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"INSTANTANEOUS" LIFETIME MEASUREMENT IN STORAGE RING WITH TOP-UP INJECTION*

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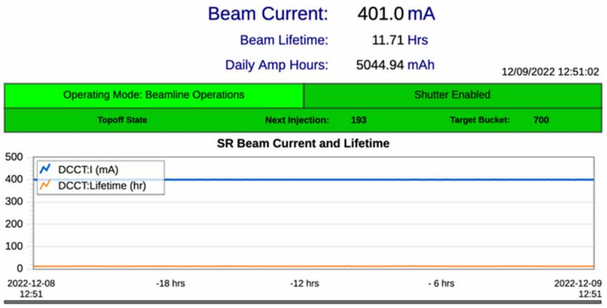
Abstract

Top-up operation becomes routine in the light sources. The goal of the top-up operation is to keep the current of the circulating beam stable to avoid variations of the heat load on the beamline optics. It is also considered for the electron-ion collider to maintain the polarization of the electron beam. Frequent re-injection makes measurement of the beam lifetime very difficult if possible. Since, only part of the bunch train is refreshed during the injection cycle then the distribution of the bunch charges in the train has a characteristic saw-tooth distribution. The slope of saw tooth is defined by the lifetime and filling frequency and can be used for the measurements. The data for processing can be obtained either from fast current transformer or from the raw ADC signal from beam position monitor. In this paper we present the theoretical considerations as well as experimental data from NSLS-II storage ring.

TOP-UP OPERATION OF THE NSLS-II

To satisfy requirements of the beam stability NSLS-II storage ring operates with top-up. Presently, around 1200 buckets out of 1320 are filled. The stored current is 400 mA, and lifetime is around 12 hours as shown in Fig. 1. Each 200 seconds approximately 100 bunches are injected into the ring to maintain current level [1, 2]. Therefore, top-up cycle takes 40 minutes. In the electron-ion collider being built at Brookhaven National Laboratory the refill is expected each two seconds making conventional lifetime measurement harder.



Beam Current: 401.0 mA
Beam Lifetime: 11.71 Hrs
Daily Amp Hours: 5044.94 mAh
12/09/2022 12:51:02

Operating Mode: Beamline Operations
Shutter Enabled
Topoff State
Next Injection: 193
Target Bucket: 700

Figure 1: Screenshot of NSLS-II status showing stored beam current and beam lifetime of 11.7 hours from the DCCT data between injections.

NSLS-II BEAM POSITION MONITORS

NSLS-II BPMs are processing 500 MHz signal induced by the circulating beam. The parameters of the bandpass filters define the rising and falling of the induced train as well as ringing down as one can see the in Fig. 2. After amplification the signal is sampled with analog-to-digital converter [3]. The ADC sampling rate is chosen so that there are 310 readings per turn. The clock is phased locked to the RF frequency. The down sampling results in the 500 MHz signal being converted into the 80 periods per turn. There is possibility to extract buffer of 100000 consecutive ADC readings per channel (more than 322 turns) for the offline analysis.

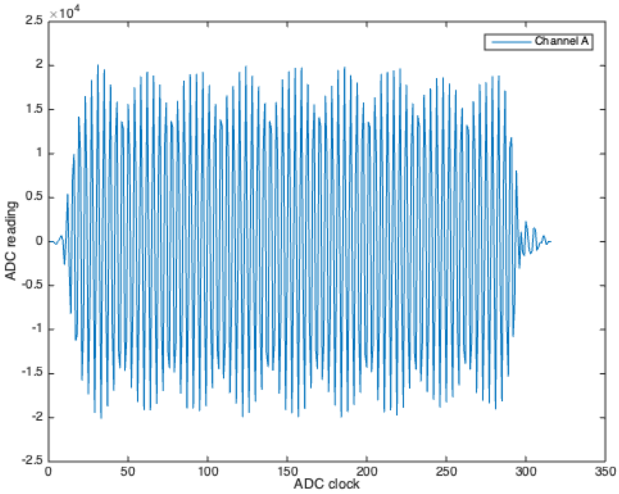


Figure 2: Raw ADC signal from NSLS-II beam position monitor. The visible modulation is due to the limited sampling rate (just below four readings per period).

To evaluate the signal level evolution along the train the sliding window was used. The user defined number of data samples around the current ADC clock were used to perform sine wave fit and the amplitude of the wave was used as signal strength. The 310 samples were padded with zeros on both sides for these calculations. The result is shown in Figs. 3 and 4. The sliding fit was using 11 points to smear the modulation caused by artefacts in the NSLS-II injection complex. The step down is clearly visible near ADC clock 236. The amplitude of the step as well as average amplitude can be used for the evaluation of the beam lifetime (in assumption that injection is stable in time) from the period of the top-up:

$$\tau_{lifetime} = T_{top-up}\frac{\langle amplitude\rangle}{step} \qquad (1)$$

The step was calculated as difference between two linear fits on the left and on the right sides shown in Fig. 4. The modulation of the intensity is caused by modulation of charge trains in the NSLS-II injection system.

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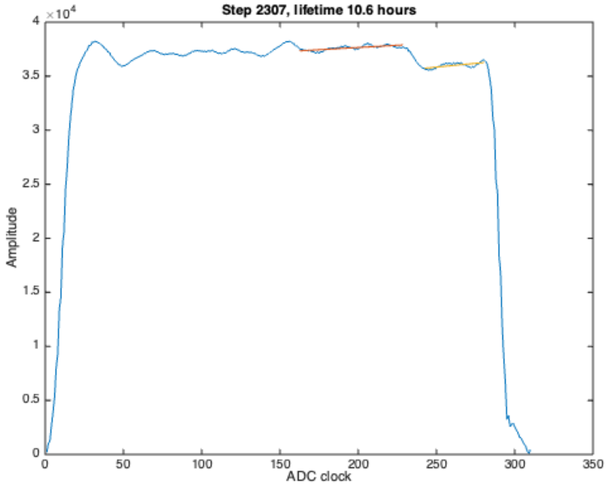

Figure 3: Amplitude of the BPM signal along the bunch train. Two red lines shows linear fit of the latest filled (left) and earliest filled (right) parts of the train. The estimated lifetime is 10.6 hours.

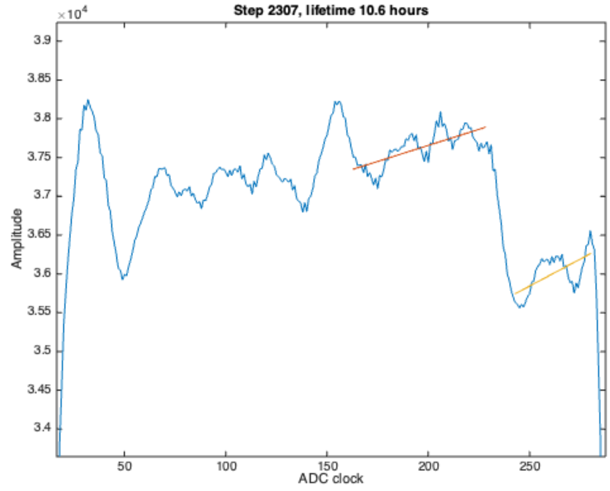

Figure 4: Zoomed in view on the step in the fill pattern.

As it was mentioned before the top-up operation causes the saw-tooth modulation of the bunch charge since the time from the injection into each bunch varies with its position in the train. Slope in the fill pattern can be used for lifetime measurements as well as it is shown in Fig. 5. The slope is measured as growth rate of the amplitude per ADC clock, time "span" is virtual fill time difference between the first bunch and the last bunch in the sequence (it is not actual time since the train of 100 bunches is injected). The modulation of the fill pattern can affect the accuracy of the measurement as well as stability of the injection system. For example, if all data between ADC samples 20 and 230 is used the calculated lifetime will grow to 18 hours, most likely due to the excessive charge injection into the region 50-150 ADC clocks.

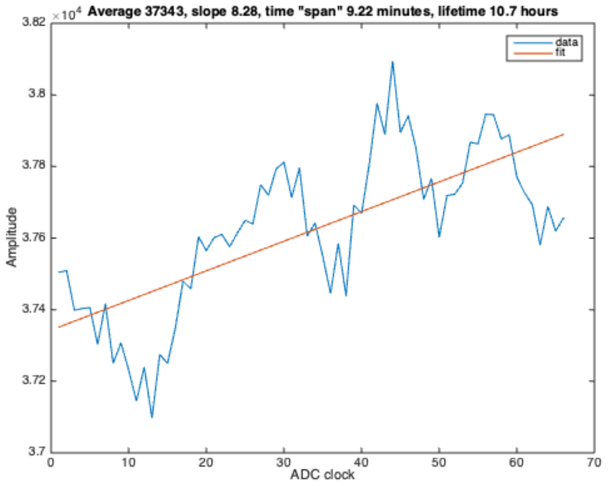

Figure 5: Lifetime measurement from the slop of the amplitude. The region selected is just before the step down.

CONCLUSION

Preliminary analysis of the BPM data from NSLS-II showed feasibility of using raw BPM data for an "instantaneous" measurement of the lifetime. The measurement accuracy can be adversely affected by modulation of injected beam amplitude as well as drifts in the delivered charge.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R. Fliller, A.A. Derbenev, T. Shaftan, G-M. Wang, "Top Off Algorithm Development and Commissioning at NSLS-II," in *Proc. 7th Int. Particle Accelerator Conf. (IPAC'16),* Busan, Korea, May 2017, pp. 2988-2990. `doi:10.18429/JACoW-IPAC2016-WEPOW060`

[2] R. P. Fliller, A.A. Derbenev, V. Smaluk, X. Yang, "Top Off of NSLS-II with Inefficient Injector," *in Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, May 2018, pp. 1327-1329. `doi:10.18429/JACoW-IPAC2018-TUPMF036`

[3] K. Vetter, J. Mead, B. Podobedov, Y. Tian, W. Cheng, "The BNL EBPM Electronics, High Performance for Next Generation Storage Rings," in *Proc. of North American Particle Accelerator Conf. (NAPAC2016),* Chicago, IL, USA, October 2016, pp. 1-5. `doi:10.18429/JACoW-NAPAC2016-MOA2IO02`