LASER FEL

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Abstract

A new Free Electron Laser(FEL) using high power laser system as a wiggler/undulator in a storage ring as a electron beam of transverse cooling with a combination of chicane for longitudinal compression is proposed. This new scheme will open an intense FEL hard X-ray laser with much compact system than those proposed in high energy linear accelerator at SLAC and DESY

1 INTRODUCTION

It is widely recognized that X-rays by synchrotron radiation(SR) light sources take advantage of X-ray imaging and medical diagnoses over conventional X ray tube by more than three order of magnitude[1] . The intravenous coronary angiography by SR is attractive as an advanced diagnosis. In particular, imaging the coronary arteries of humans following venous injection of contrast agent opened up new areas of coronary artery disease research to reduce a statistical risk of the diagnoses[2].The preferred energy of the X-ray for the intravenous coronary angiography is around 33 keV. With a conventional wiggler, the preferred energy of the electron beam is about 2 GeV. A size of conventional storage ring of this energy range is too large and costly for actual medical application. To this end, compact electron storage rings dedicated and optimized to the coronary angiography have been proposed to fit into a clinical environment in a hospital[3,4]. A typical diameters of these compact machines are between 10 to 15 m.

A new approach has been pursued for further downsizing. It is a high power Terawatt Table Top laser which opens up this possibility. The idea of the mechanism, Thomson scattering or Compton scattering, has been proposed long ago[5]. After K. J.Kim proposed a generation of femtosecond X-rays by 90 degree Thomson scattering and the successful proof of principle experiment [6,7], a fever arose in an community of accelerator facilities which already have electron linac or storage ring. Further enthusiasm was added to the fever . Telnov pointed out that the process of laser electron is also a radiation damping process for the phase space of the electron beam and can be used to "cool" multi-GeV electrons[8]. Huang and Ruth[9] pointed out this cooling could be applied to even lower energy range of a few MeV up to a few hundred MeV which energy lies in our interest for medical application for angiography[9] . In this paper, we first present the conceptional design of medical laser SR(Synchrotron Radiation) via a Thomson scattering where the whole size of the machine could be placed in only a room of a size of 5 m by 5 m with a necessary X-ray flux as much as larger machine for coronary angiography.
This laser SR then is served as a transverse cooler of an electron beam and the cooled beam is extracted and is undergone a longitudinal compression by a magnetic chicane[12] followed by a high power laser as an undulator for LASER FEL.

2 FLUX, ENERGY LOSS AND LASER RADIATIVE COOLING

A simple way to analyze the Thomson scattering(or Compton scattering) is to notice an analogy between the role of laser beam and a static magnetic wiggler(or undulater). The magnetic field B of the laser intensity dP/dA(power unit area) is simply[6]\

$$B = \frac{E}{c} = \sqrt{2Z_0 \frac{dP}{dA}} \qquad (1)$$

where Z_0=377 ohm is the free space impedance. In Terawatt laser application, where laser waist is squeezed to a size of its wavelength, the magnetic field strength is enormous compared to even a state of the art superconducting wiggler magnet; namely with 10 Terawatt laser, B=3266 Tesla. In addition, the electrical force adds to a Lorenz force and factor of 2 has to be multiplied to take into account its effect. The wave length of X-rays from an electron beam which interacts with laser field or wiggler are

$$\lambda_x = \frac{1 + 0.5a_0^2}{2\gamma^2} Y\lambda_{0x} \qquad (2)$$

where Y=2 for the laser undulator and Y=1 for a conventional wiggler and λ_0 the wave length of the laser, a_0=0.85x10-9 I 1/2[W/cm^2]λ0 [mm].

The spectral flux within the spectral of $\Delta f/f$ is

$$F[photons/s] = 8.4x^{16} I[A] P_0[GW] \frac{L}{Z_R} \frac{\Delta f}{f} \qquad (3)$$

where E is the electron beam energy, L is the laser electron interaction length, $Z_R = \pi r_0^2$ the Rayleigh length with the spot radius r_0, P_0 the incident laser power. For 1GeV electron beam interacting with CO_2 laser, the energy loss is about 8 keV.

At the laser-electron interaction region, quantum excitation and radiative laser cooling balance and the electron beam is expected to be cooled by the laser. This balance leads to the minimum normalized emittances

$$\varepsilon^n_{x,y} = \frac{3}{10} \frac{\lambda_c}{\lambda_0} \beta^*_{x,y} \qquad (4)$$

with $\lambda_c = h/mc = 2.43 \times 10^{-12}$ m, with ß* the betatron function at the interaction point. We have only two parameter to be manipulated by our hands toward smallest emittance as possible; smaller micro beta function at the interaction point and laser of longer wave length. CO_2 laser was chosen from this view point.

3 LASER COOLING AND STORAGE RING

To achieve a design flux of 10^{15} photons/s, the optical cavity of super high reflectivity mirrors referred to as a supercavity [11]with CO_2 CW laser stored in it was implemented in the 10 m circumference storage ring. The electron source is a RF Gun and the injector to the storage ring is a microtron. The system configuration is shown in Fig.1 below. The machine parameters are listed in Table 1. The beta function and dispersion are shown in Fig2.

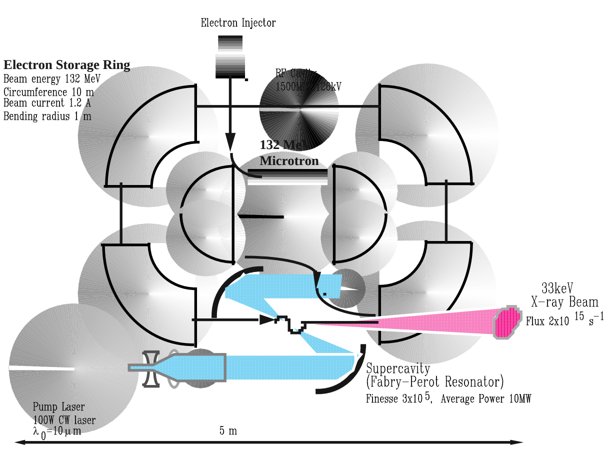

Figure 1. Fig.1 Laser cooler of electron storage ring schematic

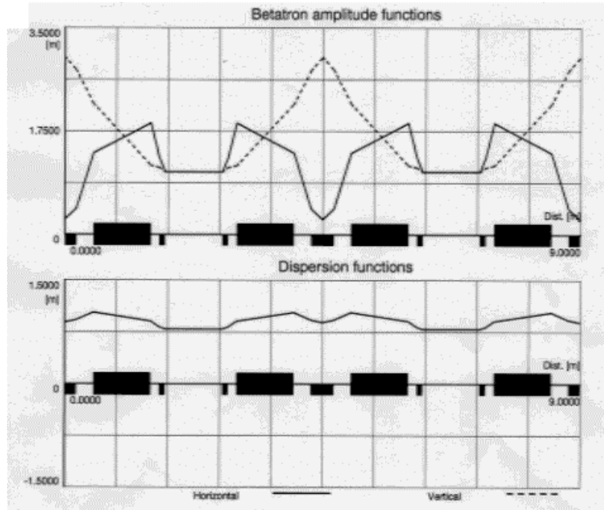

Figure 2: Beta function and dispersion of the laser cooler of electron storage ring.

4 CONDITIONS FOR LASER FEL

For a realization of FEL beam quality of the electron beam has to be very good. The necessary conditions for a single pass amplification are ;

(i) Beam Emittance, ε_n, smaller than or on the order of the wavelength λ,

(ii) Beam energy spread smaller than the FEL parameter ρ,

(iii) Gain length shorter than the radiation Rayleigh range LR, (iv) Phase slip $N_u \lambda_r$, is much smaller that the bunch length σ,.

Condition (i) can be satisfied by laser radiative cooling assuming that intra-beam scattering effect could be insignificant at this energy range.

Condition (ii) are done by cooler ring and magnetic chicane. It is argued that various effects such as non linearity in the compression and acceleration process, space charge effects, transverse wake fields,coherent synchrotron radiation effects, longitudinal to transverse coupling, second order momentum compacti

A supercavity can be made of high reflective mirrors with reflectivity of R=99.999. The finesse F of this optical resonator is,

$$F = \pi \sqrt{R}/(1-R) \qquad (5)$$

The incident power builds up by factor/π. To make spread over 20 mrad in beam size for large irradiation area for angiography, a single period of linear

Table 1: Parameters of the laser cooler storage ring of electron beam

SR X-ray parameters	
RF frequency	1500 MHz
photon energy	33keV
Peak RF voltage	126 kV
photon flux	10^{15} /s
energy aperture	1.1 %
natural spectral width	0.3 %
Quantum life time	1 hour
Electron beam parameters	
Beam radius at I.P.	100 μm
Beam energy	132 MeV
Laser parameters	
Beam current	1.2 A
Wavelength	10 μm
number of bunches	50
Peak power	1 GW
Circumference	10 m
Average power	10 MW
Bending radius	1 m
Spot radius at I.P.	100 μm
Energy loss per turn	30 eV
Damping time	155 ms
Equiv. energy spread	0.2 %
Equiv. norm. emittance	3.9×10^{-7} m.rad.
rms bunch length	4.9 mm

Table 2. Parameters of the laser cooler of electron beam

X-ray LASER FEL Angstrom region

Beta function at IP	1 cm
CO_2 laser peak power	5 G Watt
B	365 Tesla
K	3.889
wavelength λ	5.8□□
λ/4π	4.610^{-11}
N	6.25×10^{9}
bunch length before compression	5 mm
bunch length after compression	0.1 mm
n_e	$2\mathrm{X}10^{25}$
plasma ang.freq.	1.5×10^{13}
laser ang. freq.	1.9×10^{14}
FEL parameter p	0.003
momentum spread after compression	4×10^{-5}
beam energy	132 MeV
absolute emittance	2.8×10^{-12}
γ	264
Gain length L_G	1.1×10^{-4}
Rayleigh length L_R	0.006

5 SUMMARY

A possibility of very compact X-ray laser induced FEL was presented. This scheme uses optical laser twice for single pass X-ray FEL in addition with a magnetic chicane. This scheme could be a compact and less expensive way to obtain hard X-ray laser

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