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Present Status of the Photon Storage Ring Project

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Abstract

Construction of the photon storage ring, a novel free-electron laser has been started at Ritsumeikan University. The optimized scheme is composed of a 50 MeV exact circular electron storage ring having 155.8 mm orbit radius, and a concentric optical cavity surrounding the orbit. The beam injection is a 2/3 resonance method. We will start with lasing of 31.2 μm wavelength, although the final goal is of a few μm.

1. Introduction

The idea of photon storage ring(PhSR) was originated in Japan in 1989.[1] The PhSR is based on an exact circular electron storage ring and a concentric barrel shaped optical resonator surrounding the electron orbit. This instrument may be categorized in a compact free-electron laser(FEL), but an undulator is not introduced at all. Stimulated emissions occur due to interactions between electrons in the circular orbit and the synchrotron radiations accumulated in the optical cavity when the phase velocity of the radiation in the electron velocity direction and the electron velocity is matched. TE(pj1) mode is concerned to be built in the circular resonator.[2] A large gain is demonstrated by an analytical formula as well as simulations[3], which is common to a circular FEL[4] and a magnetron[5]. The minimum obtainable wavelength is determined by the quality of the electron beam. The use of relativistic electrons possibly leads to an oscillation in a few micron wavelength range[6]. One another advantage of the PhSR is that coherent synchrotron radiations[7] are generated in this small storage ring[8]. The estimated bunch length is the order of 0.1 mm, which leads to coherent radiations of a tens micron wavelength. Therefor the lasing start with this coherent radiation in the PhSR, while it start with noise signal in an conventional FEL.

In this paper we discuss the designing of a 50 MeV version photon storage ring. We have started the construction of the ring and will be completed by 1997. We will have lasing at 31.2 μm wavelength, but the final goal will be a few micron.

2. Ring parameters

The machine parameters of the electron storage ring is determined as follows. The laser growth rate of the PhSR is inversely proportional to electron energy, γ, and energy distribution, $(\delta\gamma/\gamma)^2$. In the case of the weak focusing exact circular ring $(\delta\gamma/\gamma)$ is proportional to γ^2/ρ , where ρ is the central orbit radius. Consequently the growth rate is inversely proportional to γ^3, which suggests that lower electron energy gives higher growth rate in principle. In the low energy ring, however, the emittance grows due to the intrabeam scattering, and the damping rate decreases. When we want to construct the ring with a normal conducting magnet, we find that the emittance becomes smallest at 50 MeV under 1 T magnetic field. We are concerned that in this case the Touschek lifetime becomes smallest value, around 1 sec, but this value is large enough for the lasing as well as for the injection of beam. Another concern to be made is the practical problems to construct the ring. The 150 mm electron orbit radius for the 50 MeV ring is almost the smallest size to install the acceleration cavity and the purturbator for the resonance injection.

One of the advantage of the PhSR is there in its beam injection method. The resonance injection method keep the beam in the central orbit undisturbed over more than 10 mm radial width.[9] This enable us continuous injections during FEL oscillations in PhSR.

Table 1 Machine parameter of 50 MeV ring under following conditions: RF-voltage=120 keV, coupling constant= 0.1, harmonics=8, . The growth rate is calculated for 100 μm wavelength. Correction for intrabeam scattering(IBS) is calculated at 1A beam current.

parameters\n-value	0.01		0.3		0.5		0.7	
	natural	IBS	natural	IBS	natural	IBS	natural	IBS
emittance(πmrad)	3.88E-07	8.87E-06	1.45E-08	1.88E-06	1.03E-08	1.40E-06	9.49E-09	8.57E-07
energy spread(ΔE/E)	9.05E-05	4.46E-04	9.76E-05	1.11E-03	1.11E-04	1.29E-03	1.92E-04	1.82E-03
RMS bunch length(mm)	0.247	1.22	0.317	3.6	0.425	4.9	0.949	9
horiz. bunch size(mm)	0.235	1.16	0.051	0.58	0.047	0.545	0.051	0.485
vert. bunch size(mm)	0.074	0.365	0.0063	0.055	0.0047	0.055	0.0041	0.039
growth rate(1)/turn	14.7	0.266	13.5	0.021	12.2	0.008	1.85	0.0022
growth rate(2)/turn	23.5	0.426	22.2	0.034	19.5	0.013	2.96	0.0032
power loss/turn	0.014							

note) growth rate(1):cylindrical resonatcgrowth rate(2):barrel shaped resonator

The field index of the ring may be selected to near the integer, 2/3, 1/2, or 1/3 resonance values. Since the field index affects the laser gain, we have studied the n-value dependence of the beam parameters and the growth rates for a 100 μm wavelength as shown in Table 1. Both natural values and corrected values for the intrabeam scattering are listed. It is clear from the table that the smaller index gives higher gain. The use of the integer resonance is recommended. The problem of the integer injection is that the damping speed is slower, and the injection efficiency could be relatively smaller.

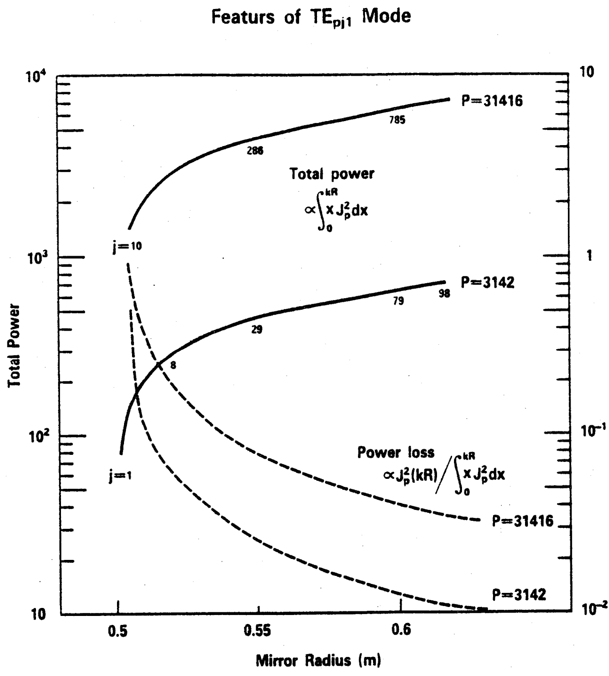
3. Optical resonator

We use TE(pj1) mode with large azimuthal, p, and radial, j, mode numbers, and axial mode number of one as the operating mode. The whispering gallery mode, which has fundamental mode numbers, (p,1,1), is inadequate for PhSR, because the optical cavity has to be set too close to the electron orbit within millimeter, and also the power loss due to the ohmic loss becomes too large. The radial mode number dependence of the power loss is shown in Fig. 1, together with the integrated power in the resonator. We can find that the filling factor decreases as the radial mode number increases, but the power loss is reduced more dramatically than the decrease of filling factor.

In order to increase the filling factor the resonator is made in a barrel shape. Strictly speaking the curvature should be specified for each wavelength. This implies that the changing wavelength for not optimized wavelengths is not easy, while it is easy with a simple cylindrical mirror. If enough large gain is observed, we will switch it to the cylindrical resonator.

The optimized curvature of the barrel shape has been obtained by the Gelerkin technique in corporating with the quasi-optics approximation.[10] For 31μm wavelength we have selected the mirror width, D=20 mm, the curvature in axial direction, Ro= 207 mm, and the mirror radius, R= 155.8 mm. The mirror has a 2x10 mm^2 slit on the surface for injecting beams as well as extracting laser radiations. Mode mixing due to this slit has already been analyzed.[10]

Fig. 1 Radial mode number(j) dependence of power loss and integrated power.



4. Basic structure of the ring and injector

We have introduced a several new features in this ring in comparison with AURORA, the first exact circular ring. The ring is made of normal conducting magnet. The vertical cross sectional view is shown in Fig. 2. In order to generate 0.94 T magnetic field in 120 mm rather wide pole gap, the pole is made in grating shape. Six trim coils are placed in the groove of the grating. Instead of using inflectors and magnetic channels, a field clamp is introduced.

Major components in the ring magnet is one purturbator and two RF-cavities. The RF-cavity is of 2.45 GHz, which serves 8 harmonics. We have already succeeded in fabricating a prototype cavity which has a 10 mm wide slit in the median plane for extracting laser beam.[11] We are planning to use a CW magnetron as a RF source. We are working on a techniques for stabilizing magnetron.

The purturbator is a one turn coaxial coil. To provide 12 kA peak current, we use pulse compression technology based on a non-linear amorphous core for generating a 0.1μsec width pulse train at 50 Hz repetition rate.

Injector is a s-band linac. One accelerator column and pre-buncher, which load 50 MeV beam, will be transferred from KEK. A 30 MW klystron, which will also be transferred from KEK, provides power to both the pre-buncher and the accelerator column. We will operate this at a 0.1 μsec macro pulse, a 50 Hz repetition rate, and 1 A peak current. Note that a long macro pulse is unnecessary for PhSR, which is normally required for a conventional free-electron laser.

5. Project goal

The initial target of the lasing wavelength is around 30μ m. This wavelength was chosen because the laser growth rate drops dramatically at shorter wavelengths. The growth rate increases as the beam current increases. Lasing of 30 μm wavelength requires about 100 mA beam current, and for 10 μm wavelength, nearly 10A. We have a experiences of accumulating 1A beam current with AURORA[12], but 10 A beam current sound too large. We hope, however, the number of electrons in bunches are order of 10^{10} in the present case, which is comparable to the 1 A in AURORA, since the circumference of this ring is smaller.

Our first objective is an accumulation of 10 A beam current with such a small and low energy ring, which must be a first experience in the world, and our success in lasing short wavelengths will be influenced by this result. An introduction of gas into the beam duct is a proposed method to accumulate large beam current without increasing beam size, as it was observed by using AURORA at 150 MeV operation. [11]

Generation of coherent synchrotron radiation in a range of 10 to 100 μm wavelength is the target before installing the barrel shaped optical resonator.

All these experimental studies are planed to be held in early 1997. We hope to complete machine by the end of next year.

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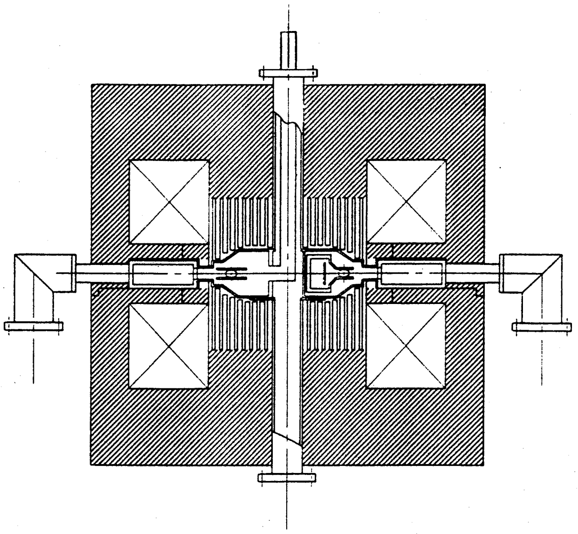

Fig. 2 Cross sectional view of Main magnet