IMPURITY INCREASE IN SINGLE BUNCH MODE OF UVSOR AND ITS CURE

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Abstract

An increase in impurity was observed in the single bunch mode of the UVSOR storage ring. This phenomenon is caused by electrons thrown out of the bucket by the Touschek effect being recaptured by the following buckets due to the radiation damping. It is successfully cured with a beam scraper system that promptly damps electrons thrown out with a momentum gain greater than a certain amount. The other possible mechanism of impurity increase is also discussed.

Introduction

The UVSOR storage ring is a synchrotron light source for molecular science and its related fields. The RF frequency of the acceleration system is 90 MHz and the harmonic number is 16. The period of the pulsed light from the ring is 11 ns when all the RF buckets are filled. The ring can be operated in a single bunch mode if the users require longer period of the pulsed light. In the mode, the period becomes to be 180 ns, which is the revolution period of the beam in the ring. The impurity, that is the rate of electrons in buckets following the single bunch, is important in this mode of operation. An impurity below 10^{-3} is required, and more stringent conditions will be required in the near future. We installed a improved single bunch system in the booster synchrotron for that purpose.[1] The impurity of the single bunch formed by the new system seems to be less than 10^{-4}, however increase in the impurity was observed in the impurity measurements. This phenomenon is explained by the mechanism that electrons thrown out of the bucket by the Touschek effect is captured again in the following buckets by the radiation damping.[2] The impurity increase was successfully cured by a fast removal of scattered electrons by means of a beam scraper.[3] Increase in impurity caused by the scattering by residual molecules in the beam pipe or the radiation excitation is possible. Impurity increase due to these effects in the HiSOR[4] that is the 1.5 GeV electron storage ring for the synchrotron radiation is also discussed.

Single bunch forming system

A selective RF knockout system is installed in the booster synchrotron in order to form the single bunch in the storage ring. The beam in the synchrotron is lost if the frequency of the transverse excitation satisfies

$$f_{\rm ko} = q f_{\rm rev} \quad \text{or} \quad (1-q) f_{\rm rev}, \tag{1}$$

where $f_{\rm ko}$ is the frequency of the excitation, q the decimal part of the betatron tune value and $f_{\rm rev}$ the revolution frequency. If the RF knockout signal is modulated by a pulse U_o that is given by

$$U_o(t) = 0 \quad \text{for} \quad 0 < t < 11\text{ns} \qquad 1 \quad 11\text{ns} < t < 90\text{ns}, \tag{2}$$

where 11 ns and 90 ns are the period of RF and that of the revolution in the synchrotron respectively, bunches in the period in which $U_o = 1$ are removed by the RF excitation, however a bunch in the period in which $U_o = 0$ remains in the synchrotron. Only the DC, the first and the second harmonic components are used to form the pulse U_o, in order to minimize the required bandwidth of the RF knockout system. The single bunch formed in the synchrotron is injected into the storage ring with a synchronized beam transfer system.

Mechanism of impurity increase

Electrons that gain momenta in a certain range Δp_i due to the Touschek effect are recaptured in the i-th bucket as shown in Fig.1. The number N_i in the i-th bucket at time t after the injection is given by

$$N_i(t) = \frac{\alpha \Delta p_i N_0 t}{p_i(\tau_{T_0} + t)} \left(\frac{p_i}{\Delta p_{\rm HF}} \right)^{2\alpha} \tag{3}$$

where N_o the number of the electrons just after the injection, α is about 1.22 in the case of the UVSOR, τ_{T_0} is the Touschek lifetime just after the injection, $\Delta p_{\rm HF}$ is the bucket height.[2]

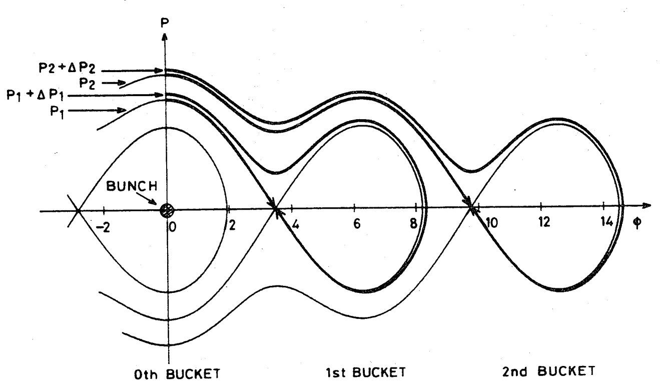

Fig. 1 The trajectory of the electron thrown out of the bucket in the longitudinal phase space. An electron with momentum gain between p_1 and $p_1 + \Delta p_1$ is captured by the bucket 1.

Measurement of impurity

A single photon counting system, the blockdiagram of which is shown in Fig. 2, is installed in the storage ring in order to measure the single bunch impurity. The number of photons from a bending magnet section in the storage ring is proportional to the number of electrons. Photons are detected by a channelplate-type photomultiplier (MCP PMT) and its output starts a time-to- amplitude converter (TAC), which is stopped by the signal synchronized to the revolution frequency. The output of the TAC corresponding to the time interval between two signals, which shows the longitudinal position of the electron that emitted the photon, is analyzed by a multichannel analyzer (MCA). An example of the impurity measurement is shown in Fig.3. The highest peak in the picture correspond to the beam current in the single bunch, and small peaks correspond to those in the following bunches.

The change in the electron number in the bunch adjacent to the single bunch is measured with the photon counting system. An example is shown in Fig. 4. The solid line in the figure show the electron number estimated by Eq.(3). Considering the errors in the measurements of the machine parameters, the agreement between the measurement and the estimation is satisfactory.

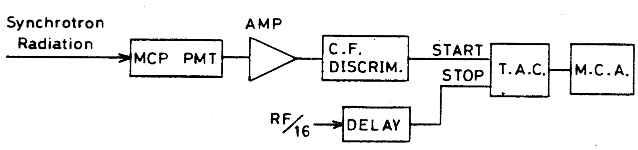

Fig. 2 The block diagram of the photon counting system.

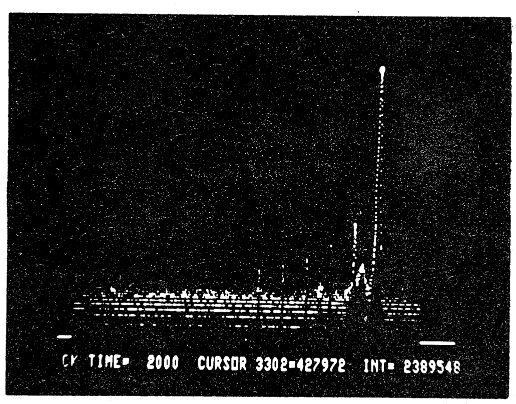

Fig. 3 An example of the impurity measurement. The highest peak corresponds to the electron number in the assigned bucket and the lower peaks correspond to following buckets.

Cure of increase in impurity

As stated before,since the increase in impurity is caused by the mechanism that electrons with larger momentum are re-captured by the following RF buckets, we will be able to suppress the increasing by introducing a beam scraper system that eliminates these electrons. A rotary scraper system shown in Fig. 5 is placed at a nonzero dispersion section of the ring. This scraper consists of a rod with a radius of 4 mm that can rotate around an axis on the ideal beam orbit with a radius of 44 mm.

Rotating the scraper, we first searched the angle of it where the impurity growth was suppressed. Without scraper inserted, we injected and accelerated the single bunch electron beam. After the acceleration up to 750 MeV, we rotated the scraper from the outer side of the beam and measured the impurity growth and the lifetime of the stored beam. When the

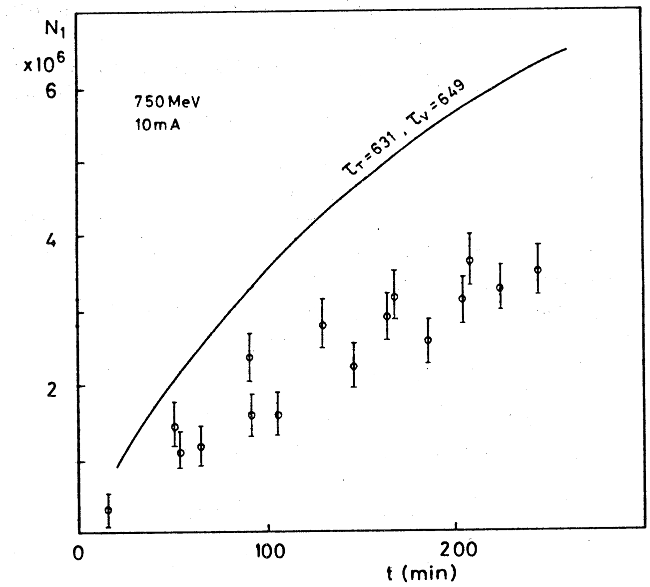

Fig. 4 The increase in the impurity. The circles show the measurement and the solid line shows the estimation.

surface of the scraper was 16 mm away from the stored beam, the increase in impurity had completely stopped as shown in Fig. 6. At this position, the electrons that have 1.4 % larger momentum are scraped out. This threshold value corresponds to the first momentum deviation $p_1 = 1.29$ %, $\Delta p_1 = 6.2\times10^{-5}$ to be captured by the adjacent RF bucket. The lifetime of the stored beam was not affected at this position.

As we found the threshold position of the scraper, we next tried to decrease the absolute value of the impurity. Firstly, we injected the 606 MeV electrons without scraper inserted, rotated it where the surface was 14 mm away from the stored beam, and accelerated the beam up to 750 MeV. The residual impurities of N_1/N_0 = 0.013%, N_2/N_0 = 0.008%, N_3/N_0 = 0.007% and N_4/N_0 = 0.006% were obtained as shown in Fig. 7. The initial current of the stored beam was 10.32 mA. These impurity are the best values in this measurement. Because

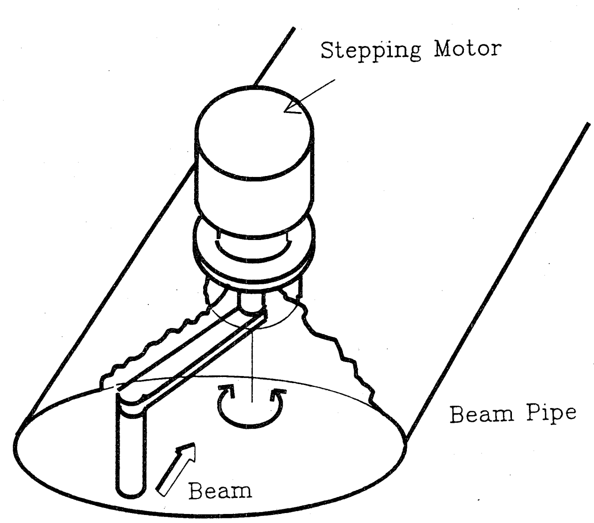

Fig. 5 Rotary scraper

the injection of the beam requires finite period of time, about 10 minutes, those original impurity cannot be decreased.

Secondly, we tried to inject the electrons with the scraper on, 14 mm from the beam. Under this condition, the injection efficiency became very bad. We cannot store the beam more than a few mA.

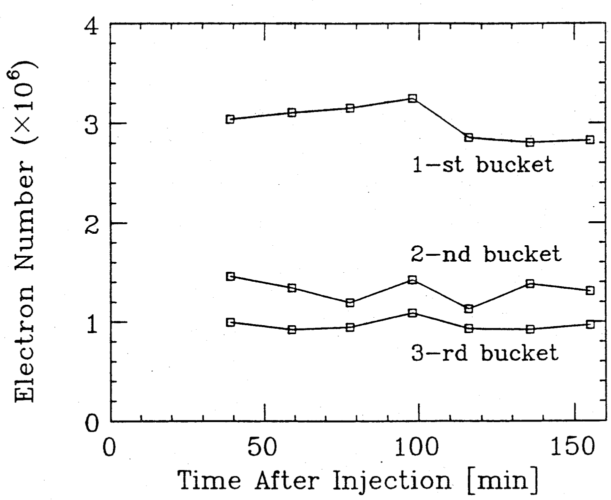

Fig. 6 Change in electron number in several bunches following the single bunch. The growth of impurity is suppressed.

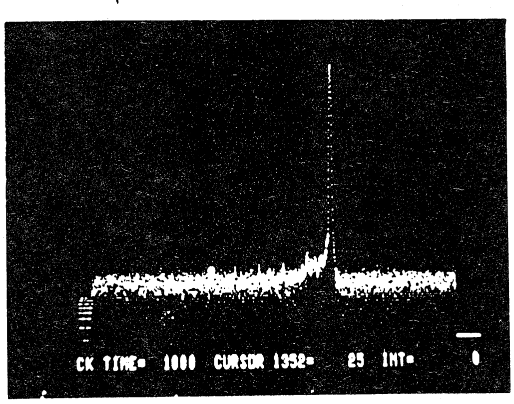

Fig. 7 The residual impurity of the single bunch injected with the rotary scraper inserted.

Other mechanism of impurity increase

In the higher energy machines, such as the Photon Factory, the TRISTAN AR or MR, the Touschek lifetime is much longer than that of the UVSOR, therefore the mechanism of the increase in impurity stated in the preceding sections is not applicable. The synchrotron radiation excitation effect in the longitudinal phase space plays an important role in these machines instead. However, this effect has small meaning in the UVSOR.

Conclusions

We have found the increasing in impurity in the single bunch mode of the UVSOR storage ring. This phenomenon is caused by the electrons that has some larger momentum by the Touschek effect are captured by the following RF buckets. An beam scraper was installed at the dispersive straight section in order to cure this effect, and it was confirmed that the system is useful to suppress the impurity increase. The position of the scraper to suppress the effect is very close to that predicted by the theory mentioned in the preceding section. In the higher energy machine, the synchrotron radiation excitation becomes more important for the impurity increase.

References

1 T. Kasuga, M. Hasumoto, T. Kinoshita and H. Yonehara: Proc. 6th Symp. on Accelerator Sci. Tech. (1987) p.195.

2 T. Kasuga, H. Yonehara, M. Hasumoto and T. Kinoshita: Jpn. J. Appl. Phys. **28** (1989) 541.

3 M. Tobiyama, T. Kasuga, H. Yonehara, M. Hasumoto, T. Kinoshita, O. Matsudo, E. Nakamura, K. Sakai and J. Yamazaki: Jpn. J. Appl. Phys. submitted.

4 M. Tobiyama, I. Endo, T. Ohta, T. Sugano and M. Taniguchi: Rev. Sci. Instrum. **60**(1989) 1713.