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PRELIMINARY REPORT ON THE FEASIBILITY OF USING THE IUCF COOLER RING SYNCHROTRON AS AN ELECTRON STORAGE RING

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The IUCF Cooler Ring is a proton storage synchrotron dedicated to nuclear and particle physics research. A number of important experiments have been performed in the Cooler Ring. In recent years, electron beams in storage rings have also been widely used as an alternative probe. Having both capabilities in the same laboratory will offer great diversity in the studies of fundamental physics. Thus the adaption of the IUCF Cooler Ring to an electron synchrotron may prove to be instrumental in nuclear and particle physics research. It may also be used as a synchrotron radiation light source. Synchrotron radiation laser light from electron storage rings has been widely used in the research of basic atomic and molecular physics, condensed matter physics, material science, biological sciences, chemical science, medical science and material processing. Such a capability might reach an even broader spectrum of users at the IUCF facility. It may also be a great facility for educational purposes.

I. Introduction

The IUCF Cooler Ring is a versatile storage synchrotron. Its capability of storing and cooling light ion beams is important in the study of the proton and nuclear substructures. Alternatively, using the electron as a probe to unravel the nature of nuclear structure has also met great success. Thus studying the electron storage capability in the IUCF Cooler may be an interesting and possibly rewarding venture.

Besides the benefit of being used as a probe for nuclear and particle physics, an electron storage ring may also serve as a synchrotron radiation source. Given 1 GeV electron energy in the Cooler Ring, the critical wavelength would be in the X-ray range.

The study of the interaction of X-rays with matter goes back to the beginning of the century and has resulted in an large number of important discoveries, e.g. the understanding of the structure of crystallography, the unravelling of the structure of the DNA, etc..

Traditionally, X-rays were generated in X-ray tubes, where the radiation was produced by the bremsstrahlung of electrons as they struck an anode. These processes are inefficient and most of the electron energy is converted into heat. The dissipation of the heat sets a practical limit on the X-ray intensity that can be produced from the X-ray tubes. The resultant spectrum consisted of a continuous background with lines superimposed at fixed energies. The angular distribution of the emitted photons was approximately isotropic. Photon polarization was only partial and was a function of the continuous part of the spectrum.

More recently, X-rays have been successfully produced from the synchrotron radiation of electron beams. Synchrotron radiation from an electron storage ring can, in principle, produce any intensity either in a continuous spectrum or in sharp tunable lines. It has excellent directional properties, well defined polarization, and can also have a very fast time structure. The availability of very intense, tunable X-ray sources gives rise to a multitude of applications. An extremely wide spectrum of important problems, ranging from pure science research to the semiconductor device production, from the basics of catalysis and corrosion to the properties of metals and alloys, from the detailed structure of protein molecules to the preventive diagnostics of heart diseases, can be studied.

We are interested in investigating the feasibility of using the IUCF Cooler Ring for electron or positron storage, to provide a suitable electron source for nuclear and particle physics and to produce high brightness synchrotron radiation.

2. Possible characteristics of IUCF Cooler Ring for electron storage ring

A. Emittance:

The emittance of an electron storage ring depends on the lattice design. For the Cooler Ring, the emittance is given by

$$\epsilon_x = C_q \gamma^2 \frac{\langle H \rangle_{dipole}}{J_x \rho} = 0.716 \langle H \rangle \quad \pi\mu\text{rad}$$

Table 1. Properties of the electron beam in the Cooler Ring

Energy[GeV]	0.2	0.75	1.00
Syn. Rad. [keV/Turn]	0.058	11.5	36.4
τ_x [sec]	2.5	0.05	0.02
τ_z [sec]	1.99	0.0377	0.0159
τ_e [sec]	0.84	0.0160	0.0067
ϵ_x [μm-rad]	0.1	1.6	2.7
$\sigma_{\Delta p/p}$ [10^{-4}]	1.02	3.81	5.09
σ_l [mm]	0.85	6.22	9.58
τ(Touschek) [min.]	6.	4000	12000

where $C_q = 3.84 \times 10^{-13}$m, $J_x \approx 1$ is the damping partition number, $\gamma \approx 2000$ at 1 GeV energy, ρ is the magnetic rigidity and the function, H, is given by $H = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2$. Based on the operational parameters of the Cooler Ring, i.e. Circumference = 86.82 m, Bρ = 3.6 Tm, B = 1.47 T, $\nu_x = 3.78$, and $\nu_z = 4.85$, properties of the electron beam can be obtained (see Table 1), where τ_x, τ_z, τ_e are respectively the damping time of the electron beam, and ϵ_x is the horizontal emittance. $\sigma_{\Delta p/p}$ is the rms momentum spread of the beam, σ_l is the rms bunch length and τ is the Touschek life time corresponding to single Coulomb scattering loss. The vertical emittance depends on the coupling. Normally, the vertical emittance is about one hundredth of the horizontal emittance. In order to obtain good quantum lifetime, the required voltage is about 300 kV. The advantageous harmonic number is 144, which corresponds to 497.1733 MHz.

B. Critical wave length:

A synchrotron radiation light source is normally a synchrotron, which transforms the kinetic energy of a relativistic electron beam into electromagnetic radiation. The critical wavelength, λ in Angstroms, of synchrotron radiation emitted from an electron in a bending magnet is determined by the magnetic field, B, and electron energy, E: λ(Å)=18.6/B(T)/E^2(GeV), where the electron energy is determined by E(GeV) = 0.3B(T)ρ(m) $\approx$ 1 GeV. Using the parameters of the IUCF Cooler Ring, we obtain the critical wavelength on the order 13 Å, which is in the X-ray range. Shorter wave lengths may be obtained using insertion devices.

C. Power, Rf considerations and Cooling requirement:

The total power radiated in a storage ring of energy, E, and magnet bending radius, ρ, and currents, I, is given by

$$P(W) = \frac{88.5E^4(GeV)I(mA)}{\rho(m)}.$$

Thus the power loss per unit angle is given by $p(W/mrad) = 0.00578E^4[\mathrm{GeV}]I[mA]$, and the power loss per unit area in the dipole section will be

$$Power/area = 0.00578\frac{E^4[GeV]I[mA]}{\sqrt{6\epsilon_z\beta_z}\rho} \quad [W/m^2]$$

where $\epsilon_z \approx \epsilon_x/100$.

The total current and the lifetime available depends on the operational condition of the Cooler Ring. The damping time is given by

$$\tau_i[ms] = \frac{C[m]\rho[m]}{13.2J_iE^3[GeV]} \approx \frac{16}{E^3[GeV]}.$$

The voltage requirement becomes then $V > 2 \times 36.3E^4[GeV][\mathrm{kV}]$, where the factor of 2 arises from the fact that the stable phase angle is about 30°. To achieve good quantum lifetime, $V > 300$ kV is needed.

D. The harmonic number, h:

Let assume that we have a 200 MeV electron source. The momentum rigidity is then $B\rho = 0.667$ Tesla-meters. Thus the low field requirement is B=0.273 Tesla. The required frequency swing for the rf cavity is therefore $\frac{\Delta f}{f} \approx 3.3 \times 10^{-5}$. Since the revolution frequency is $f_0 = 3.45291$ MHz, the harmonic number must be larger than 44 to achieve a cavity length less than 1 meter. The rf frequency should be 350 MHz or 500 MHz, where commercial Klystrons are available. TRISTAN, DORIS, and CESR are using 500 MHz systems and the APS, PEP, LEP etc. use 350 MHz systems.

3. Conclusion

We have made some rough estimation of the possible performance of the electron beam storage in the present Cooler Ring operational condition. The result is encouraging. Although the emittance is not small, we shall study retuning the lattice to achieve a smaller emittance. Further work is needed in studying the injection schemes from various electron sources, vacuum chamber design, retuning of the lattice for better emittance, beam current limitation due to coherent instabilities, etc.