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PRESSURE AND LIFETIME BEHAVIOR OF NSLS STORAGE RINGS

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I. INTRODUCTION

Total beam lifetime in an electron storage ring is primarily governed by the contributions of the following phenomena:

A. Quantum lifetime depends on the size and the transverse distribution of electrons inside the bunch. Since both NSLS rings are high brightness machines and consequently contain narrow bunches of small size, this effect is negligible in beam life consideration.

B. Touschek effect loss is caused by collisions between electrons in the same bunch. The time constant τ_T depends on many machine parameters¹ which should be measured for an individual machine if a meaningful calculation of τ_T is to be made. In order to be able to compare the dependence of τ_T on various quantities with those of gas scattering

$$\tau_T \propto \frac{\gamma^3 a^2 V_{RF}}{\rho} \text{ where}$$

a = horizontal aperture

V_{RF} = bucket size or RF voltage which determines RF acceptance a as well as longitudinal beam size. In the UV ring the effect of V_{RF} is small compared to that of a^2

$$\rho = \text{electron density} = \frac{N(\text{number of } e^-)}{V_D(\text{bunch volume})} .$$

A detailed treatment of Touschek effect is discussed in Ref. 2.

C. Beam Gas Interactions:

1. Bremsstrahlung

$$\tau_B \propto \frac{X_0}{MP} \text{ where}$$

X_0 = radiation length of residual gas (g cm⁻²)

M = mass number (AMU)

P = pressure (torr)

2. Coulomb Scattering

$$\tau_{CS} \propto \frac{\gamma^2 d^2}{Z^2 P} \text{ where}$$

d = limiting aperture

γ = relativistic factor

Z = atomic number

3. Trapped Ions

$$\tau_{TI} \propto \frac{CR}{PZ} \text{ where}$$

CR = self-clearing rate which depends on the number of filled buckets.

τ_{TI} can be increased by introducing either clearing electrode or by switching from electrons to positrons. Since the placement of clearing electrodes is critical, positrons represent a much better solution to ion trapping, and at DCI three times longer lifetimes were observed for positron operation.

D. Instabilities

Various instabilities can cause both fast and slow decays, and these have been observed in both rings. On many occasions the lifetime in the x-ray ring changes without any change in pressure and instabilities can be good candidates for these losses.

The above mechanisms C1 through C3, as well as machine problems limit the beam lifetime in the x-ray ring. In the UV ring, in addition to beam gas interactions, the Touschek effect plays an important role as shown in the next sections.

II. CONDITIONING OF NSLS STORAGE RINGS

A. VUV Ring

At the beginning of the 1984 shutdown, the pressure at 200 mA read 3.3 nTorr on the TV monitor with 326 A-hours of time integrated beam current. At the end of the shutdown, the entire machine was baked out and dipole vacuum chambers were glow discharged³⁻⁴ using Ar10%O₂. A failure of an unprotected turbo molecular pump contaminated the ring with Fomblin oil. Additional Ar10%O₂ glow discharge and beam cleaning with 10⁻⁸ Torr of hydrogen, introduced into the vacuum chamber by powering titanium filaments, were used by T.S. Chou to successfully remove fluorin from the walls.³ Unfortunately, beneficial effects of glow discharge cleaning in the ring could not be determined. Pressure behavior read on the TV monitor as a function of time integrated beam current is

shown in Fig. 1. It should be noted that these pressures are based only on uncalibrated DIP (distributed ion pumps) currents mounted in the bending magnets where the incident photon flux is the highest, resulting in the high pressure points around the ring. Two calibrated gauges, one installed in the middle and the other at the end of U1B2 dipole, read pressures in a ratio 3-4:1, depending on the stored currents. Thus, the average pressure in the ring is smaller than this value. Pressure behavior due to beam conditioning (Fig. 1) shows a drop from 3.3 to 2 nTorr for 200 mA current. The two interruptions of the curve are due to:

- a. At 650 A-hrs. the ring was brought to 20 Torr of air when RGA feedthrough was broken.
- b. At 1024 A-hours the ring was brought to 0.8 Torr, when the U14 ion pump feed-through was broken.

In both cases, the recovery was rapid and depended on the pressure to which the ring was brought. Good lifetime was established after 20 and 5 hours, respectively. Useful operation for experimenters was obtained even earlier.

X-Ray Ring

X-ray ring conditioning can be divided into three periods:

- a. Four months of operating at 1.7 GeV after the vacuum overhaul, and bakeout described in ref. 5,6. Note that with a total of 11 A-hours of conditioning, the beam current lifetime was increased from 20 mA at 20 minutes to 60 mA at 70 minutes and 18 mA at 5 hours.

b. Operation at 2.4 GeV shown in Fig. 2 and described in Ref. 8. After a total of 120 A-hours the resulting beam lifetime was five hours at 80 mA.

c. Operation at 2.5 GeV shown in Fig. 3. With 200 A-hours of time integrated beam current 100-120 mA at 6 hours were obtained.

After the original bakeout,⁵⁻⁶ the x-ray ring was brought three times to LN₂ boil off. In a few A-hours good beam lifetime was restored.

III. BEAM LIFETIME

The knowledge of average pressure and gas composition enables us to calculate pressure dependent lifetime.⁶ Comparison with measured beam decay can provide us with quantitative estimates on other mechanisms such as Touschek effect and trapped ions. Unfortunately, inadequate instrumentation permits us to make only rough estimates of various factors influencing beam lifetime and a prediction of any pressure dependent improvement is difficult. This situation will be improved after the next shutdown.

A. UV Ring

Twelve meters of 51 meter circumference are filled with bending dipoles where the pressure is high due to incident synchrotron radiation. Calibrated gauges and a mass spectrometer installed in the center and at the ends of U18M2 dipole, together with TV pressure readouts, are used to calculate partial pressure in the ring. The partial pressures listed below, obtained at 220 mA beam current with total pressure of 3 nTorr, yield beam lifetime of 360 minutes. This should be compared with a measured lifetime of 150 min.

H₂ = 2.2 n Torr

H₂O = 0.3

CO-N₂ = 1.6

CO² = 0.4

At 380 mA calculated $\tau_c = 260$ minutes, while the measured $\tau_m = 90$ minutes. More extensive plots of pressures and lifetime vs. beam current taken over a 20 day period are shown in Figs. 4 and 5 for 1 and 6 bunch operation. Consistently lower lifetimes measured between 350 and 550 mA while pressure is decreasing monotonically could be due to instabilities or trapped ions. Touschek effect seems to play an important role. Better instrumentation to be installed during the next shutdown will permit us to obtain correct pressures around the ring and to determine more accurately pressure dependent lifetime.

X-Ray Ring

Partial pressures of following gases:

$$H_2 = 2.3 \text{ n Torr}$$

$$CO = 1.1 \text{ n Torr}$$

$$CO_2 = 0.16 \text{ n Torr}$$

were measured for a 110 mA beam with total and TV pressures of 2.3 and 1.6 nTorr respectively. This corresponds to calculated lifetime of 12.5 hours using equations in Ref. 6, while measured lifetime τ_m was 380 min. Due to inadequate instrumentation, lower pressures in straight sections are not taken into account in these calculations. Neither is the higher pressure - 25 nTorr measured between rf cavities due to air leaks. This region accounts for - 8 meters or - 5% of ring circumference. In this length the pressure decays parabolically from a maximum of 20-25 nTorr of nitrogen at the cavity to low pressure at two adjacent ion pumps. At low currents, below 50 mA, this

pressure is ~ 40 times higher and its effect on the lifetime should be strongest. However, even at high currents the lifetime is certainly affected by the leaks in rf cavities. In addition, high pressure regions are prime candidates for trapped ion pockets.

From estimates based on a few calibrated gauges and one RGA, the total calculated lifetime, τ_c , excluding trapping effects could be ~ 10 hours at 110 mA and 16 hours at 50 mA. When comparing τ_c with τ_m , shown in Figs. 6,7,8 and 9, we see that τ_m is always too short. During last summer, however, substantially longer τ_m were recorded for 50 mA beams and the agreement between τ_c and τ_m was better. It is also seen (Fig. 9) that for the same pressures large variations in τ_m are recorded. Variations in machine parameters or trapped ions could be responsible for these variations.

IV. CONCLUSIONS

1. Lifetime has been improving in both rings as a result of beam conditioning which lowers wall desorption and pressure. Due to low pumping speed of both the DIP's and the lumped ion pumps, the improvement in pressure is now very slow. Large pressure in the cavity region has a significant effect on lifetime.
2. When the rings are carefully bled to LN₂ boil-off in order to replace a component or an assembly, no serious vacuum degradation occurs and good lifetime is restored with only a few hours of conditioning.
3. If air is accidentally introduced into the vacuum system, beam lifetime degradation depends on the air pressure reached in the vacuum system. The degradation is minimal, if the pressure stays below 1 Torr.
4. In the UV ring, lifetime and pressure are repeatable as functions of current (Fig. 3 and 4). This repeatability was checked over a period of more than a month. Mechanisms such as the Touschek effect, trapped ions, instabilities etc. play an important role in lifetime determination. Other cures such as increasing limiting aperture and possibly changing some machine parameters have to be sought in addition to reducing desorption and increasing pumping speed.
5. X-ray ring lifetime varies by more than a factor of 2 for the same pressure (Fig. 9). Trapped ions, small random variations in machine parameters or changes in equilibrium orbits may be possible explanations.

References

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Fig 1

Fig 2

Fig 3

X Ray Rings
E = 2.52 GeV
I = 110 mA

Pressure x Torr

Shut down Dec. 24, 1955

Time Integrated Current (A-hours)

Fig 5

Fig. 6

2A71
16 P71

2 runs Nov 22
E 2.523 G₁ ✓

TV Pressure (atm)

8. 7

Beam Current (mA)