KICKER BASED TUNE MEASUREMENT FOR DELTA

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Abstract

We have set up a tune measurement for the electron storage ring Delta based on broadband beam excitation with a kicker magnet and measurement of the relaxation betatron oscillations turn-by-turn. By averaging over several kicks the kick amplitude may be as low as 1 μrad in standard user runs, leading to negligible beam distortion. Signal to noise ratios in excess of 10 are reliably achieved down to 200 μA beam current using a maximum kicker amplitude of 30 μrad. The measurement can be repeated 10 times per second. The precision of the frequency estimate is as low as 10^{-5}. A simple tune feedback algorithm based on this measurement compensates for tune shifts due to vacuum chamber movement and orbit movement in sextupoles.

INTRODUCTION

A precise, reliable and fast measurement of the tune is an essential prerequisite for the stable operation of a storage ring. Fast tune measurements in an electron machine require an excitation of the beam prior to the tune detection. After exciting the beam the tune is inferred from side bands of the revolution harmonics in the spectrum of a difference signal of two adjacent beam pickups.

The most simple beam excitation would be a broadband constant beam shaker excitation with white noise covering the whole spectrum up to half the revolution frequency. All frequencies in the desired bandwidth are excited with equal strength and at all times. Betatron resonances can be seen immediately as peaks in the frequency spectrum.

The total perturbation applied to the beam by the excitation shaker, though, is inacceptable for synchrotron light users. It can be lowered either by constraining the bandwidth of the beam excitation around a center frequency and scanning this frequency over the desired bandwidth (frequency scan method) or by constraining the time, the broadband excitation signal is applied to the beam (kicker excitation method).

Although DELTA is equipped with a frequency scan method tune measurement [1] which is an excellent tool for peak evaluation done by the human eye, we have tried for quite a while to implement an automated tune stabilization mechanism based on this measurement without great success. Mainly the sudden appearance of noise signals kept us from providing a reliable enough automated measurement for tune stabilization [2].

The advent of fully digital off-the-shelf turn-by-turn (TBT) beam position monitor electronics [3] allow an increase in precision and a decrease in measurement time compared to the frequency scan method setup.

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EXPERIMENTAL SETUP

The experimental setup for the kick-method (see fig. 1) is relatively simple compared to the frequency scan setup while the cost is comparable. Although not at an optimal

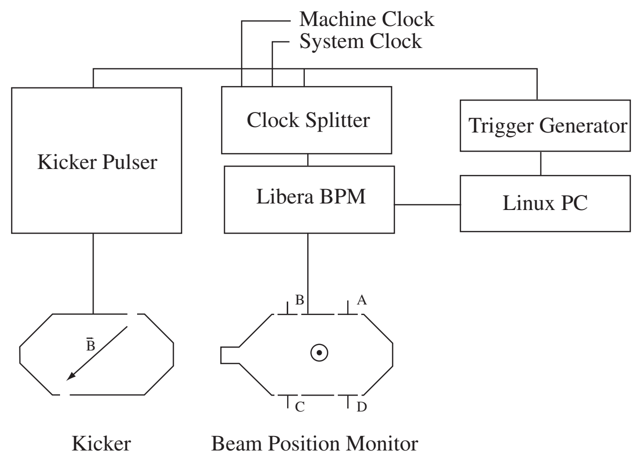

Figure 1: Setup overview.

ninety degrees, the phase advance between the kicker magnet and the chosen BPM is such that a moderate kick in the diagonal plane generates well measurable betatron oscillation amplitudes at the BPM position in the horizontal and the vertical plane. The measured amplitudes may still be increased by at least a factor of two by choosing a better suited BPM head which is currently not equipped with a Libera monitor. A large beta function at the BPM enhances the measurement of the betatron oscillation. Due to dephasing the collective beam oscillations are damped after about 1000 turns to less than one half of their original amplitude.

The maximum measurement repetition rate is limited to about 12 to 15 s^{-1} by the processor load of the Libera device. We do not exceed 10 s^{-1} which generates a load of about 55 %.

Beam excitation kicker

The kick is applied to the beam by the DELTA diagnostic kicker magnet [4]. The kicker magnet is driven by a typical halfwave pulser (see fig. 2), employing an IXYS Power MOSFET as the switch. A charging voltage U_{ch} of 300 V results in a peak current of 100 A, measured with a current transformer CT. A trigger pulse of 1.2 μs generates a FWHM pulse width of 250 ns which is determined by the cable/kicker impedance together with the capacitor C_2. Following MAFIA simulations [4] 100 A pulse current generate a kick of 30 μrad at the full beam energy of 1485 MeV in the horizontal as well as in the vertical plane. The pulse repetition rate of the kicker is limited by the charging resistor R_{ch} to about 100 Hz.

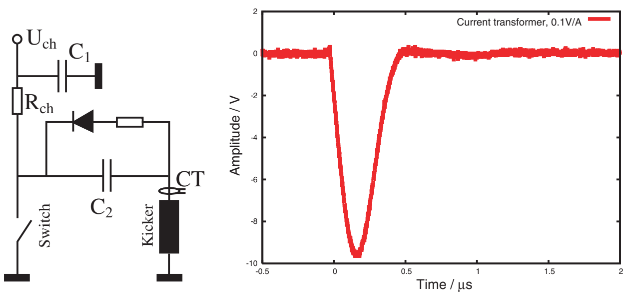

Figure 2: Schematic view of a typical half-wave pulser and pulse trace measured with a current transformer CT. As the switch we use an IXYS Power MOSFET.

Libera beam position monitor

An I-Tech Libera beam position monitor provides the turn-by-turn measurement data of the beam orbit. Currently we use firmware version 1.21 on the Liberas with the DIAMOND EPICS driver [5] version 0.63. This version of the firmware does not allow to switch off the Digital Signal Conditioning (DSC) without having large orbit jumps. DSC generates noise on the turn-by-turn data which renders the measurement unusable for tune measurement. Therefore, this Libera is for now not used for slow orbit detection and is dedicated solely to tune measurement. Subsequent versions of the firmware will allow to switch off DSC without orbit jumps [3] and thus the BPM will in the future be used for slow orbit correction in parallel to tune measurement.

Unfortunately, the Libera internal automatic gain switching (AGC) is not supported by the DIAMOND EPICS driver. AGC is thus done with a set of two EPICS records. An improved version of the Libera internal AGC is planned to be used with future firmware versions. Triggering the Libera with 10 Hz with the 'Free Run' option of the EPICS driver switched ON leads to a processor load of abut 55 %. Trigger rates in excess of 10 Hz are possible but are currently not used. The driver puts 2048 TBT points, starting at the trigger event, into a waveform record. This record is then further processed by an EPICS client application on a Linux PC.

Peak detection and evaluation

Peak detection and evaluation is done in several stages with a multithreaded algorithm on a PC.

At first, 1024 points of the TBT data starting at the trigger event are fourier transformed using the FFTW software package [6]. From the resulting spectrum, connected areas with amplitudes in excess of the average plus 5 sigma are considered a peak. Peaks are added to a list containing their amplitude and frequency. Under normal circumstances, the list contains 1-2 elements after searching the whole spectrum. Due to coupling the vertical betatron frequency is, with low amplitude, visibel in the horizontal plane and vice versa, even at some distance from the coupling resonance. At low beam current the list may contain additional noise peaks.

The identification of the proper peak, especially at low beam current, is based on several criteria that contribute with different weights to the final choice. Peak height is the most important criteria, while being in a region of in-

(a)

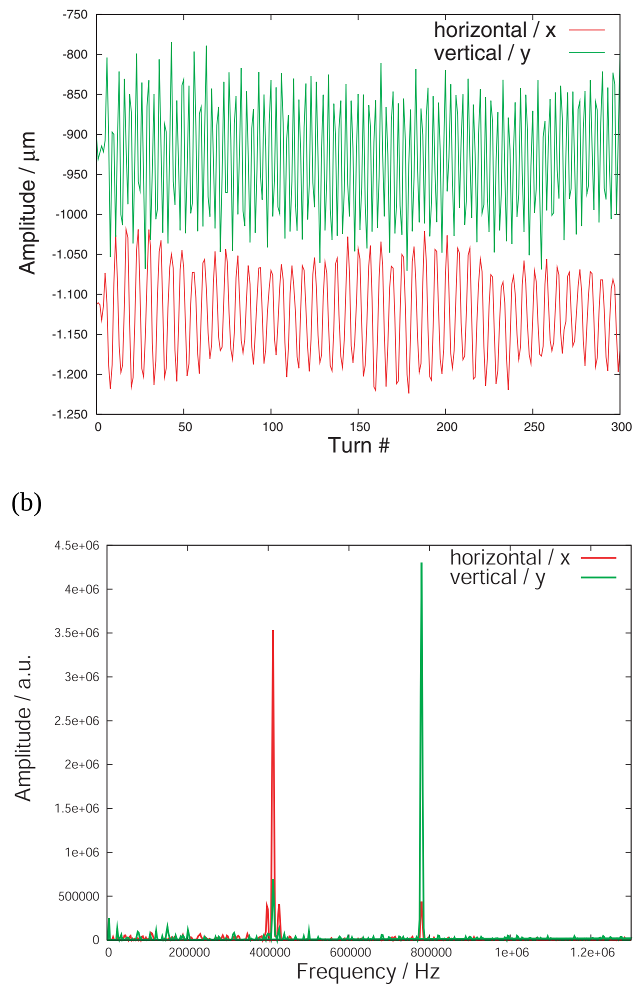

Figure 3: (a) Beam response in the horizontal (red) and vertical (green) plane measured after applying a kick of 30μrad to a beam of 80 mA beam current.

(b) FFT-Spectrum of 1024 data points. The modulation in fig. (a) of the horizontal signal and the sidelobes on the spectrum in fig. (b) are due to an uncorrected horizontal chromaticity.

terest and the distance from the former 'good' peak is also considered.

The most helpful strategy with noisy power spectra is the employment of previous knowledge. Based on the fact that, due to dephasing, the betatron amplitude decays within 1000 turns, we generate two power spectra each from 1024 data points, one starting at turn 0 the other starting at turn 1024. By substracting the two spectra point by point, noise peaks with constant amplitude cancel out while damped oscillations are enhanced.

The precision of the FFT method is limited to plus or minus half a spectrum bin, which is in our case ± 2.5 kHz or $2 \cdot 10^{-3}$. A signal to noise ratio (SNR) between 10 and 15 is easily achieved on a per kick basis down to a beam current of 4 mA. Further reduction of the beam current requires several kicks for a successful measurement. Since the phase of the betatron amplitude between kicks is constant, the turn by turn data points of consequent kicks can be added to increase the SNR. Applying this method, tunes can reliably measured down to a beam current of 0.2 mA. On the other hand this method can also be applied at high currents during user runs in order to further decrease the beam perturbation. Averaging over a maximum of 20 kicks at 120 mA beam current allows to decrease the kick amplitude down to 1 μrad or 10V charging voltage respectively.

An experiment with the X-ray absorption beamline BL8 at DELTA has been carried out in order to check for beam distortion. The temporal resolution was determined by the ion chambers filter rise times to between 3 and 10 ms. The spatial resolution was set by the entrance slit of the beamline to about 15 % of the FWHM of the vertical photon beam size. At maximum kick amplitude beam distortion was clearly seen on the ion chamber signal. Lowering the kick amplitude led to a decrease in the distortion amplitude to negligible level. Filter settings for typical beamline operation average out beam distortion with this repetition frequency anyway.

Once the FFT evaluation is done, the data, frequency and amplitude of the tune peak is fed into a thread which fits a sinewave to the measurement data using a Marquardt-Levenberg algorithm implemented by the free software package LEVMAR [7]. While the precision of a frequency measurement using a fourier transform increases linearly with the number of data points, the precision of the ML algorithm increases proportional to it's fourth power. Using amplitude, frequency and phase as the fit parameters and fitting to noisy data with side frequency peaks this precision however can not be reached. Nevertheless, an increase in precision of two orders of magnitude to better than $2 \cdot 10^{-5}$ is routinely achieved fitting to 512 data points. Even though the starting points of frequency and amplitude for the fit are known to better than 1 %, runs with test data have shown that the best strategy for archieving a good fit is to run the algorithm with a set of three phases between 0 and π and three frequencies in the middle and at the edges of the power spectrum bin. After running those 9 fits in a row the parameter set providing the least quadratic deviation from the data points is taken as the result.

CONCLUSION

We have set up a tune measurement based on the kick method which is more reliable, more than twice as fast and has a two orders of magnitude higher precision than the previously applied frequency scan method. Based on this setup a PID based tune feedback algorithm is implemented that helps beam operators in setting up the machine during machine startups. The high precision achieved allows to set up an online-chromaticity measurement based on a frequency modulation of the main oscillator with very low amplitude.

For the last six months this method is regularly applied as the standard tune measurement method at the Delta storage ring. We have tested it at 1485 MeV and at 550 MeV beam energy, with multibunch filling patterns as well as in single bunch operation. A further increase in reliability may be done using a BPM position more optimized for phase advances and betafunctions.

ACKNOWLEDGEMENTS

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