

# LOCAL IMPEDANCE ESTIMATION OF NSLS-II STORAGE RING WITH BUMPED ORBIT\*

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## Abstract

As the newly constructed 3rd generation light source, NSLS-II is expected to provide synchrotron radiation of ultra high brightness and flux with advanced insertion devices. To minimize the beam emittance, damping wigglers are used and there is a small aperture located at the straight section with the damping wiggler and whose vacuum chamber is coated with non-evaporable getter (NEG). We used the local bump method to find the effect on the beam from the narrow aperture and this paper discusses the results.

## INTRODUCTION

To reduce the electron beam emittance as well as to serve as broadband sources of very bright and high flux x-rays, 1.8T damping wigglers (DW) are installed at NSLS-II storage ring. As the first stage, 3 sets of the wigglers are installed where each set consists of 2 wigglers of 3.5 m. Most of the NSLS-II storage ring uses extruded aluminum vacuum chambers and their apertures are  $\pm 38$  mm in the horizontal direction and  $\pm 12.5$  mm in the vertical direction. However, the damping wiggler chambers have vertical apertures of  $\pm 5.75$  mm with tapers. The narrow gap results in very limited linear conductance and, in this case, lumped pumps at the ends of the chamber will not be enough for the desired vacuum. To simplify the pumping system design, narrow-gap chambers as the DW chambers are NEG coated and the damping wiggler chambers are also included.

As the emittance of the synchrotron radiation source approaches the diffraction limit, and the vacuum chambers are becoming extremely narrow, the NEG coating is seriously considered for the solution of the vacuum system. However, there are concerns about its impact on the resistive wall impedance. Various studies have been undertaken and more are being underway, including the experience reports [1] [2], calculations and experiments [3] [4]. Also, some analytical methods to calculate the impedance of the layered structure are developed [5-9]. However, because of the uncertainties in NEG coating, the impedance from the calculation or simulation can be far from the real value. Therefore accurate impedance measurement at the NEG coated location is even more important than the measurements for the conventional cases.

The local transverse impedance will change the transverse kick factor and the focussing effect will shift the phase at the location. If the dependence of the phase advance on the beam current is found, the local kick factor can be obtained [10] [11]. Like a quadrupole, if we make a local orbit bump, the transverse kick factor will generate closed orbit

distortion, and by comparing the changes in the closed orbit between high and low beam current, the kick factor can also be obtained [12] [13]. We used the local bump methods to measure the kick factor at the NEG coated damping wiggler ID chamber. Because we are interested in the effect of the vertical narrow gap, all the measurements in this paper are regarding the vertical direction.

## LOCAL ORBIT BUMP

To measure the local effect on the closed orbit using a local bump, it is very important to make a clean flat bump without any significant leak. To completely contain a local bump within a long straight where the damping wiggler is installed, only 2 upstream and 2 downstream regular correctors can be used. Given the maximum corrector strength (1 mrad) and their locations in the lattice, a phase space scan in a model found the maximum feasible height of a vertical position bump at the long straight to be 2 mm. A Python module and its frontend interactive script (as an IPython notebook) have been developed to create a local bump of an arbitrary target height/angle. This code can work both in online (actual machine) and offline (simulation using PyTracy) modes. This allows an operator to reliably and quickly create a large-amplitude bump by pre-computing corrector setpoint values for a desired bump in the offline mode, loading these values into the machine, and finally fine-tuning the bump online. With this software, a local bump with 1.8-mm vertical height was successfully created for the purpose of the impedance measurement. The leakage of the bump was minimized after multiple iterations of orbit correction using SVD. The maximum and RMS difference between the achieved orbit and the target orbit around the ring (180 regular BPMs) was  $34.7 \mu\text{m}$  ( $\sim 1.9\%$  of the target height) and  $12.4 \mu\text{m}$  ( $0.7\%$ ), respectively. Figure 1 shows the resulting local bump together with the generated bump with simulation. The simulated bump will be used to estimate the local impedance with fitting.

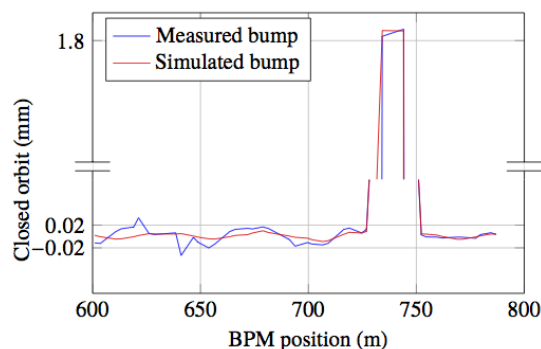


Figure 1: Local bump in the DW28.

\* Work supported by DOE contract No: DE-AC02-98CH10886

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## ORBIT MEASUREMENT

We used the method of reference [12] where the closed orbits are measured for high beam current with and without the local bump and for low beam current with and without the local bump. By subtracting the difference of low current orbits from the difference of high current orbits, the pure effect from the local bump of the beam current difference can be obtained.

To measure the effect from transverse kick factor more accurately, we measured the closed orbit in the single bunch mode. We also wanted to record the turn by turn data of the kicked beam and the single bunch mode is considered to give more reliable data because the BPMs cannot read the bunch by bunch positions. However as the newly constructed machine, NSLS-II storage ring is not yet well conditioned and optimized. To make the decay of the kicked beam slower, we made the linear chromaticity very small and the limit of the stable single bunch current was only about 0.55 mA which corresponds to about 1 nC bunch charge. Besides, the beam current should be at least about 0.15 mA for reliable BPM readings. We chose 0.56 mA as the high current and 0.16 mA as the low current and measured the closed orbits with and without the local bump for each case.

Figure 2 shows the standard deviations for the closed orbit measurements. As can be seen, even though the levels are kept in the  $\sim 1 \mu\text{m}$  level, the uncertainties are high for the low current measurements. Especially, around 600 m there are high peaks and we know that the peaks are coming from the nearby RF system. The BPM signal at 0.16 mA is too weak and the leaked RF signal disturbs the BPM readings. When we analyzed the data, we marked the unreliable BPMs and excluded them.

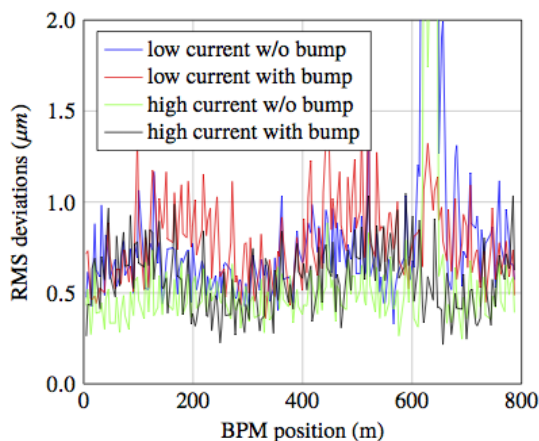


Figure 2: Standard deviations in closed orbit measurements.

Figure 3 shows the measured and simulated orbit distortion. For the simulation, we used the corrector settings for the local bump of Fig. 1. For the high current, we replaced the drift representing the ID vacuum chamber with a fictitious long quadrupoles whose focussing component corresponds to 500V/pC/m with 1 nC bunch charge.

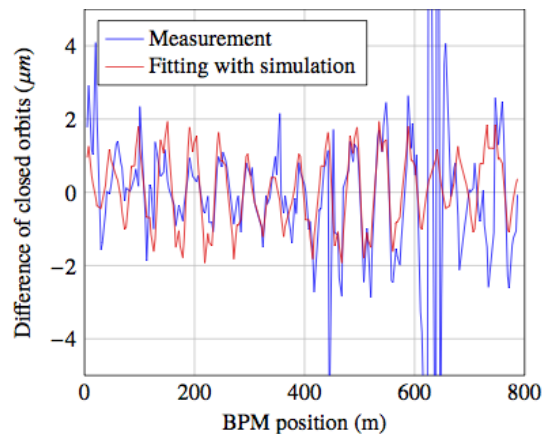


Figure 3: Fitting the measurement with the simulation.

## PHASE MEASUREMENT

Usually, the tune dependence on the beam current is measured to estimate the overall impedance and, in fact, the local change of the focussing will change the local phase advance. By measuring the difference of the phase advances with different beam currents, we can find out the local transverse kick factor. There are well known methods [14] [15] with which the tune, phase, and beta functions can be accurately measured from turn-by-turn data. However, to measure these parameters, the stored beam must be disturbed and the accuracy is quite lower than the measured closed orbit, where the orbit is very stable with time. Many factors are involved in the measurement including, e.g., the kick strength, bunch current, chromaticity. Not only all these factors significantly affect the measured data, but different analysis method also give different results. The oscillation of the kicked beam is not static and decays with different patterns depending on the beam properties. Therefore, for the analysis of the linear properties, we should choose some relatively stable turns and the obtained values represent the averaged local properties. For the given turns, the measurements can be very accurate. But if we need to compare the values with kicks at different situations, it could be easily meaningless, especially when the beam signal is very weak as in our case.

We measured turn-by-turn data with various kicks with and without the bump. Each measurement recorded 10,000 turns and, even with numerous approaches, we could not observe a consistent effect of the beam current on the phase advances in the damping wiggler chambers. However, we found that the tunes measured at the later part of the data are highly reliable. We obtained the difference of the tunes in the same way in obtaining the closed orbit difference. One case of the tune differences is shown in Fig. 4. It is understood as the higher order effect [16] and will not be discussed in this paper.

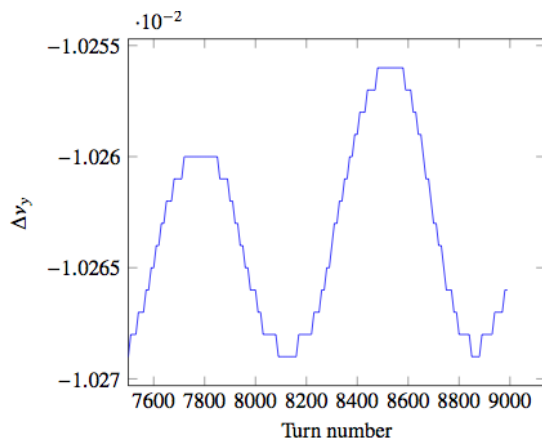


Figure 4: Tune difference: (high current with bump - high current without bump) - (low current with bump - low current without bump)

## CONCLUSION

Even though the fitting of Fig. 3 shows reasonable agreement, it should be reminded that the error bars are on the same order as the orbit difference. Even though 500V/pC/m is a rough estimate, it is quite reasonable considering the fact that the estimated kick factor of the pure aluminum DW ID chamber is 170V/pC/m [17] and the resistivity of the NEG coating is about 10 times bigger than that of the aluminum [9] [18]. Because at the high frequency of single bunch, about 10 GHz, the skin depth becomes much smaller than 1  $\mu\text{m}$ , and the aluminum cannot be seen by the wave [9]. Furthermore, it is known that the NEG on aluminum is not smooth and has a granular structure [18].

To find the resistive wall collective effect from the NEG coated narrow chamber, we carefully designed the local bump orbit to strictly localize the bump effect. With the local bump, the transverse kick factor from the chamber was obtained by comparing the closed orbits of high/low beam currents and with/without the local bump. We also obtained the effect on the vertical tune. Even though the error bar is comparable to the magnitude of the data because of the quite limited single bunch beam current, we found that the effect is not far beyond the reasonable expectation.

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