SIMULATIONS AND MEASUREMENTS OF THE BPM NON LINEARITY AND KICKER TIMING INFLUENCE ON THE TUNE SHIFT WITH AMPLITUDE (TSWA) MEASUREMENT AT BESSY II *

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Abstract

The **T**une **S**hift **W**ith **A**mplitude (TSWA) does not only determine the position of the stable fix points for the **T**ransverse **R**esonant **I**sland **B**ucket**s** (TRIBs) [1–4] but also represents a global observable for the nonlinear optics in general. For theoretical investigations of the TRIBs a reliable nonlinear optics of the machine is required and thus all measurable global observables for the nonlinear optics are of great interest. The measurement of the TSWA [2] for the BESSY II standard optics was performed using an injection kicker to excite high amplitude betatron oscillations and then extract the amplitude dependant frequency from the synchrotron radiation damped oscillation with a Hilbert transformation. With TRIBs optics the injection kicker was not able to sufficiently excite the beam. The impact and correctability of the BPM nonlinearity at the reached amplitudes and the reason for the failure of the excitation method for our TRIBs optics shall be looked onto in this paper.

INTRODUCTION

The TSWA is calculated from a measurement of the beams betatron oscillation frequency in dependance of the according oscillation amplitude, which is damped due to synchrotron radiation damping. The Hilbert transformation of the damped oscillation is used to extract the instantaneous amplitude and frequency over time. A button type **B**eam **P**osition **M**onitor (BPM) is used to measure the beam's center-of-mass position. The digital **B**unch-by-**B**unch-**F**eed**B**ack (BBFB) [5] system offers the diagnostic capabilities to read out the BPM extremely fast and perform the entire measurement with one excitation kick. The BBFB system with its fast 12 bit ADC can take the bunch positions of all 400 bunches over 30k turns or one single bunch over 80k turns in one measurement providing an ideal oscillation signal as input for the Hilbert transformation. The BBFB readout is triggered by the kicker and the measured data is directly analyzed and visualized with a python tool allowing for online measurement of the TSWA. The excited betatron oscillation amplitudes are required to be in the order of 10 mm for good signal to noise ratios in the TSWA measurement. Thus a strong kick and accurate beam position measurement at high offsets are required. This paper presents results of simulations on the kicker efficiency at

BESSY II and compares different simulations of the BPM nonlinearity with one another and a measurement.

KICKER TIMING

When the pulse duration of the kicker exceeds the revolution time the kick at every turn subsequently sums up with that of the preceeding turn according to the phase advance or tune of the particle. For tunes close to the next integer resonance the kicks sum up well even over multiple turns while for tunes close to an half integer resonance they cancel each other. The maximum oscillation amplitude excitable by a kicker thus depends on the interaction of the particles tune and the kicker pulse duration and waveform. The longer the kicker pulse becomes and the closer the particle tune is to the next half integer resonance the smaller the excited oscillation amplitude at the same peak kick strength becomes as shown in Fig. 1. These simulations confirm the observation from our TSWA measurements. For excitation of high amplitudes with our TRIBs optics the diagnostic kicker with its pulse duration of less than 2 revolution periods is required.
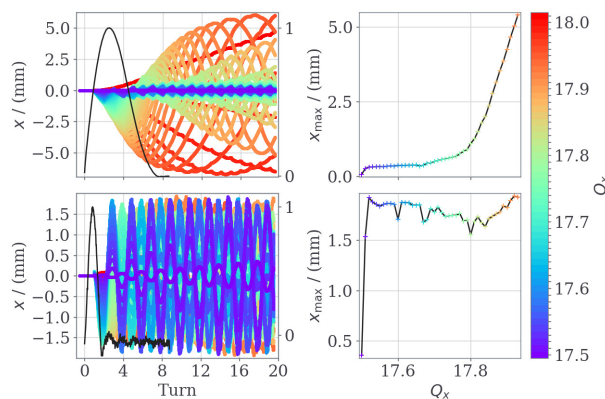

Figure 1: A simulated comparison of the kick efficiency in dependence of the horizontal tune for the BESSY II injection and diagnostic kicker for excitation of betatron oscillations of the beam. The Black line in the left plots shows the measured relative amplitude of the kickers with peak kick angle simulated at 0.1 mrad. The upper case shows the injection kicker with a pulse length of about 8 revolution periods and the accordingly strong dependence of the excited amplitude on the horizontal tune. Below the results of the same simulation using the BESSY II diagnostic kicker with a pulse length of less than 2 revolution periods are shown revealing a in comparison negligible dependence of the kick efficiency on the horizontal particle tune. [6–8]

BPM SIMULATION

Four button (A, B, C and D) BPMs are used to measure the beam position. Multiple stripline or button pickup electrodes are placed around the beam. The distribution of the induced mirror voltages V_i on these due to the passing beam is used to calculate the beam position.

$$X = \frac{(V_A + V_D) - (V_B + V_C)}{V_A + V_B + V_C + V_D}, \qquad x = K_x \cdot X \qquad (1)$$

$$Y = \frac{(V_A + V_B) - (V_C + V_D)}{V_A + V_B + V_C + V_D}, \qquad y = K_y \cdot Y \qquad (2)$$

The linear correction factors K_i depend on the BPM geometry. They can be calculated by directly solving the Laplace equation for the given geometry. For simple (e.g. cylindrical) geometries analytic solutions are possible. Numerical calculations can be used for all BPM geometries. The **B**oundary **E**lement **M**ethod (BEM) represents an efficient numerical tool to calculate the position sensitivity from a given 2D BPM geometry with an accuracy in the order of 1%. For cylindrical BPMs the results can be compared to analytical calculations to verify the implementation of the BEM. For the simulation of the BESSY II button type BPM used for the TSWA measurement an own version of the BEM as presented in [9] has been implemented in Python. As clearly indicated in Fig. 2 the linear calibration factors are not sufficient to calculate the beam position at amplitudes above 2mm. The correction factors can also be determined from calibration measurements. Either on a test bench where an RF antenna is used to simulate the field of a high energy beam or from direct beam based measurements.
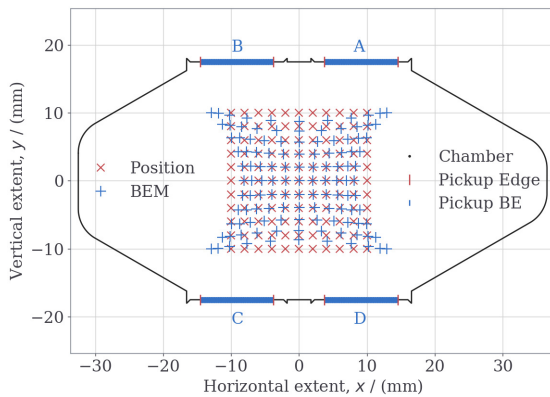

Figure 2: BESSY II BPM geometry and visualization of the results according to equation 1 from the BEM simulation of the induced voltages on each pickup for the shown beam positions (red). [6]

Since the TSWA measurement requires high amplitudes in the order of 10 mm a nonlinear correction must be applied. The linear correction factors can be retrieved from the simulated beam position data X, Y and used the input beam positions as shown in Fig. 3. The linear coefficient of the odd order polynomial fit is the linear correction factor,

valid for small amplitudes. In order to evaluate measured beam position data X, Y of higher amplitudes the complete polynomial fit function can be used to correct for the BPM nonlinearity at high amplitudes.
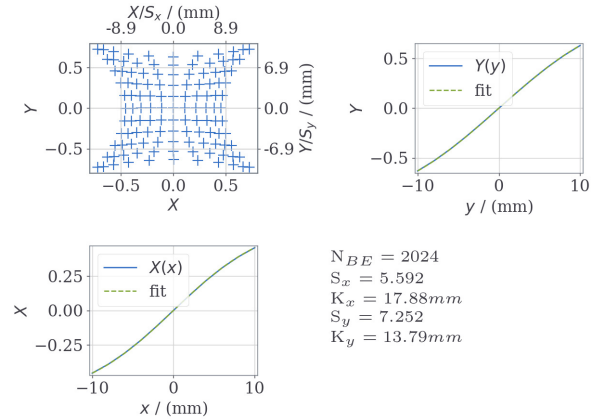

Figure 3: Calculation of the BPM sensitivity $S_u = \frac{\partial U}{\partial u}$ and callibration factors $K_u = \frac{1}{S_u}$ from an 11-th order polynomial fit of the BEM simulation results. The number of simulated boundary elements N_{BE} is given. [6]

Comparison of BEM, CST and BpmLab

To check the accuracy of our python implementation of the 2D BEM based calculation beyond the comparison to analytical results for the simple case of a cylindrical BPM geometry the BESSY II button type BPM geometry was also simulated with other tools as shown in Fig. 4. The results from ALBA's Matlab based BpmLab [10] tool and CST Studio [11] are compared. BpmLab is based on a 2D finite element calculation of the given BPM geometry while CST does a 3D finite element based calculation. The results of all simulations agree well within the required accuracy of a few %.
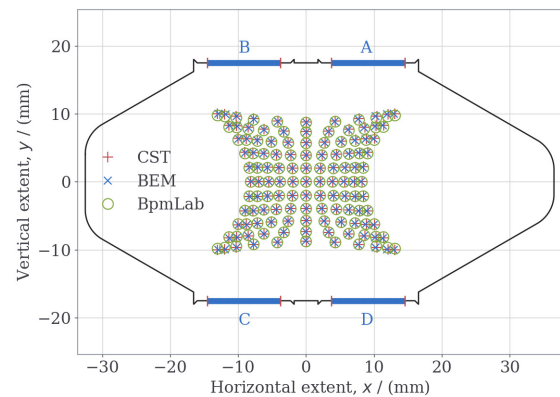

Figure 4: Visualization of the BESSY II BPM nonlinearity for large amplitudes from BEM simulation. [6]

A comparison of the extracted linear correction factors from an 11th order polynomial fit to the simulated beam position data are highlighted in Table 1.

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Table 1: Obtained Correction Factors

	K_x / mm	K_y / mm
BEM	17.9	13.8
CST	18.2	13.8
BpmLab	18.5	13.6

BEAM BASED BPM MEASUREMENT

A beam based measurement of the BPM calibration factors is possible with a linear driven beam offset at the position of the BPM. Hereby the calibration factors must be normalized to the bunch current. If a fast BPM readout system like the BBFB system is available a kicker can be used. This relies on the in first order linear dependence between the excited amplitude and the kicker strength. Due to the TSWA this method will be impacted by the changing kick efficiency in dependence of the new tune. Therefore a fast diagnostic kicker is required. Another method is based on a closed orbit bump with 3 or 4 steerers which is used to drive an offset of the beam at the position of the kicker. This offset depends linearly on the strength of the steerers. The method used for the measurement shown in Fig. 5 was to exploit the nonzero dispersion at the BPM to drive an offset in linear dependence of the cavity's frequency. For positive offsets the measured nonlinearity of the BPM response is in good agreement with the simulated response and shows the expected linear behavior when corrected with the 11th order correction from simulation. For negative offsets at high amplitudes an additional error in the order of 1% is visible. This could be caused by a misalignment of the BPM not included in the simulation. A non-linearity of the RF-Front-End (e.g. hybrid, mixer) could also be the cause.
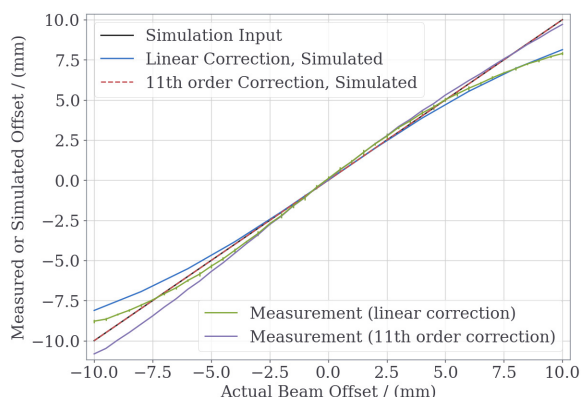

Figure 5: Comparison of the BPM sensitivity measurement with results from the BEM simulation. [6]

CONCLUSION

For the tune independent excitation of high amplitudes a kicker pulse duration in the order of a single turn is required. Therefore at BESSY II only the diagnostic kickers provide the possibility for an online measurement of the TSWA for all optics. The nonlinearity of the BESSY II button-type BPM geometry at high amplitudes must be taken into account. Simulation and measurement of the nonlinearity show that the observed nonlinearity lies within the expected one due to the geometry. A correction from a higher odd order polynomial fit to the simulated or measured BPM response is possible and eliminates this problem. The impact of decoherence and head-tail damping effects on the measured amplitude damping are subject of future measurements of the damping time based on the optical beam profile and comparison to measurements where every amplitude is excited separately.

ACKNOWLEDGEMENTS

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