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A Method of Local Impedance Measurement by Sine-wave Beam Excitation

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Abstract

We have developed and tested a technique, which significantly improves the accuracy of the orbit bump method of local impedance measurement. This technique is based on in-phase sine-wave (AC) excitation of four fast correctors adjacent to the vacuum chamber section, impedance of which is measured. The narrow-band sine-wave signals provide better signal-to-noise ratio. Use of fast correctors to the beam excitation eliminates the systematic error caused by hysteresis. The systematic error caused by orbit drift is also supressed because the measured signal is not affected by the orbit motion outside the excitation frequency range. The measurement technique is described and the result of experimental testing carried out at NSLS-II is presented.

Introduction

The beam intensity in storage rings is limited by collective effects of beam dynamics resulting from the interaction of a particle beam with electromagnetic fields induced in a vacuum chamber by the beam itself.

The impedance distribution along the ring is not uniform and beam-based measurement of local impedance is a subject of importance for accelerator physics.

How to measure local impedance?

The interaction of a bunched beam with the transverse broadband impedance is characterized by the kick factor:

$$k_\perp = \frac{1}{2\pi}\int_{-\infty}^{\infty} Z_\perp(\omega) h(\omega) d\omega$$

where $Z_\perp(\omega)$ is the frequency-dependent transverse impedance; h is the bunch power spectrum.

A transverse dipole kick $\Delta x'$ caused by the beam-impedance interaction is

$$\Delta x' = \frac{q}{E/e} k_\perp x_0$$

where q is the beam charge, x is the beam transverse offset, E is the beam energy, e is the electron charge.

A local transverse impedance acts on the beam as a defocusing quadrupole, strength of which depends on the beam intensity.

The orbit bump method [1, 2] is based on the measurement of a wave-like orbit distortion created by the wakefield kick $\Delta x'$ proportional to the beam charge and its transverse position at the impedance location. If a local orbit bump is created at the impedance location, the intensity-dependent orbit distortion is:

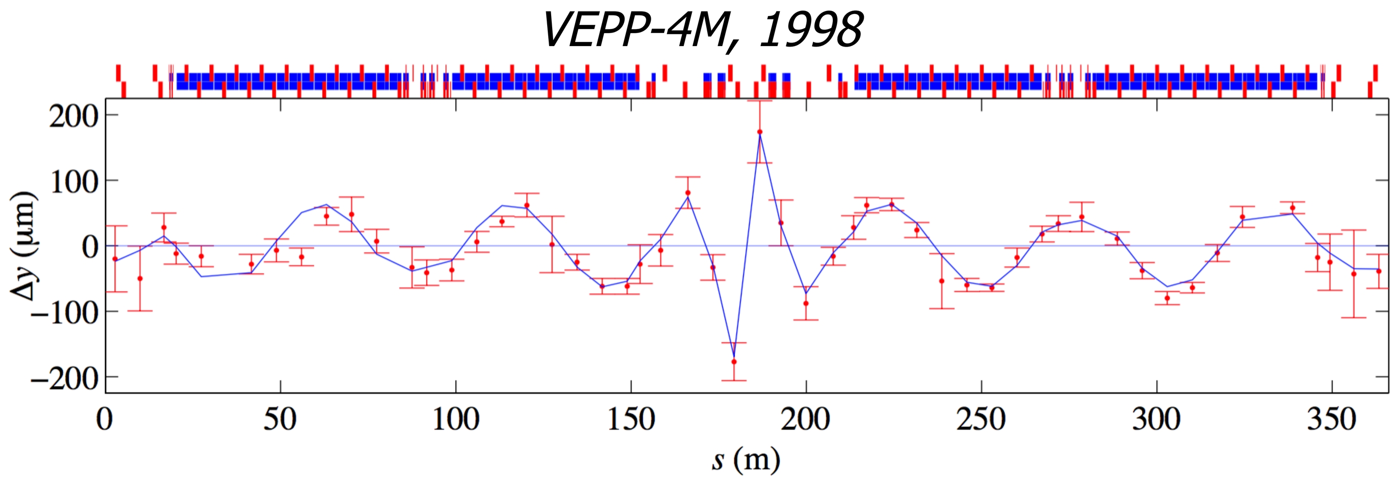
$$\Delta x(s) = \frac{\Delta q}{E/e} k_\perp(s_0) x(s_0) \frac{\sqrt{\beta(s_0)\beta(s)}}{2\sin\pi\nu_\beta}\cos\left(|\mu(s)-\mu(s_0)| - \pi\nu_\beta\right)$$

where s_0 is the impedance location, $x(s_0)$ is the orbit bump height, ν_β is the betatron tune, β is the beta function, μ is the betatron phase advance.

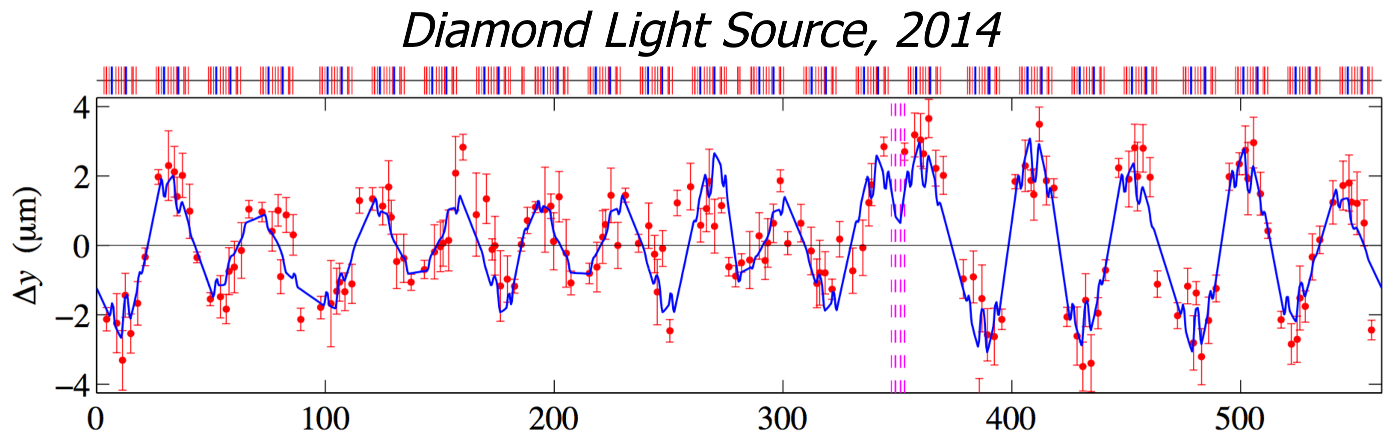
The orbit bump method is more sensitive than the method [3] based on the measurement of intensity-dependent betatron phase because the beam position monitors (BPMs) are used in the narrowband orbit mode rather than in the broadband turn-by-turn mode and the noise is much smaller.

Evolution of BPM electronics resulted in great improvement of the bump method accuracy from 20−40 μm at the very beginning of the method development [1] to 0.2−0.5 μm in resent measurements [4].

VEPP-4M, 1998



Diamond Light Source, 2014

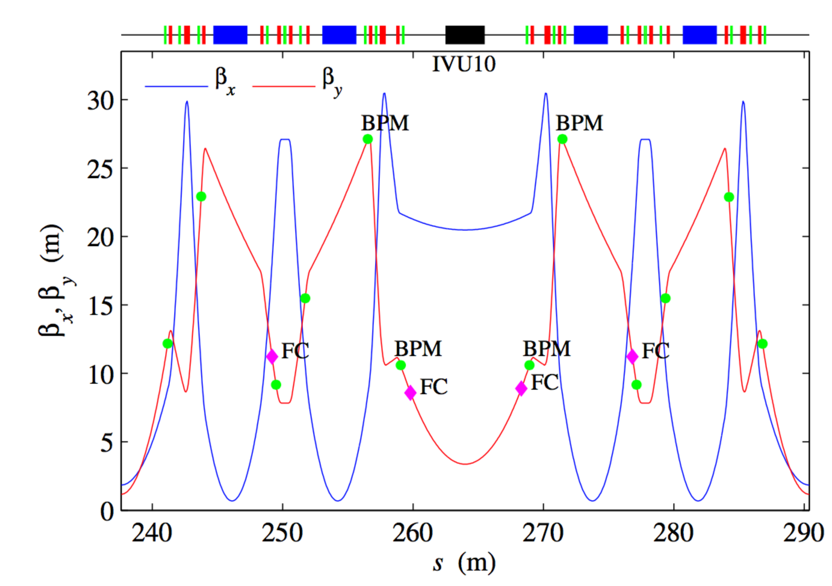


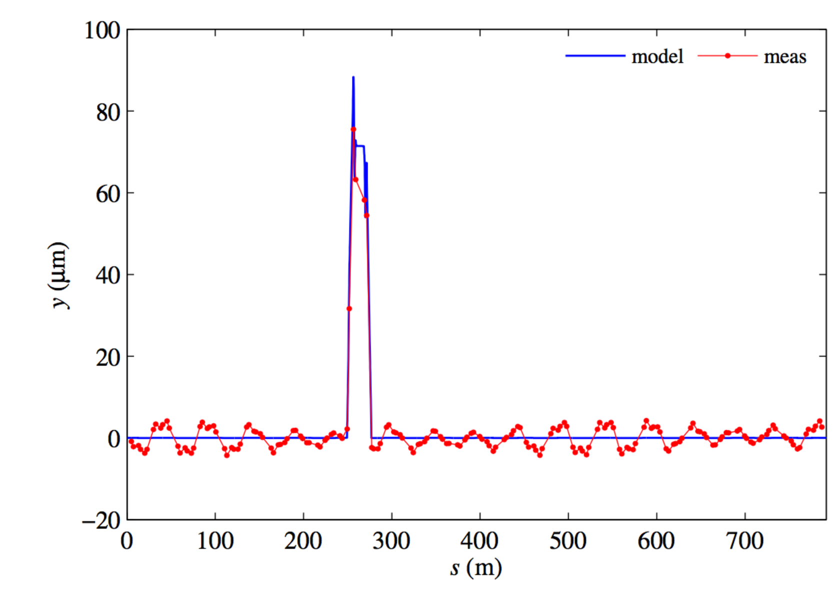
Further improvement looks problematic because of the systematic errors caused by hysteresis effects of correctors and by the orbit drifts along the measurement.

Description of the method

To improve the bump method accuracy, we propose a technique based on excitation of an AC orbit bump by use of fast orbit correctors [5]. The fast correctors are working in a bandwidth up to hundreds Hertz and they are typically installed at synchrotron light sources for fast orbit feedbacks. Recent developments of lattice correction techniques using an orbit response matrix measured by sine-wave excitation of fast correctors show that the AC orbit can be measured with a precision of the order of 0.02 μm [6, 7].

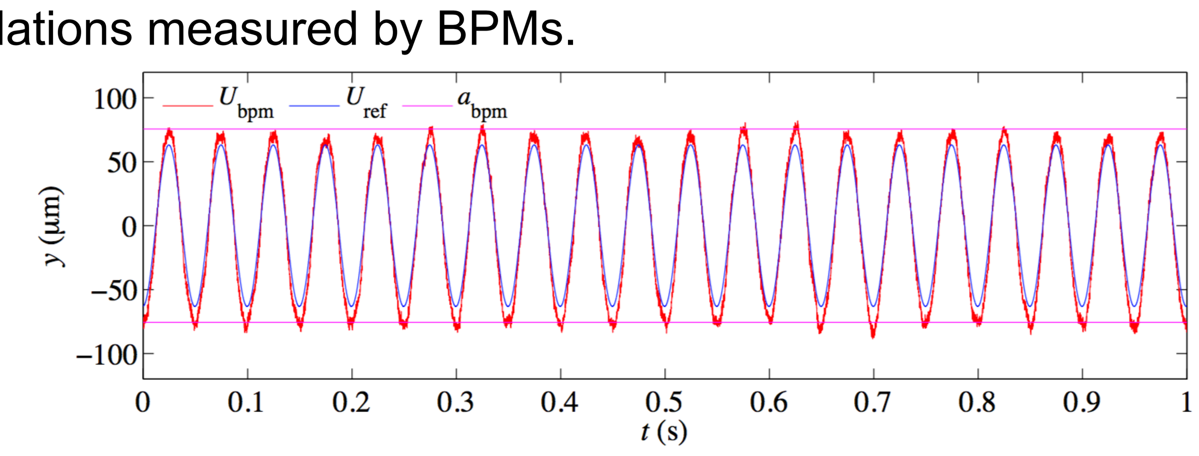
To create the AC orbit bump, four fast correctors are excited simultaneously by a sine-wave driving signal. Proper excitation amplitudes for the correctors are obtained by scaling the driving signal with the factors pre-calculated using the model lattice. If the bump is perfectly matched, the beam oscillates between the outer two correctors and the orbit outside the bump is not perturbed.





To measure the kick factor of a vacuum chamber section, the AC bump is created in that section and the orbit oscillation is measured by all BPMs as a function of the beam charge variation Δq. The intensity-dependent orbit distortion $\Delta x(s)$ at the location of each BPM is a difference of the oscillation amplitudes measured by the BPM.

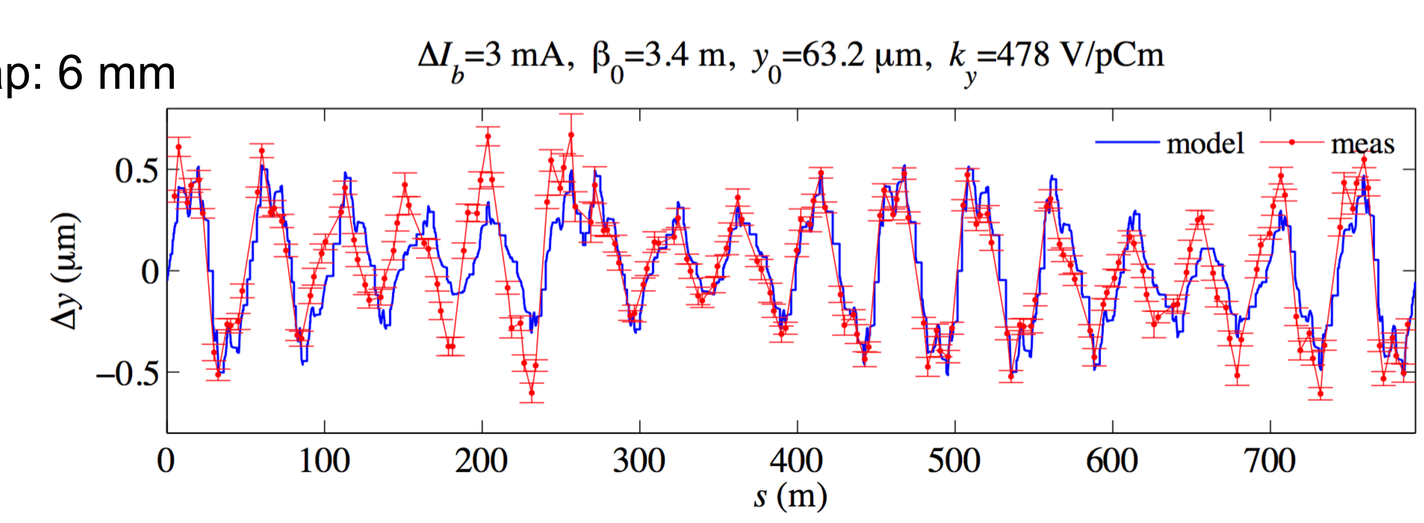
The same driving signal is used as a reference for synchronous detection of the beam oscillations measured by BPMs.



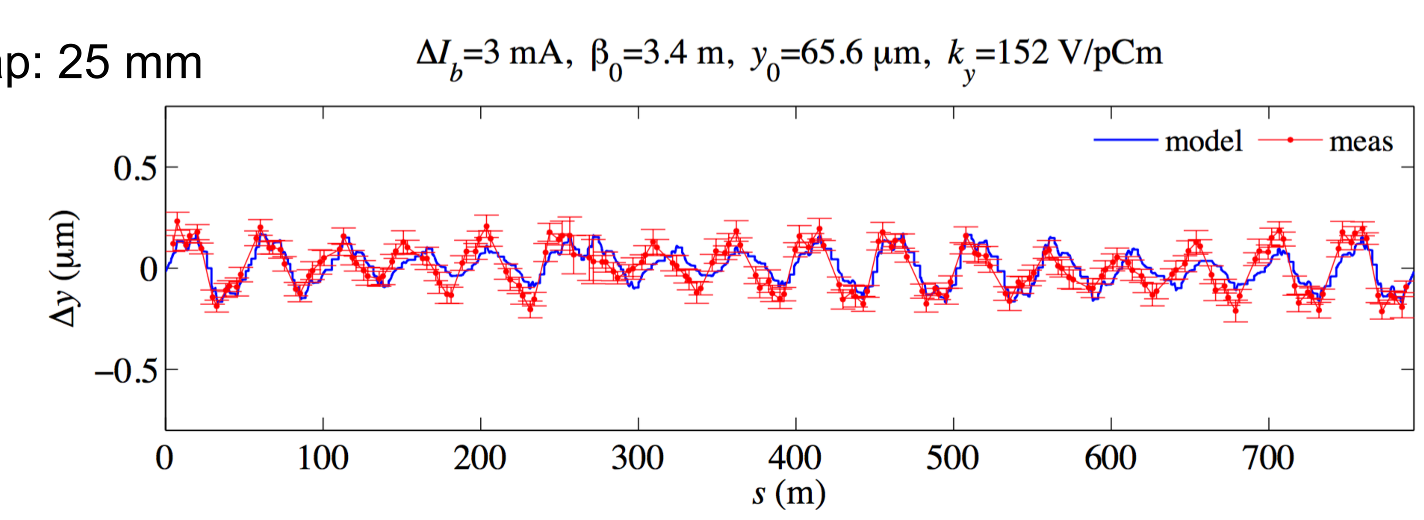
Experimental results

The proposed technique has been tested at NSLS-II. The vertical kick factor of a variable-gap in-vacuum undulator has been measured in two cases: closed gap of 6 mm (maximal impedance) and open gap of 25 mm (minimal impedance).

gap: 6 mm



gap: 25 mm



The results of this experiment have demonstrated that the measurement resolution is good enough to measure the orbit distortion of the order of 0.1 μm, which is an order of magnitude smaller than the sensitivity of the conventional bump method.

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