

OBSERVATION OF +1 BUCKET BUNCH IMPURITY GROWTH AT THE APS STORAGE RING*

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Abstract

The APS storage ring has three fill patterns: a 24-singlet, a 1+8x7 hybrid with a leading bunch of 16 mA, and a 324-singlet. Bunch purity of better than 1×10^{-6} is required for +3 and higher bucket numbers for the first two fill patterns during user operations. A PAR bunch cleaning system is used to clean the satellite bunches. During top-up user operation, beam charge in satellite bunches grows due to the long lifetime of the low charge satellites. Recent storage ring developments, including operating with the bunch-by-bunch feedback system, reduction of chromaticity, and lattice correction, have increased the dynamic and momentum aperture of the storage ring. We observed unusual beam charge growth in +1 buckets, which indicates leakage of electrons from the main bunches to the +1 satellite buckets. This report describes the observation and the dependence of leakage on chromaticity settings, and gives a brief analysis.

OBSERVATION OF ABNORMAL +1 BUNCH GROWTH

Figure 1 shows the normal growth of the +1 satellite bucket relative counts in the 24-singlet fill of the RHB (reduced horizontal β -function) lattice, recorded in the first run period of 2013. It has a typical growth rate of $\sim 2 \times 10^{-8}$ per hour. Figure 2 shows an abnormal growth of the +1 bucket counts with a growth rate of $\sim 3 \times 10^{-6}$, about 150 times higher than normal value. Typical injector bunch impurity for the +1 satellite bucket is at the 8×10^{-7} level and can not explain this abnormal growth. A test was conducted with injected beam turned off and top-up injection systems continuously running. We observed significant growth of net counts in the +1 satellites while the -1 buckets showing no growth. A plot of the result is shown in Figure 3. This test confirmed that the +1 bucket counts come from leakage of main bunches.

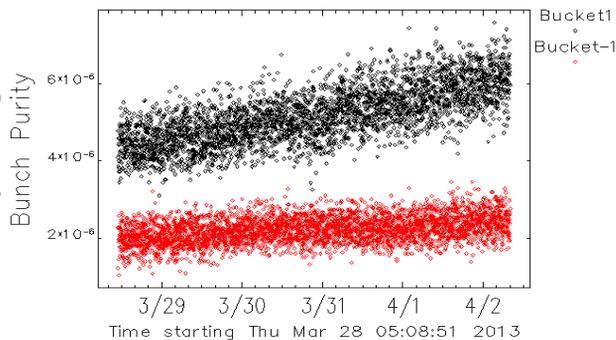


Figure 1: Normal accumulation of the +1 satellite bucket during user operations.

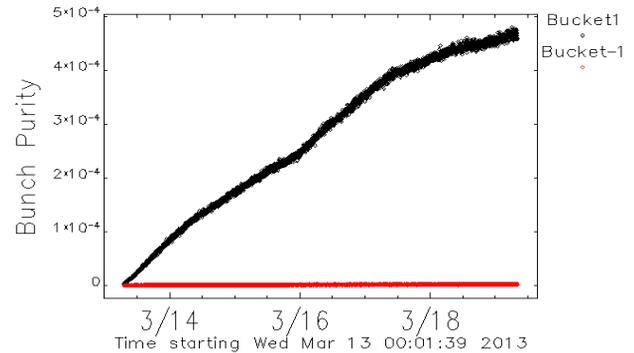


Figure 2: Abnormal growth of the +1 satellite bucket during top-up user operations with lower chromaticity.

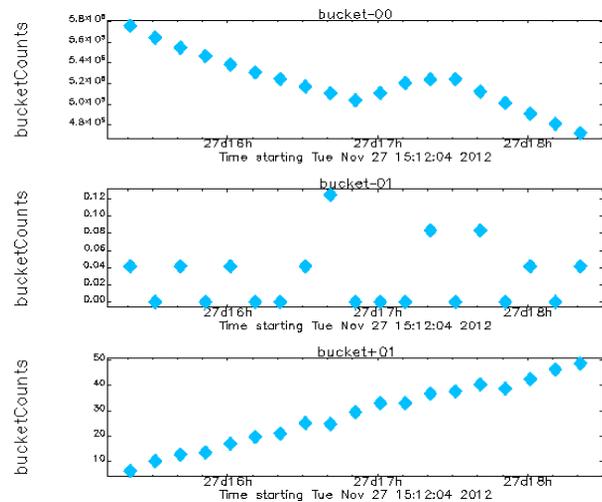


Figure 3: Average bucket count change during a test in which the injected beam is turned off while top-up injection systems were running. Top: main bucket. Middle: -1 bucket showing no growth. Bottom: +1 bucket showing steady growth.

LEAKAGE RATE FITTING

In order to find the relationship between the +1 bunch impurity and the change in storage ring chromaticity, we varied chromaticity in 0.5 steps and collected bunch purity data during Run-1 of 2013. We fit the resulting data with `sddsgenericfit` [1].

The +1 bucket relative counts can be expressed with the following differential equation:

$$dI = \frac{I_0}{T_0} C_{inj} dt - \frac{I}{T_b} dt + I_0 R_{leak} dt \quad (1)$$

The variables are defined as:

I_0 --- main bucket beam current

I --- +1 satellite beam current
 T₀ --- main bucket lifetime
 R_{leak} --- defusing rate from main to +1 bucket
 C_{inj} --- +1 bucket ratio of injected beam
 T_b --- +1 bucket beam lifetime

The solution of this equation can be expressed as:

$$\frac{I(t)}{I_0} = \frac{I(0)}{I_0} e^{-\frac{t}{T_b}} + C_1 [1 - e^{-\frac{t}{T_b}}], \quad (2)$$

where I(0) is the initial +1 satellite current, and C₁ is the expected final +1 bucket impurity defined as:

$$C_1 = T_b \left(\frac{C_{inj}}{T_0} + R_{leak} \right). \quad (3)$$

Injector +1 bunch impurity was estimated from bunch purity data taken immediately after a fill-from-zero. Average beam lifetime over the data collection time was used as T₀, mainly determined by the lifetime of the main bunches.

Table 1 lists fit results and other relevant parameters. The negative leakage rates in some cases are probably due to measurement error, which only indicates a very low or zero leakage rate. Figures 4 and 5 show plots of leakage rate and expected final +1 bunch purity versus chromaticity, respectively. The dependence of leakage rate on x-chromaticity is clear. The results also show that in order to avoid high +1 bucket counts we need to operate with a minimum x-chromaticity of ~4.0.

Table 1: Measured and Fit Parameters

Data date	x-chrom	+1 bucket asymptote impurity	+1 bucket lifetime (s)	Main bucket lifetime (s)	Leak rate (1/s)
03-13	3.122	9.29e ⁻⁰⁴	7.02e ⁵	4.04e ⁴	1.30e ⁻⁹
03-20	3.625	1.37e ⁻⁰⁴	2.79e ⁵	3.90e ⁴	4.68e ⁻¹⁰
03-27	5.638	2.15e ⁻⁰⁶	5.77e ⁵	3.49e ⁴	-2.0e ⁻¹¹
04-03	4.127	1.82e ⁻⁰⁶	5.47e ⁵	3.19e ⁴	-2.27e ⁻¹¹

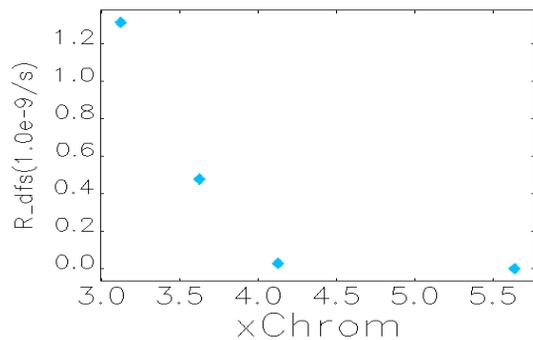


Figure 4: Fit leak rate versus x-chromaticity.

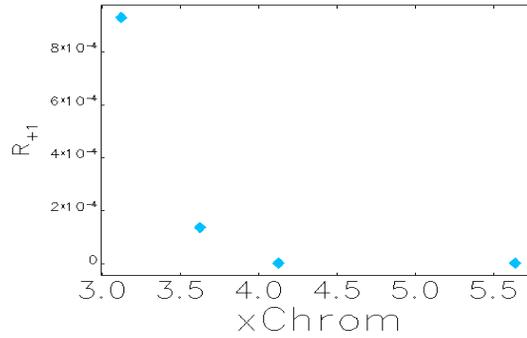


Figure 5: Expected final +1 impurity versus x-chromaticity.

ANALYSIS

The fact that +1 buckets gained electrons while -1 buckets did not implies occurrence of a longitudinal recapture process.

Earlier studies of beam dynamic aperture and lifetime [2] found that decreasing chromaticity and subsequent reduction of non-linear tune shift extends the momentum acceptance of the APS storage ring beyond that of the normal-chromaticity lattice. We speculate that it is possible that “lost” electrons due to Touschek scattering or other processes stay longer around the longitudinal separatrix, as shown in Figure 6, and are recaptured in the following bucket due to another scattering event. However simulations we performed with *elegant* so far are unable to confirm this theory. One possible reason is that the required simulation time, on the order of 10⁴ seconds scale, and total initial particle counts are too high for us to achieve in the limited time available. Further studies, such as varying gap voltage while observing change in the +1 bucket impurity and continued simulations with different parameters are planned.

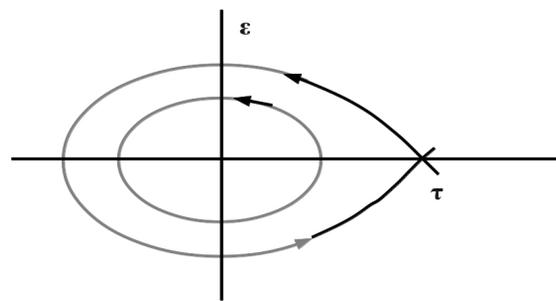


Figure 6: Longitudinal phase-space diagram of a storage ring bucket.

CONCLUSIONS

Recapture of electrons that are lost from the main bucket into the +1 satellite bucket has been observed during the most recent 24-singlet RHB lattice user run when x-chromaticity is +3.6 or lower. This is the first time we have observed this process in the APS storage ring. The leakage rate depends on the value of the x chromacity and

is estimated to be around 10^{-9} /s. During a week-long top-up fill, the accumulated +1 bucket bunch impurity can be as high as a few times 10^{-4} . The recapture process stops completely when x-chromaticity is above 4.0. This observation may have implications for future APS storage ring lattice development.

ACKNOWLEDGEMENT

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REFERENCES

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