EMITTANCE BLOW-UP WITH A MAGNETIC SHAKER AT DIFFERENT CHROMATICITIES

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Abstract

The ESRF-EBS storage ring is operated with constant vertical emittance at 10 pm. The emittance blow-up is obtained with a magnetic shaker exciting the beam with a noise in a range of frequencies including the betatron tunes. The amplitude of the shaker is tuned by a feedback depending on the measured emittance. The coherent oscillations given to the beam by the shaker at each turn become incoherent thanks to the chromaticity and the amplitude detuning. Simulations and measurements have been performed to assess the efficiency of the emittance blow-up as a function of the chromaticities.

INTRODUCTION

At the ESRF EBS, the vertical emittance after optics and coupling correction is on the order of 1 pm, so well below the diffraction limit for most of the energies of the photons used in the beamlines [1, 2]. Increasing the vertical emittance does not reduce the brilliance of the x-rays and is beneficial for the reduction of collective effects and in particular for the Touschek effect, which causes the main lifetime limitation.

The emittance blow-up is produced by a magnetic shaker powered with a noise signal with a large range of frequencies including the vertical tune.

HARDWARE

The emittance measurement at the ESRF EBS is performed with four X-ray pinhole cameras, of which two identical ones are used for continuous emittance monitoring and for feeding the emittance feed-back loop. The X-ray source point is located within the first permanent magnet dipole of a storage ring cell, having a magnetic field of 0.625 T. The pinhole and the detector are placed in air.

The emittance blow-up is performed with a magnetic shaker. The shaker is a fast magnet used to apply an AC dipolar kick to the beam in order to excite betatron resonances. The bandwidth of the magnet is approximately 1 MHz, which is enough to excite a few of the low-frequency betatron modes. The magnet is located outside the vacuum chamber. In order to avoid the reduction of the bandwidth of the shaker due to the eddy currents, the vacuum chamber in this location is made of ceramic with a thin titanium coating. The shaker can provide both horizontal and vertical magnetic fields and can be used to increase both the vertical and the horizontal emittances.

The shaker magnet is fed by an amplifier from Amplifier research [3]. The amplifier used is the 800A3A, which can deliver up to 800 W of RF power (at the 3 dB compression point) with an input signal between 10 kHz and 3 MHz.

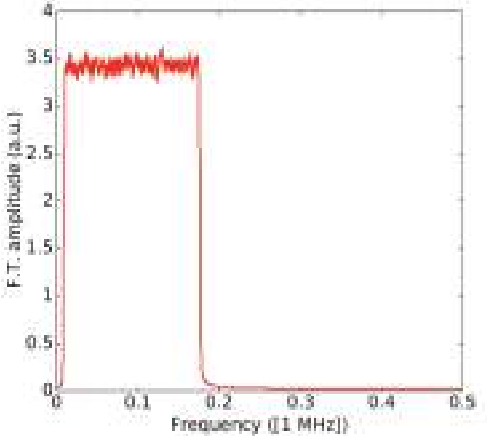

Figure 1: Spectrum of the noise sent to the shaker to perform emittance blow-up.

An arbitrary waveform generator is used to generate the noise signal which will excite betatron resonances on the beam, which will then be converted in an emittance increase after dilution of the beam in the phase-space. The waveform generator is a Keysight A33500B. It is configured to output an arbitrary waveform (with a maximum sample number of 1,000,000). The waveform generator is configured to continuously play the waveform without the need of a trigger signal to start the waveform. When the end of the waveform is reached, the waveform generator then starts again a new cycle. The repetition rate of the cycles are defined by the number of samples of the noise signal.

The signal was generated with a Python script in a Jupyter notebook by making the sum of multiple sine waves with frequencies which are multiples of 100 Hz, and random phases. The resulting signal has a spectrum shown in Fig. 1. This signal was designed to be able to excite betatron resonances in a wide band of frequencies.

SIMULATIONS

The multi-particle simulation is done with a simplified version of the EBS ring using AT [4, 5], including only a few elements: a 6x6 linear transformation, including the radiation damping, a nonlinear element with chromaticity and detuning with amplitude, an RF cavity, a quantum diffusion element and the shaker. The shaker is kept on and the particles are tracked for more than 32000 turns, which is several radiation damping times. The horizontal and vertical emittances are computed at each turn and the apparent emittances, using the particle positions of 10, 100 and 1000 turns,

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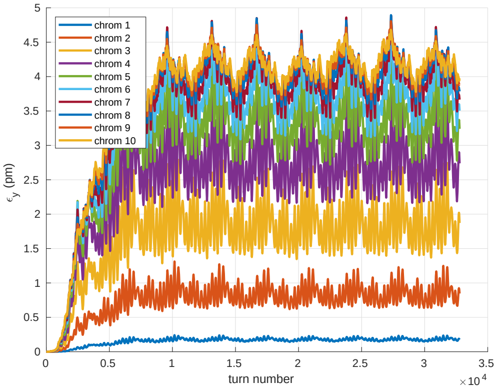

Figure 2: Vertical Beam position spectrum measured with vertical beam emittance blow-up is activated.

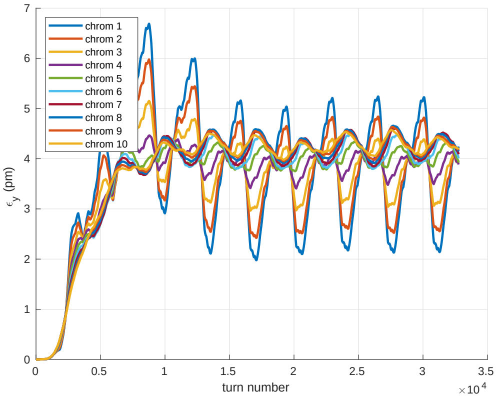

Figure 3: Vertical Beam position spectrum measured with vertical beam emittance blow-up is activated.

are also computed. Different repetition times of the noise signal have also been tested in the simulations.

In Fig. 2, the turn by turn emittance for different vertical chromaticities are shown. In Fig. 3, the emittance is computed using the coordinates of 1000 consecutive turns.

The simulation shows that at low chromaticity the emittance is not increased as much as the pinhole camera would measure integrating the signal in several hundred turns.

The residual oscillations visible, with a periodicity of about 3500 turns, are due to the repetition frequency of the noise signal sent to the shaker, which is 100 Hz in this case.

In Figs. 4 and 5, the vertical emittance for three shaker amplitudes are computed respectively turn by turn and integrated for 10 turns as a function of vertical chromaticity.

MEASUREMENTS

In order to verify the simulations of the blow-up efficiency for different chromaticities, a series of experiments has been performed at ESRF.

The emittances have been measured using the standard parameters of the pinhole camera, with an integration time of 10 ms. The apparent emittances have been measured using the BPM signal in turn by turn mode, using the beta functions at the BPM positions. Only the 128 Spark BPMs

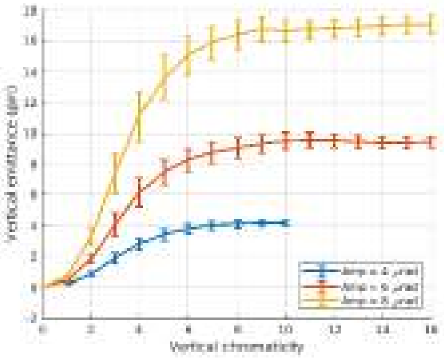

Figure 4: Vertical Beam position spectrum measured with vertical beam emittance blow-up is activated.

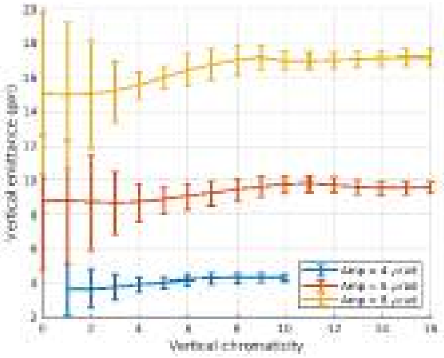

Figure 5: Vertical Beam position spectrum measured with vertical beam emittance blow-up is activated.

have been used, because they have a better spatial resolution than the Libera Brilliance [6].

The emittance blow-up feedback was set at different values: the vertical at 0, 20, 40, 60, 80, 100 and 120 pm; the horizontal at 7 different values from 130 pm to about 400 pm. The turn by turn position of the beam has been acquired 5 times for 10000 turns for each emittance value. The measurements have been repeated for different values of horizontal and vertical chromaticities: from 10, 8, 6, 4, 2 and 0.

The filling mode during the measurement was multibunch 1/3, so about 300 bunches were filled, with 10 mA total current.

In Figs. 6 and 7, the apparent emittance measured with the 128 Spark BPMs at the ESRF has been plotted as a function of the emittance measured with the pinhole camera, respectively in horizontal and in vertical.

In Figs. 8 and 9, the fraction of the emittance measured with the pinhole camera that is coming from the center of mass coherent oscillations is shown for different chromaticities, respectively for the horizontal and vertical planes.

Even with no excitation, the measured apparent emittance from the BPMs is in the order of a few pm, coming completely from the noise of the BPM signals. This puts a limit to the precision of the measurements.

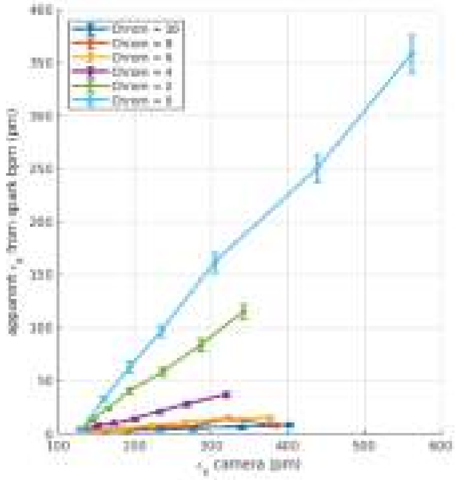

Figure 6: Horizontal apparent emittance measured with the 128 Spark BPMs at the ESRF as a function of the emittance measured with the pinhole camera.

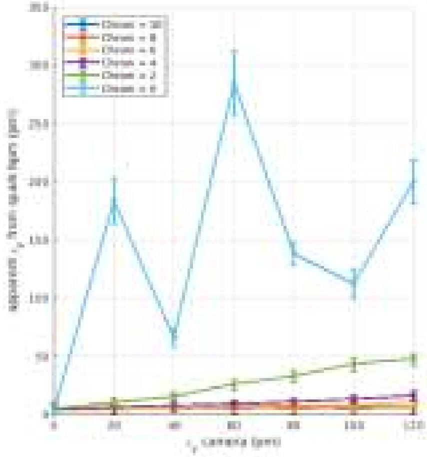

Figure 7: Vertical apparent emittance measured with the 128 Spark BPMs at the ESRF as a function of the emittance measured with the pinhole camera.

The measurements performed on the machine confirm that if the chromaticity of the ring is low the shaker would produce less emittance blow-up than what the pinhole camera would measure.

CONCLUSION

The measurements performed at the EBS storage ring confirmed the results of the simulations. When the chromaticity is above 6, the emittance measured with the pinhole camera is accurate and the error is less than 10 %. With chromaticity equal 4, the vertical apparent emittance measured with the BPMs is on the order of 30 % of the one measured with the pinhole camera at 20 pm and about 15 % at 60 pm. The operational chromaticity at the ESRF storage ring is 9 in both planes and so the emittance blow-up is efficient.

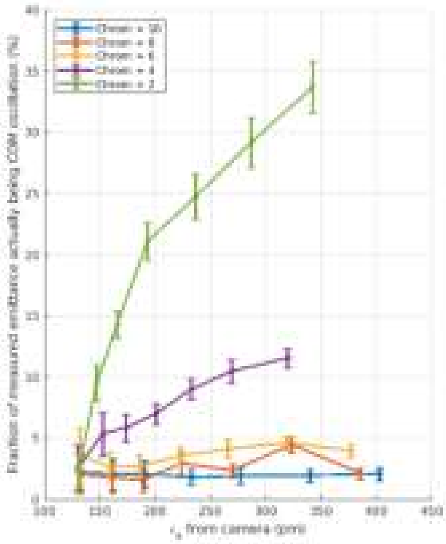

Figure 8: Fraction of the horizontal emittance measured with the pinhole camera that is coming from the center of mass coherent oscillations.

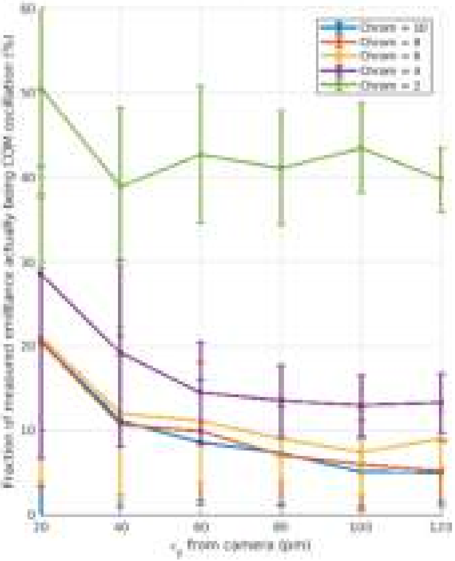

Figure 9: Fraction of the vertical emittance measured with the pinhole camera that is coming from the center of mass coherent oscillations.

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