THE ALPHA PROJECT AT IU CEEM*

J. Doskow, G. East, R. Ellis, Y. Jing, Y. Kim, S.Y. Lee, T. Luo, P. McChesney, X. Pang, T. Rinckel, C. Romel, P. Sokol, IUCEEM, Indiana University, USA

Abstract

The Advanced eLectron and PHoton fAcility (ALPHA) project at Indiana University Center for Exploration of Energy and Matter includes a 50 MeV linac, 100 MeV electron synchrotron ring of 20 m circumference, and a radiation effect experimental area for the external beam line. The ring can also store beam bunches for inverse Compton X-ray source.

INTRODUCTION

For radiation effect experiments in testing electronic components, electron beams at 40-50 MeV energy are commonly used as energy deposition. Unfortunately, electron beams from linacs have an intrinsic rf bunch structure, which may make it difficult to differentiate from the electronic signals of the devices. Debunching the rf structure will be desirable. Furthermore, a shorter bunch with high charge deposition would also be useful to understand critical sustainability of electronic devices. We thus design a debuncher ring that can debunch the rf structure in a single pass, and has the ability to store multiple-pulses for high intensity short pulse operation as the bunch compressor.

THE RING

The accelerator is composed of 4 dipoles, 2 gradient damping wigglers, one Lambertson septum, 2 magnetic kickers, one travelling wave kicker, and rf cavity. The accelerator uses the existing dipoles that were constructed for the Cooler Injector Synchrotron [1].

General Layout of the ring

The general lay out is shown in Fig. 1:

- Each dipole is 2 m in length
- Straight section is 3 m in length
- Each gradient damping wiggler is 60 cm in length with B_1/B=1.9 m^{-1}. Figure 1 shows the lattice function for the bending radius of wiggler ρ_w=0.7 m.
- Adjusting ρ_w, the compaction factor and the damping partition of the horizontal plane provides modification of the ring parameters.

Table 1: Parameter of the Ring

Parameter	Value	
Circumference	20 m	
Dipole	2 m	ρ=1.273 m
Betatron tunes	1.75 / 0.75	

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#psokol@indiana.edu; shylee@indiana.edu

As shown in Fig. 2, the compaction factor is about 0.5 when the damping wiggler is turned off or $\rho_w=\infty$. Thus the ring can debunch a linac beam with $\Delta p/p$=0.5%. With two magnetic kickers located at 0.27 m from the dipole, the closed orbit will pass through the Lambertson septum for a single path operation. On the other hand, if $\rho_w < 2$ m, the damping partition number become positive and the ring can serve as a storage ring to accumulate electrons for high charge operation. Details of the lattice is given in Ref. [2]

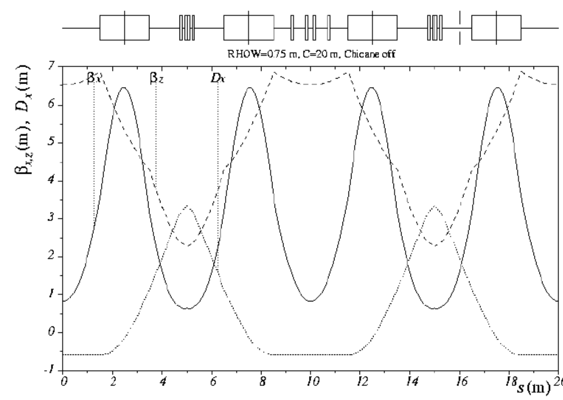

Figure 1: Layout of the ring

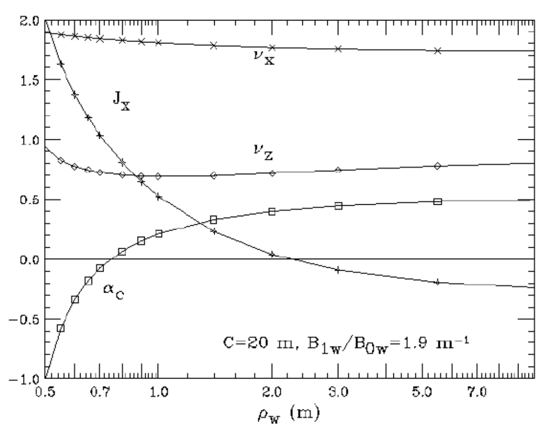

Figure 2: Betatron tunes, compaction factor, and damping partition vs. bending radius of the wiggler

Dipoles

The synchrotron uses the existing dipoles of the Cooler Injector Synchrotron [1]. Each dipole is 2 m in length with edge angle 12º. The bending radius is 1.273 m, and the field strength can provide electron beam energy from 20 MeV to 600 MeV. The ALPHA dipole power supply will provide electron beam energy up to 100 MeV.

Linac

To test the performance of the storage ring, we use a refurbished medical linac (Clinac) for the injector. The linac beam will go through two 45º bend to align with the Lambertson injection line. A 20º vertical bend will bring the beam to the Lambertson septum. The linac is capable of delivering 20 MeV electron at about 20 mA of beam current. This initial commissioning will be carried out in June 2010.

The rf system

The revolution frequency is 15 MHz. We refurbish the CIS rf cavity [3]. The CIS cavity was designed to accelerate protons from 7 MeV to 240 MeV with frequency 2-10 MHz. It is a ferrite loaded cavity with tuning capacitors. For a fixed frequency operation of the ALPHA accelerator, we remove 4 ferrite rings and shorten the cavity length. The rf system modification is in progress.

In the future, we plan to install a high frequency rf system in order to obtain beams with short bunch length. The frequency of the rf system has not been determined.

The gradient damping wiggler

The gradient damping wiggler is an effective way of changing the compaction factor and the damping partition number. The construction, test and fabrication of the damping wiggler will be discussed in detail of a separate contribution in these proceedings [4].

The Lambertson septum

The Lambertson septum is located at the center of the 3 m long injection/extraction straight section. The Lambertson provides 20 degree bends in the vertical direction. Another 20 degree dipole located on the injection beam line and extraction beam line will bring the beam to the horizontal direction. The Lambertson magnet has been successfully built and installed in the ring.

The injection and extraction beam line

The matching of the injection and extraction beam line optics has been carried out. For the radiation effect experiment, nonlinear beam spreader with octupoles has been implemented. Details are presented in a paper in these proceedings [5]

The travelling wave kicker

Extraction of electron bunch is accomplished by the combination of a pair of magnetic kicker for orbit bump and a travelling wave kicker with rise time of less than 10 ns, and a flat top or more than 50 ns. To kick the beam with kick angle θ_{max} of 23 mrad, the required kicker voltage is 97.7 kV. The details of the design is given in Ref. [6]

BEAM DYNAMICS OF LOW ENERGY THE SYNCHROTORN RING

The Low energy electron storage ring encounters many challenges including the Touchek lifetime, intrabeam Coulomb scattering, beam gas scattering, and small damping rate. In this section, we explore these effects.

The Touschek lifetime

The Touschek lifetime is an important issue for all low energy electron storage rings. The Touschek lifetime is sensitive to the parameter:

$$\xi=\left(\frac{\Delta p}{\gamma\,\sigma_{px}}\right)^2$$

where Δp is the bucket height and σ_{px} is the horizontal momentum width, and γ is the Lorentz factor. The operational parameters of the accelerator can be varied to change the ξ parameter from order 1 to order 10^{-3}. Since the Touschek lifetime has a minimum at ξ =0.03, this accelerator is a sensitive laboratory for detailed study of the physics relevant of the Touschek lifetime. Choosing rf voltage, the Touschek life time can be as long as hours.

The beam gas scattering

Beam gas scattering can increase beam emittance and reduce beam lifetime. We include the beam gas scattering in the emittance modelling to be discussed in the study of intrabeam scattering.

The intrabeam scattering

All low energy synchrotron ring suffers intrabeam scattering. In this study, we use the MAD program to calculate the intrabeam scattering growth rate at a given beam energy and peak current. Once the growth rate is obtained, one can solve the equilibrium emittances and momentum spread and loopback to the MAD program for a self consistent calculation of the growth rate. The resulting emittance and momentum spread is shown below as a function of energy. The dependence of the beam parameter on lattice function can be calculated.

In the presence of inverse Compton scattering, one can also calculate the effect of laser cooling and quantum fluctuation due to laser electron interaction. We also study the lattice dependence by varying the damping wiggler parameters. These results will be published shortly [7].

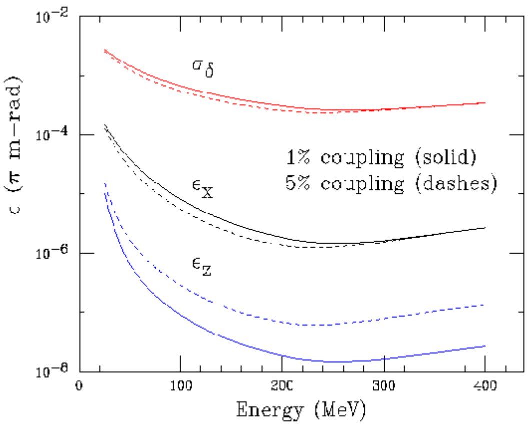

Figure 3: An self-consistent equilibrium emittance and momentum spread for a beam with 25 A peak current and pressure of 0.1 nTorr.

INVERSE COMPTON SCATTERING

There are a number of inverse Compton X-ray (ICX) sources proposed for the production of X-ray source. Assuming the laser wavelength to be 1μm, the X-ray energy will be a few keV to 100's keV range.

The ICX insertion in the ALPHA storage ring will be located at a 3 m long straight section. With a chicane of 4 dipoles, the back-scattered X-ray can be extracted from the interaction point (IP) easily. The energy of X-ray is given by

$$E_x = E_L \frac{1-\beta\cos\theta^*}{1+\Delta-\beta\cos\theta}$$

where E_L is the laser beam energy, βc is the speed of the electron beam, θ* is the crossing angle of the laser and electron beams, θ is the angle of the scattered X-ray photon with respect to the electron beam direction, $\Delta=E_L[1-\cos(\theta-\theta^*)]/Ee$ is a small correction term, and Ee is the electron beam energy. For a head-on collision, θ*=π. The scattered X-ray photons are confined to a cone of 1/γ with respect to the electron beam direction, and have tunable energy by changing the electron beam energy or the angle of the X-ray photon with respect to the electron beam direction.

The bending angle of the chicane magnet can vary from zero to 110 mrad. The scattered X-ray can easily be separated from the circulating electron beam at a distance 25 cm from the collision point. The X-ray flux is given by

$$\frac{dN}{dt} = L\sigma_T$$

where $\sigma_T = 8\pi\ r_0^2/3$ is the Thomson scattering cross-section, and L is the luminosity of the electron-photon scattering.

For head-on collisions, the luminosity is

$$L = f\frac{N_e N_\gamma}{4\pi\sigma_x\sigma_z}$$

where *f* is the encountering rate, Ne is the number of electrons per bunch, N_γ is the number of photons in a laser pulse, $4\sigma_x\sigma_z$ is the effective overlap-area that laser and electron beams interact. The expected photon flux is about 3×10^{13} photons/s with a 1TW laser and 10 nC electron beam.

Installing a mini-β insertion with four quadrupoles to the 3m long IR straight section, we can squeeze the IR beam size by a factor of 10, and increase the luminosity by a factor 10.

PRESENT STATUS & CONCLUSIONS

In April 2010, we have completed the ring installation, and have begun to carry out experimental measurement of beam characteristics of the Clinic beams. The measured normalized emittance of the clinic beam is about 3 π-mm-mrad. The commission of the ring will be in the summer, 2010.

Next year, we will install an S-band linac for 50 MeV electron beams. The linac beam will be injected into the storage ring. At the same time, a laser system will be installed for ICX experiments.

REFERENCES

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