# MEASUREMENTS USING BUTTON BPM SUM SIGNAL*

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*Abstract*

Modern digital BPM detectors measure not only the beam positions, four buttons SUM signal can be very helpful for machine developments and operations. At NSLS-II, BPM SUM signal has been used from commissioning stage, to investigate localized beam losses. During top-off operation, precise beam lifetime measurement within relative short period of time becomes important. With many BPMs along the ring, BPM SUM can be a much more accurate tool to measure the beam current and lifetime. BPM SUM signal shall be proportional to beam current, and it depends on button sizes, BPM chamber geometry, cable attenuations, electronics attenuations, beam position, bunch lengths, fill pattern etc. Experience of BPM SUM signals measurements at NSLS-II storage ring will be presented.

## INTRODUCTION

NSLS2 is an advanced third generation light source recently constructed at Brookhaven National Laboratory. The 3GeV storage ring generates ultra-low emittance of less than 1nm.rad horizontally and 8pm.rad vertically. The machine has started top-off operation since October 2015. Top off user operation current has been gradually increased to 250mA and highest storage current of 400mA has been achieved during studies. Typical lifetime at 150mA is ~10 hours, which determines the top-off interval ~2 minutes to keep the beam current stabilized within +/− 0.5%. At 500mA, beam lifetime is expected to be around 3 hours, this will require top-off period ~ 1 minute.

Precise measurement of current/lifetime within short period of time will be important to characterize the storage ring performance. This kind of tool will be essential to measure the lifetime glitches due to vacuum burst. NSLS-II DCCT typically needs 60 seconds to fit the lifetime. Using the precise BPM SUM signal in 10Hz rate, it's likely that beam lifetime can be measured within shorter period of time. There are more than 200 BPMs in the storage ring, averaged lifetime from BPMs around the ring will further improve the measurement accuracy. Similar experiments have been carried out at other light sources, using the commercial available BPM electronics [1, 2]. We present here the experience at NSLS-II storage ring where in-house developed BPM electronics are used.

## BPM SUM AND LIFETIME

4-button BPMs are used in NSLS-II storage ring. 4-button signals are fed to the BPM electronics through ~30 meters of LMR-240 cables. 180 BPMs in the multipole magnets girders are the same geometry, BPMs in the straight sections have several different type of geometries [3]. Button signals pass through +/− 10MHz band pass filter with center frequency at 500MHz, before they were sampled and processed. In house developed BPM electronics supplies the BPM SUM signal in ADC, TbT, FA and SA rate, where the first three data types are available on-demand. 10Hz SA data is continuously available through the EPICS IOCs.

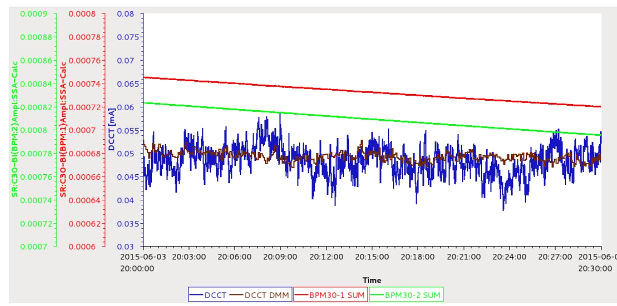


Figure 1: BPM SUM signal and DCCT current readings with 50μA single bunch filled in the ring.

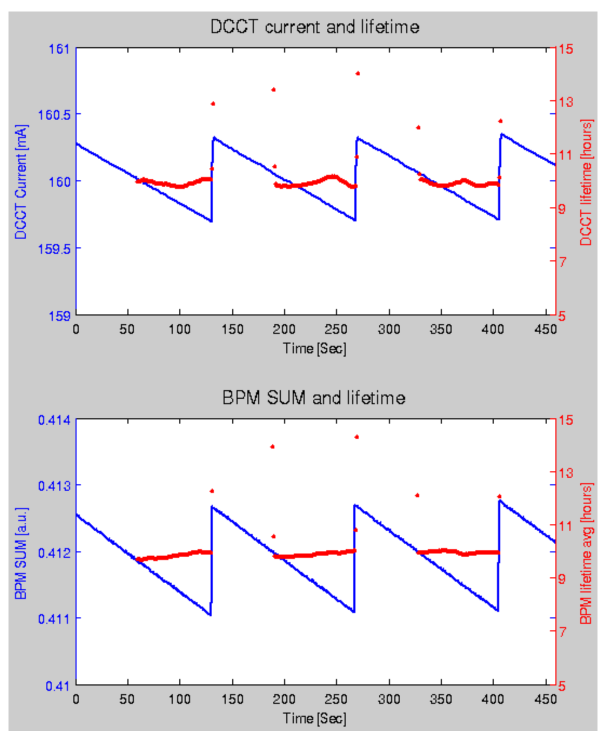


Figure 2: BPM SUM signal, DCCT current and their fitted lifetime during top-off operation.

Figure 1 show an example when pretty low single bunch current was stored in the ring. There was ~50μA filled in one bunch, which has about the same bunch charge with 50mA evenly distributed in 1000 bunches.

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DCCT was not able to fit the lifetime from 30-minutes of data due to noisy DCCT readings. BPM SUM signal however can see the beam decay during the time and fit the lifetime to be ~14.5 hours.

Another example shows in Figure 2 is the BPM and DCCT SUM signal during top-off operations. 60 seconds of history data was used for the lifetime fitting. Even with one BPM SUM signal, the fitted lifetime has better resolution. Using 180 BPMs lifetime, the measurement accuracy can be greatly improved which means the lifetime can be derived with shorter latency.

## BPM SUM DEPENDENCY

BPM SUM signal is not only determined by stored beam current, it will be affected by the button and chamber geometry, cable and electronics attenuation/gains, environment temperature, bunch lengths, beam positions and fill patterns.

There are 180 large aperture BPMs in the storage ring, with same button and chamber geometries. Ignoring the button and gap changes at high current, these BPMs will have the same transfer function. Different types of insertion device BPMs SUM signal can be normalized based on the calculated coupling factor [3]. Lifetime can be derived from the initial values and slopes of the BPM SUM signal, hence absolute calibration from BPM SUM to beam current is not necessary. Attenuation of cables from button to electronics has been measured. BPM electronics attenuation will affect the BPM SUM signal. During top-off operation, the attenuators are typically set at fixed numbers. If the beam orbit has large offset, BPM SUM signal will see the nonlinearity effect. This effect can be compensated using the calculated coefficients [4]. Typical beam positions are well within 2mm range to the geometrical center, BPM SUM signal nonlinearity is negligible.

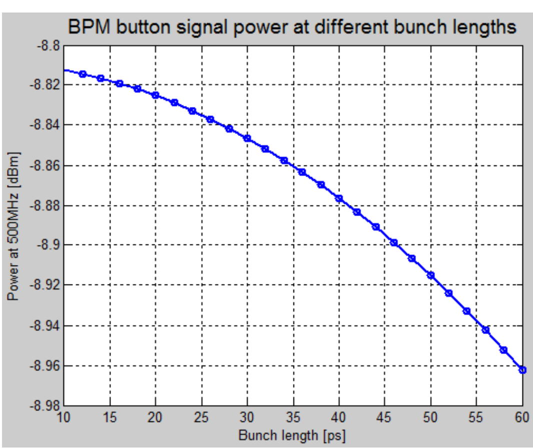

Figure 3: Calculated button BPM signal level at different bunch lengths.

Bunch length and fill pattern may affect the BPM SUM signal. Time domain button signal calculation has shown ~1% different of the 500MHz signal level, while comparing bunch lengths of 15ps and 35ps. Figure 3 gives the result of NSLS-II large aperture BPM button signal at different bunch lengths, with total beam current of 500mA. The power was calculated at electronics detection frequency of 500MHz. Button capacitance of 2.3pF and cable cutoff frequency of 1GHz was used.

Bunch lengths will be affected by RF gap voltages and ID gaps, especially with damping wiggler (DW) gaps. Bunch lengthening effect at high single bunch current due to longitudinal impedance is significant at NSLS-II storage ring [5], hence the BPM SUM signal is expected to be affected. Investigation of the bunch length effect on BPM SUM signal has been carried out using the archived data during operations/studies.

Environment temperature affects the cable attenuation and BPM electronics gain. NSLS-II tunnel and rack temperatures are controlled within +/− 0.1 °C which is essential for the accurate BPM SUM measurement. We have observed SUM signal level decrease by ~3% when rack temperature rose ~ 8 °C.

## BUNCH LENGTH EFFECT

A dedicated BPM electronics was connected to 4-button signals with combiner/splitter, so that the beam orbit drift will not affect the measured SUM signal. Storage ring has been filled to ~200mA in 1000 bunches at different RF voltage and DW gaps. BPM SUM signal vs. DCCT current reading slopes are compared in Table 1. With same 1000 bunches fill, BPM SUM signal didn't change much (< 0.1%) with different RF voltages and DW gaps. With single bunch fitted up to 5mA per bunch, the linear slope decreased ~ 0.4% which is likely due to the bunch length increase at high single bunch current. Figure 4 gives the BPM SUM vs. DCCT beam current in single bunch and multi-bunch fills. In both cases, BPM SUM signal is linear proportional to the DCCT current readings.

Table 1: Compare of BPM SUM vs. DCCT Slopes

| Vrf [MV] | DWs | Fill pattern | SUM vs. I_dcct slope [1/mA] |
|---|---|---|---|
| **3** | 0 | 1000 bunches | 0.00098999 |
| **1.8** | 0 | 1000 bunches | 0.00099052 |
| **1.8** | 1 | 1000 bunches | 0.00098942 |
| **3** | 0 | 1 bunch | 0.0009859 |
| **2.3** | 0 | 1 bunch | 0.0009869 |
| **1.8** | 0 | 1 bunch | 0.0009859 |

At another chance, RF voltage varied significantly (1800kV down to 560kV with 1DW) with single bunch stored in the ring. RF voltage varied from 1800kV to 560kV with one DW and from 1800kV to 750kV with two and three DWs. It has been observed that BPM SUM signal decrease ~2% at low RF voltages with one and two DW gaps closed. In the case of three DWs, BPM SUM signal decreased ~40% at low voltage of 750kV. With one DW, 0-current bunch length increase from 15ps to 35ps while RF voltage varied from 1800kV to 560kV, BPM SUM signal decreasing of 2% is in rough agreement with the calculated curve in Figure 3.

Based on these observations, it's fair to say that BPM SUM signal represents the stored beam current if bunch lengths are not significantly changed. During user operation, insertion devices gaps vary frequently and there was no impact on the BPM SUM signal.

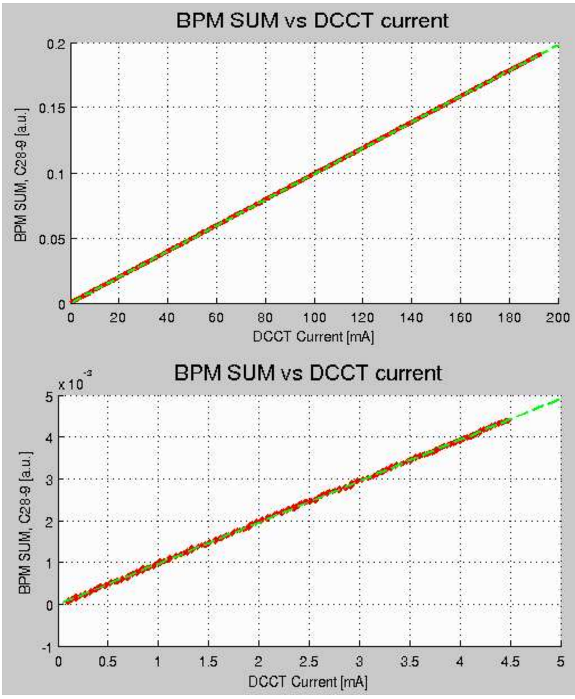


Figure 4: BPM SUM signal measured during 1000-bunch fill (top) and single bunch fill (bottom). Red dots are the raw data and green dash lines are the fitted curve.

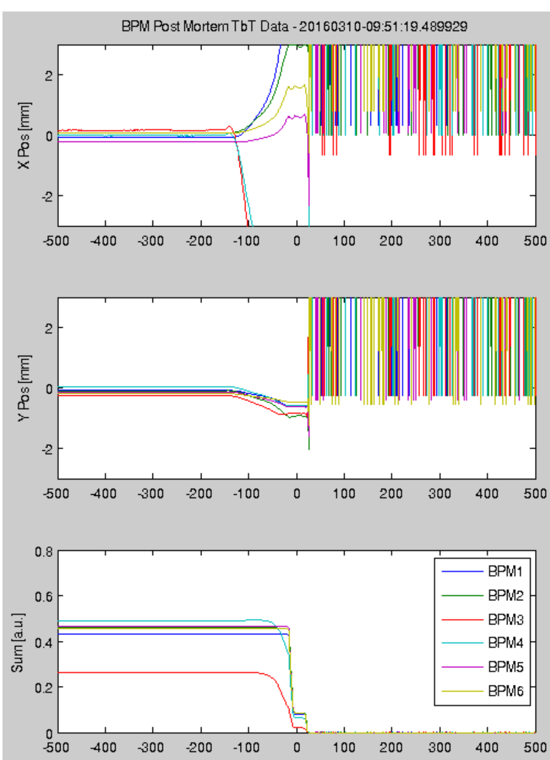


Figure 5: Post-mortem BPM TbT positions and SUM signal captured during the beam dump. Six BPMs in C30 were plotted where BPM3 and BPM4 are in dispersive section.

## SUM SIGNAL WITH FAST RATE

Typical beam current and lifetime measurement use BPM SUM signal with 10Hz rate. NSLS-II BPM electronics supplies the data at other higher rate which may be interesting for fast involving beam dynamics. ADC raw data of button SUM signal has been used at early commissioning stage. Partial beam losses were found from the ADC button SUM signals when beam was circulating the ring for multiple turns [6].

BPM SUM signal is available on demand in turn by turn (TbT) and 10kHz (FA) rate. These data gives the possibility to look in to fast motions of beam orbit/trajectory and beam current. At each beam dump or significant beam loss, post-mortem (PM) data was saved for all BPMs in TbT and FA rate. Figure 5 is a typical TbT beam position and SUM signal during beam dump. Six BPMs in one cell data was plotted. BPM3 and BPM4 locate in dispersive region. For this particular case, beam was dumped due to RF cavity trip. Large horizontal orbit at dispersive BPMs trigged the active interlock (AI) which captured the PM data. AI trigger happened on turn #0 in the figure.

From ~100 turns before the AI trip, dispersive BPMs SUM signal start to decrease which is related to the large position offset in the horizontal plane. After correction the BPM SUM signal with position dependency coefficients, the SUM signal can fully reflect the TbT stored beam current in the ring.

## CONCLUSION

BPM SUM signal has been investigated for accurate beam current and lifetime measurement. With hundreds of BPMs available in the storage ring, beam lifetime can be accurately measured from the SUM signal with fast response time. BPM SUM signal depends may be affected, especially with bunch lengths and environment temperature (which changes the electronics gain). These effects have been studies. BPM SUM signal is available in TbT and FA rate. High rate signal is helpful to understand the fast evolution of beam position and storage current.

## REFERENCES

[1] A. Kosicek, P. Leban, B. K. Scheidt, "Beam Lifetime Measurements with Libera Brilliance", BIW 2010.
[2] B. K. Scheidt, F. Ewald, B. Joly, "High Quality Measurements of Beam Lifetime, Instant Partial Beam Losses and Charge Accumulation with the New ESRF BPM System", DIPAC 2011.
[3] W. Cheng, B. Bacha, O. Singh, "NSLS2 Beam Position Monitor Calibration", BIW 2012.
[4] W. Cheng, et. al., "Performance of NSLS2 Button BPMs", IBIC 2013.
[5] W. Cheng, et al., "Longitudinal Bunch Profile Measurement at NSLS2", IBIC 2015.
[6] W. Cheng, et al., "NSLS2 Diagnostic Systems Commissioning and Measurements", IBIC 2014.