ANALYZING THE RELATIONSHIP BETWEEN THE BEAM LIFE TIME AND AVERAGE GAS PRESSURE

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Abstract

For a low-energy third-generation synchrotron storage ring like Taiwan Light Source (TLS), the beam life time is a critical issue to determine the future expansion and design criterion of the insertion devices. The beam life time also affects the routine operation of the beam energy, from 1.3 GeV to 1.5 GeV has been successfully operated, which could increase the beam life time. There were various ways and experiments that have been carried out at TLS to investigate dominating factors of the beam lifetime. The dominating factor of beam life time was intra-beam scattering at 1.3 GeV. From various operation experiences of 1.5 GeV, the dominating factor of overall beam life time is changing. A simple algorithm is setup to interpret the relation between residual gas pressure and beam lifetime using archived data during 1.5 GeV normal operation.

1 INTRODUCTION

There are several well known factors [1] that will cause the store beam with finite lifetime. The major issues that affect the beam lifetime include: 1) elastic or inelastic scattering on the residual gas, ions, and electrons reside in the vacuum chamber, 2) scattering with the particles that confined within the same rf bucket, 3) energy loss due to synchrotron radiation emission, 4) beam instability due to the energy coupling between interrupted surface of vacuum chamber and stored beam. Some of these effects will interact with stored beam coherently and causing sever beam lost. Some will only affect individual particle motion, each particle ignoring the history of other particle. During a light source users' shift, a dedicated synchrotron light source will provide a stable and high brightness beam. The major issues on lifetime will be confined to gas scattering and Touschek lifetime. The ZAP [2] offers a good analysis tool to estimate the gas and Touschek lifetime under certain assumptions and known structure of a storage ring. There are also several papers [3,4,5] that have discussed and measured the lifetime at TLS, which is using various methods and different conditions to estimate the Touschek and gas lifetime. The conditions of the storage ring is changing from time to time. The insertion devices, the physical aperture of vacuum chamber, the operation energy, and beam current will have influence on the estimation of beam lifetime. We will utilize a very simple algorithm and an interesting phenomena to deduct the gas lifetime at 1.5 GeV beam energy.

2 THE PHENOMENA OF HOLIDAY EFFECT

An interesting phenomena has been found which was related to the beam lifetime vs. beam current during the machine startup right after holiday. Figure 1 shows two typical start shifts for users beam time. The first shift of the two typical cases indicates a shorter beam lifetime compared to the second users' shift. The injection, operation, filling pattern, working point, beam energy, and the chromaticities are all identical for the first two shifts of same day except the vacuum condition. The only uncontrolled parameter that causes a shorter beam lifetime is the residual gas adhere on the surface of chamber and bases pressure. We will try using the residual gas pressure as the only free parameter that affects the beam lifetime, then estimates the Touschek and gas lifetime.

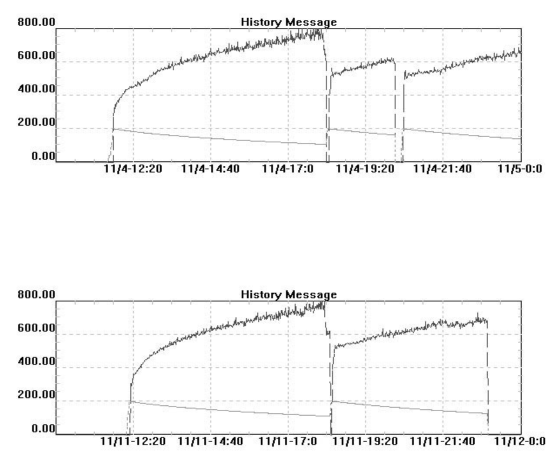

Figure 1. The beam current and lifetime vs. time. These data were taken during the first and second users' shift after a holiday machine shutdown.

The machine is scheduled to shutdown 36 hours for normal maintenance without venting any chamber once a week. From our judgment, the residual gas will deposit several layers on the clean surface of vacuum chamber during the normal maintenance. The first injection after maintenance will give out a lot of gas by photo-desorption. It is offering a good opportunity to analysis relation between beam lifetime and gas pressure without interrupt the normal operations.

The normal operation conditions are set as: 1.5 GeV beam energy, 200 mA beam current, 800 kV RF gap voltage, multi-bunch operation. The photon beam stability is maintained within .5% peak-to-peak variation which is determined by a 50 αm pin-hole detector. The filling pattern is set to be nearly identical for two different users' shifts. This gives us the same Touschek effect during the two shifts. The only effect on the beam lifetime will come from the vacuum pressure.

3 ANALYSIS OF THE ARCHIVED DATA

The beam lifetime, beam current, and average pressure were recorded on archived data. Figure 2 shows the beam lifetime vs. the beam current. The lower lifetime curve represents the first injection shift. The upper lifetime curve represents the second injection shift. A hyperbolic regressions method is used to have a best fit for the measured results. The correlation between the measured data and fitting curve is strong for the 4th order fitting. Hence, we can write

$$\tau^{-1}(I) = a_1 I + a_2 I^2 + a_3 I^3 + a_4 I^4 + O(I^5).$$

Figure 3 shows the average pressure vs. the stored beam current. The upper curve of average pressure represents the first injection shift with higher vacuum pressure. The lower curve of figure 3 represents the second injection shift. The average gas pressure as function of the beam current will be fit by polynomial regressions to have a best fit of the measure data points. We have

$$P(I) = P_0 + \lambda_1 I + \lambda_2 I^2 + \lambda_3 I^3 + \lambda_4 I^4 + O(I^5)$$

where P_0 is the bases pressure. As a well known calculation for the overall beam lifetime,

$$\tau_T^{-1} = \tau_{Touschek}^{-1} + \tau_{Gas}^{-1}$$

If two users' shift with the same filling pattern, we can assume the Touschek related lifetime are identical. The subtraction results of the inverse lifetime between the first and second shift will proportion to the difference of induced gas pressure. This leads to

$$\tau_{T1}^{-1} - \tau_{T2}^{-1} = \alpha (P_1 - P_2)$$

where α is a constant depend on the beam current, P_1 and P_2 are the pressure at the same current for the first and second shift, respectively. The proportional constant can be solved, so as the lifetime of Touschek related lifetime, and the gas lifetime for two different users' shifts. Figure 4 shows the calculated intra-beam scattering related lifetime and gas lifetime of first users' shift. The dominate factor of beam lifetime at the winter of 1996 is gas scattering.

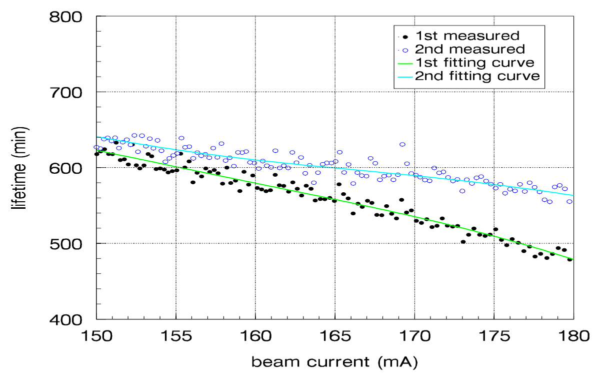

Figure 2. The measured data for the beam lifetime vs. beam current, a hyperbolic fitting curve and the interpolation line is drawn.

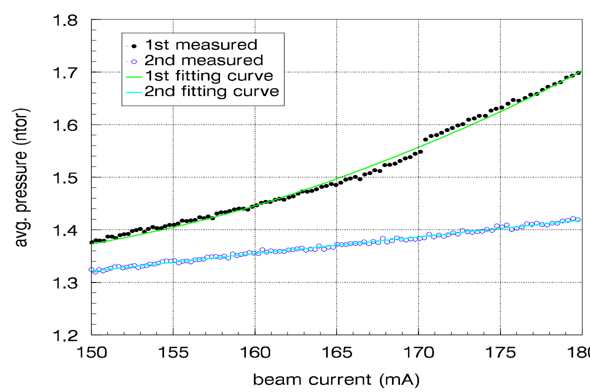

Figure 3. The measured data for the average pressure vs. beam current, the polynomial fitting curve and the interpolation line is drawn.

4 DISCUSSION

For most dedicated synchrotron radaition source, the structure of lattice and hardware are changing from time to time. It is necessary to have frequent check of beam parameters to maintain in a ultimate performance of a storage ring. Here, we offer a simple method to check the lifetime dominate factors. From the calculated results, the Touschek lifetime strongly depends beam current. For high current and multi-bunch operation mode, the bunch lengthening effect will enter the calculated Touschek lifetime which makes the lifetime longer than expected. Using the simple algorithm to analysis archived data, it seems to us that the calculated gas related lifetime is a dominate factor for the TLS during the winter 1996 period. The improvement of the vacuum pressure will improve the beam lifetime a little bit.

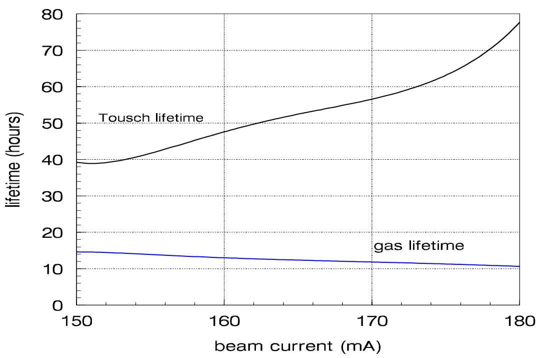

Figure 4. Using the method discussing at section 3 with the interpolation function of beam lifetime and vacuum pressure, the calculated Touschek like lifetime is over 40 hours, the gas lifetime is over 10 hours.

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5 REFERENCES

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