FIRST MEASUREMENTS OF PULSE PICKING BY RESONANT EXCITATION (PPRE) AT THE MAX IV 3 GeV STORAGE RING

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Abstract

At synchrotron light storage rings there is demand for serving high-brilliance users requesting multibunch operation while simultaneously serving timing users who require single-bunch operation. One method to accomplish this is PPRE developed and currently in user operation at BESSY-II. In the method, the transverse emittance of one of the bunches in the bunch train is increased by an incoherent betatron excitation. Part of the light from this bunch can then be separated from the multibunch light by an aperture in the beamline, resulting in single-bunch light for the experiment. Methods such as this expand the scope of storage rings without requiring special fill patterns. This is of growing interest due to the upgrade trend towards diffraction-limited storage rings where it becomes more challenging to operate with inhomogeneous fill patterns. Measurements of PPRE were performed at the MAX IV 3 GeV storage ring utilizing the bunch-by-bunch feedback system both for excitation and as a diagnostic. Furthermore, measurements involving direct beam imaging at the diagnostics beamline allowed quantifying the effect of this excitation on the horizontal and vertical emittance.

INTRODUCTION

The MAX IV facility includes two storage rings (operated at 1.5 GeV and 3 GeV, respectively) and both rings have been designed for operation with a uniform, multibunch fill pattern [1]. A discussion on timing modes has been initiated by the user community and several research areas have been identified that would benefit from other repetition rates than provided by the baseline fill pattern [2]. At the 1.5 GeV ring it is possible to operate in single-bunch mode a few weeks per year for timing users, but a solution that allows serving both timing and high-flux users simultaneously is likely required if timing-based experiments should be conducted at the 3 GeV ring since the ring has been designed with the purpose of providing world leading flux and brilliance to users.

Both MAX IV ring are operated at 100 MHz RF frequency and employ passive harmonic cavities (HCs) to damp instabilities and increase Touschek lifetime [3]. For the 3 GeV ring, the HCs are also essential for conserving the ultralow emittance (328 pm rad) at high bunch charge [4]. Since the HCs are passive, the bunch lengthening depends on both the cavity tuning and the fill pattern. Studies at other rings, e.g. [5–10], have shown that inhomogeneous fill patterns give rise to transients in the cavities that decrease the average bunch lengthening. It would thus be preferable to be able to serve timing users at the MAX IV 3 GeV storage ring while operating the ring in normal multibunch mode.

One method that has this potential is pulse picking by resonant excitation (PPRE), developed and operated for users at BESSY II [11]. The method relies on excitation resulting in emittance growth of a single bunch in the bunch train. Part of the light emitted from this bunch can then be separated from the light produced by the multibunches by an aperature in the beamline. The main advantage of this method is its simplicity and the possibility to conduct the excitation in the horizontal plane, thus conserving the vertical plane for monochromatization [11]. The purpose of these measurements was to study the feasibility of the PPRE method at an ultralow emittance storage ring such at the MAX IV 3 GeV storage ring, with focus on the relation between excitation and emittance growth.

PULSE-PICKING BY RESONANT EXCITATION

The PPRE method is based on quasi-resonant excitation of incoherent betatron oscillations of the electrons in a single bunch in the bunch train. This can be achieved by a gated stripline kicker feed by an input signal with a frequency close to the betatron tune. The tune spread of the electrons in the bunch caused by chromatic and amplitude-dependent tune shifts, instabilities and tune variations results in an incoherent excitation of the electrons [11]. If the incoherent excitation is sufficiently large taking into account the Landau damping this results in an emittance increase which is greater than the induced center-of-mass motion [12].

MEASUREMENT SETUP

The beam was excited horizontally by the Dimtel bunch-by-bunch feedback system [13] that has been installed in the MAX IV 3 GeV storage ring for the purpose of damping instabilities. The feedback system has the capability to excite individual bunches in the bunch train, but during these measurements all bunches in the fill pattern (~10 bunches) were exited to enable measurement of the beam size. Data was, however, only extracted for a single bunch. Beam size measurements were conducted utilizing the B320B diagnostic beamline [14]. The beamline utilizes the obstacle diffraction method [15] and has been optimized to measure the small nominal beam size of the MAX IV 3 GeV storage ring. The influence from three different aspects were studied during the measurements: excitation frequency, sweep pattern and excitation amplitude, with the aim to conclude how to perform the excitation to maximize the emittance growth while maintaining negligible bunch oscillation.

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RESULTS

Excitation Frequency

Figure 1 displays normalized bunch RMS oscillation and size in both transverse planes as function of horizontal excitation frequency. It can be noted that the current setup at the diagnostic beamline has an upper limitation for when the beam size cannot be measured reliable anymore. In addition, due to the required exposure time of the CCD camera the measurement cannot distinguish between emittance growth and beam oscillation. This can, however, be analysed by correlating the measured beam size to the oscillation detected by the bunch-by-bunch feedback system. In this way, excitation frequencies of interest for PPRE operation where the emittance growth is greater than the oscillation increase can be found.

The frequency was scanned around the horizontal betatron tune. Two peaks (around 116.1 kHz and 119.5 kHz for the displayed measurement result) are visible where the size increase without corresponding peak in the oscillation, indicating the beam size growth was mainly caused by emittance growth. In addition, beam size growth occurs at the synchrotron side bands (around 116.7 kHz and 118.6 kHz), but since the beam size cannot be measured reliable in these areas it is not possible to draw any conclusions. It can, however, be noted that the horizontal excitation at these frequencies results in a small increase of the vertical beam size without equal increase of the vertical oscillation, indicating this is caused by growth of the vertical emittance.

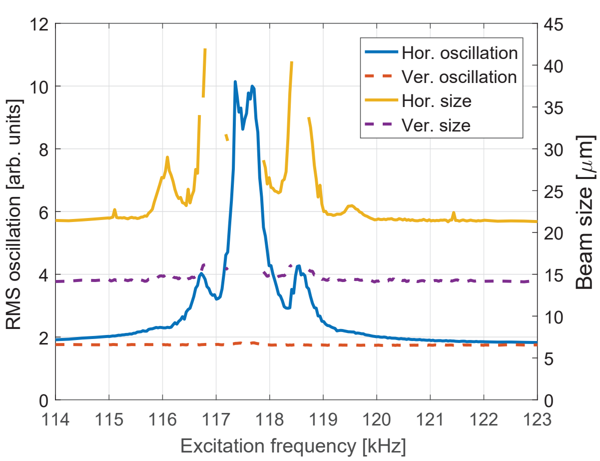

Figure 1: Bunch RMS oscillation and size as function of excitation frequency. In this measurement, the horizontal betatron tune was measured to 117.5 MHz. The measurement was conducted at an excitation amplitude of 0.1.

Sweep Pattern

The bunch-by-bunch feedback system provides the opportunity to sweep the excitation frequency for a given frequency span and period. Figure 2 displays the bunch RMS oscillation and size as function of the sweep frequency span. Furthermore, Figure 3 displays the bunch RMS oscillation and size as function of the sweep period. The effect of the sweep pattern on the measured beam sizes in these measurements were small, but small influence on the oscillations were observed. The measurement results are however not conclusive and further studies are required to evaluate the influence of the sweep pattern.

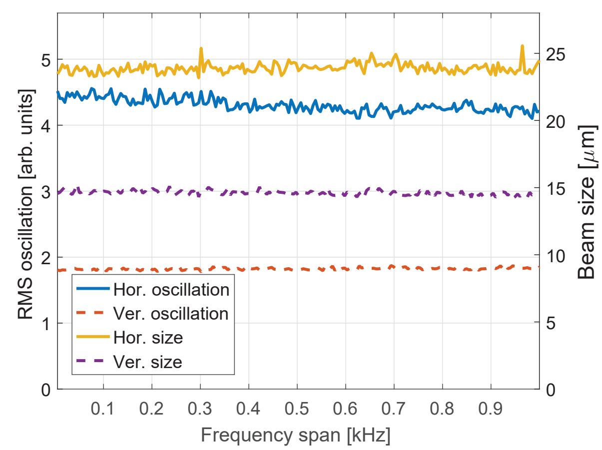

Figure 2: Bunch RMS oscillation and size as function of sweep frequency span. The measurement was conducted at a constant excitation frequency of 115.9 kHz (corresponding to the leftmost peak for this measurement), a sweep period of 100 μs and an excitation amplitude of 0.1.

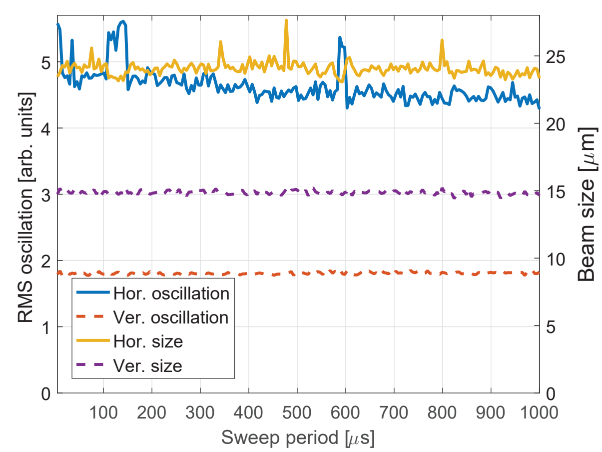

Figure 3: Bunch RMS oscillation and size as function of sweep period. The measurement was conducted at a constant excitation frequency of 115.9 kHz (corresponding to the leftmost peak for this measurement), sweep frequency span of 1 Hz and an excitation amplitude of 0.1.

Excitation Amplitude

Figure 4 displays the RMS oscillation and beam size as function of excitation amplitude. It can be noted that both the beam size and and oscillation mostly increase linearly with the excitation amplitude, but some nonlinear behavior can be observed at excitation amplitudes below 0.1.

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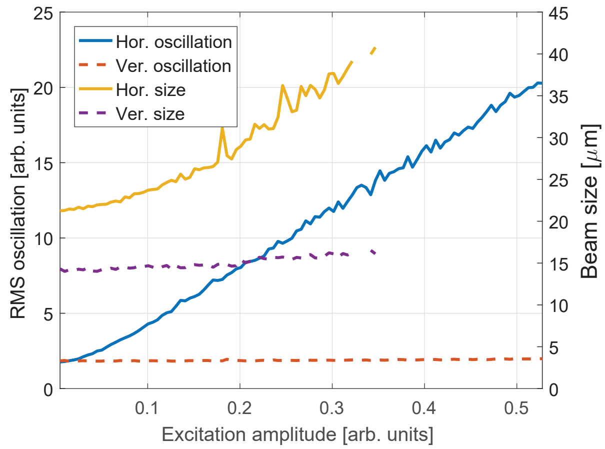

Figure 4: Bunch RMS oscillation and size as function of excitation amplitude. The measurement was conducted at a constant excitation frequency of 115.9 kHz (corresponding to the leftmost peak for this measurement) without any sweep pattern.

DISCUSSION AND FURTHER WORK

The measurements indicate the existence of excitation frequencies where the measured beam size grow mainly due to emittance growth and not beam oscillations. The emittance growth appears to be largest at excitation frequencies below the betatron tune. Is is however not possible from these measurement to drawn any conclusions on acceptable oscillation growth since the signal from the bunch-by-bunch feedback system has not been calibrated. Calibration is planned utilizing BPM readings to evaluate the possibility of PPRE operation at the synchrotron sidebands. It is possible that the oscillation induced by excitation at the sidebands is within the acceptance of the intended PPRE mode users, resulting in these being the most interesting excitation frequencies to achieve sufficiently large emittance growth.

To be able to study the ratio between beam size and oscillation increase for excitation at the synchrotron sidebands an upgrade of the diagnostics beamline is required to be able to perform reliable beam size measurements above ∼1.5 times the nominal beam size. Work is ongoing to develop a second branch at the diagnostic beamline with the ability to measure larger beam sizes.

Furthermore, simulations are planned to simulate the PPRE process and compare simulated predictions of the beam size and oscillation growth with the measurement results. In addition, simulations of the diagnostic beamline are considered to evaluate the effect of emittance growth versus increased oscillation on the measured beam sizes.

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