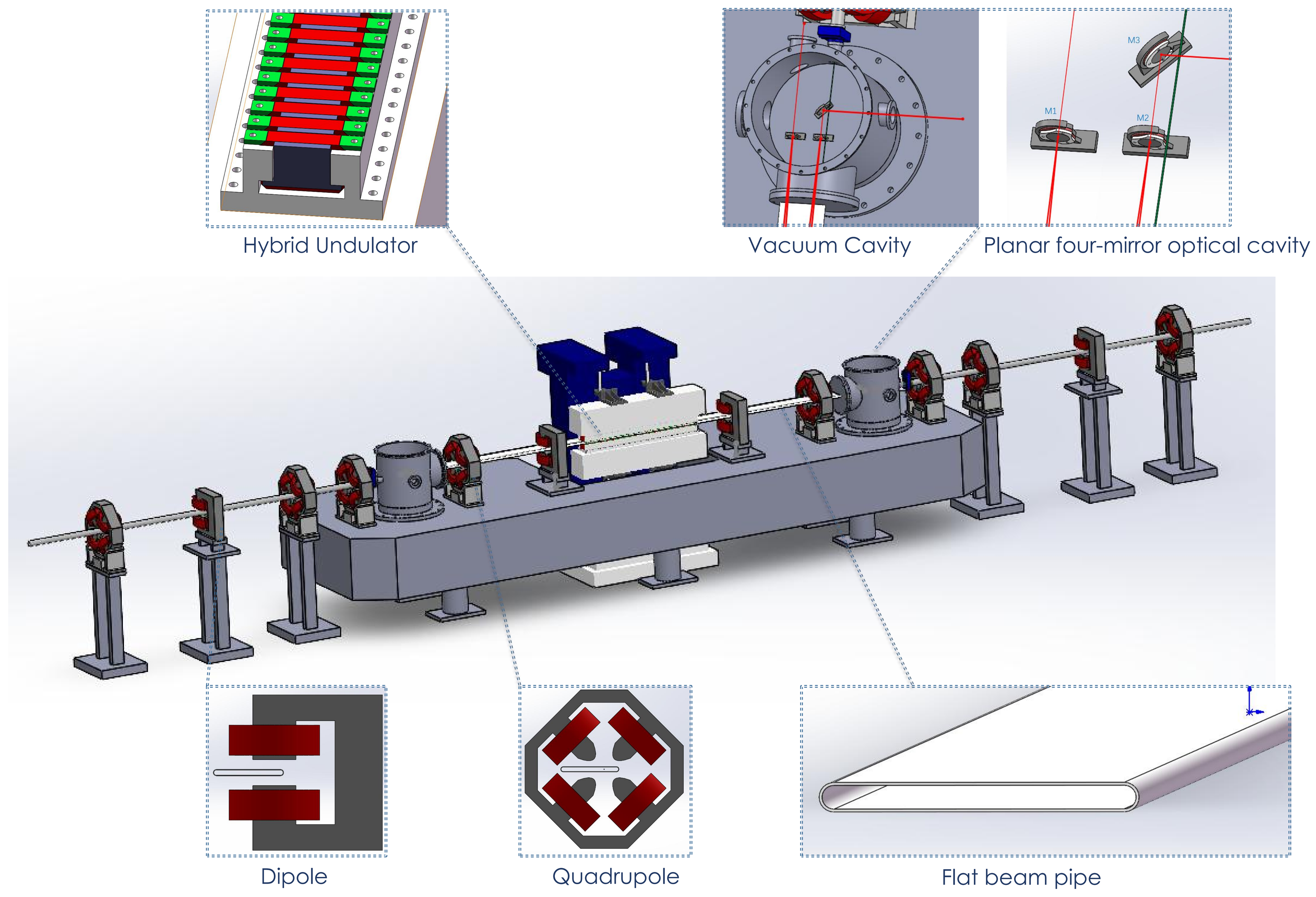


Fig. 4 Optical function of SSMB laser modulator lattice

Preliminary Engineering Design

According to this set of physical parameters and the design of Lattice, a preliminary engineering design of laser modulator is carried out. A hybrid undulator with stronger peak magnetic field is used, and a four-mirror optical cavity is used to provide high repetition rate and high power laser.



Electron and laser are in the same vacuum environment, and the vacuum system is specially designed, including two vacuum cavity structures for placing four-mirror optical cavities and a flat beam pipe. The vacuum chamber is a vertical barrel structure, which mainly considers the injection and extraction of laser and the connection with the beam pipes. The flat beam pipe mainly considers the transmission of laser.

Summary and Prospect

The laser modulator provides energy modulation with wavelength of um order, and combined with Lattice design, steady microbunches with longitudinal length of tens of nm can be realized in the whole ring. Now, the generalized longitudinal strong focusing(GLSF) scheme proposed by SSMB project team can compress the longitudinal length of the microbunch to several nm by using laser modulators, and then EUV can be generated. At present, the further optimization goal of laser modulator is to shorten the cavity length of four-mirror optical cavity as much as possible, so as to facilitate the injection of high-power and narrow-bandwidth laser. The possible scheme is to use in-vacuum undulator.

References

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