BEAM MOTION MONITOR

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Abstract

The Beam Motion Monitor (BMM), developed at HZB, permits the permanent measurement of the betatron tunes at the BESSY storage ring without exciting the beam. The accurate tune determination is essential for the stable operation and performance optimization of storage rings. With this system it is possible to detect the transverse beam oscillations of less than 1 nm [rms]. The large dynamic range of more than 120 dB for observing the beam motion, the fast update rates (10 Hz) of the full spectrum (DC to $f_{rev}/2$) allow to use this system for beam dynamics studies and for detecting beam instabilities.

The high sensitivity of the BMM is achieved by carefully balancing the signals of opposite positioned stripline electrodes which are fed into hybrid-combiners. In the difference signal the common mode created by the bunch charge and DC-position offsets is suppressed. The major advantage of the BMM is its operation without switching and adjusting for different currents and fill patterns in the storage ring. All components for this system are available on the market.

INTRODUCTION

The BESSY electron storage ring is a third-generation light source operating at an energy of 1.7 GeV with a stored current up to 300 mA. In the storage ring, electrons might be stored in any pattern consisting of up to 400 bunches (Fig. 1).

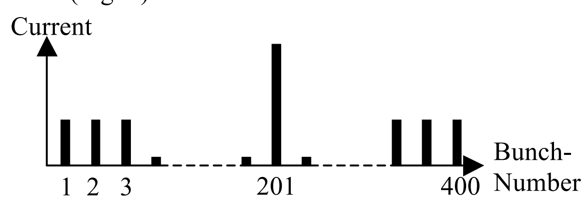

Figure 1: Typical fill-pattern in the BESSY storage ring.

The machine is operated for the users in two optics modes (normal and low alpha). In the low alpha mode the tune frequencies are different from the tunes in the normal optics. The different fill patterns and optics modes allow our users to get the requested synchrotron light at the beamlines. The monitoring of current, fill pattern [1] and tunes is essential for achieving the desired performance of the machine for these modes. In the control room the operator has access to the above data in real time.

DIAGNOSTIC TASK

With conventional diagnostics the beam circulating in the BESSY storage ring appears to be stable. Beam motion at the betatron frequencies are very small and certainly below the noise floor of our Rohde&Schwarz spectrum analyser. The tunes can only be measured by exciting the beam with a swept tracking or white noise generator. This will perturb the beam and is not allowed during the user runs. However, the permanent tune measurement is very important for performance monitoring and diagnostics of instabilities of the beam. All IDs, magnets, cavities and power supplies in the storage ring have more or less influence on the tunes. Therefore strange variations of the tune frequencies or their amplitudes may point to malfunctioning components of the storage ring. This has motivated us to look for possibilities of tune measurements without exciting the beam.

PRINCIPLE OF MEASUREMENTS

Each circulating bunch induces a short pulse at the stripline pickup in the storage ring. The strength of this signal is primarily determined by the bunch charge. The repetition rate is given by the number of bunches circulating in the ring and their temporal distance. If the circulating bunches are oscillating either horizontally or vertically around the ideal orbit then the RF signal shows a small amplitude modulation. The modulation level is very small and it is not possible to detect it easily with a direct measurement because of the strong nearby RF carrier.

The sensitivity for the detection of beam motion can be improved by using the difference signals from a set of striplines (Fig. 2). The use of hybrids and power-combiners for all 4 pickup signals allows in fact the detection of horizontal and vertical movements with much higher resolution [2].

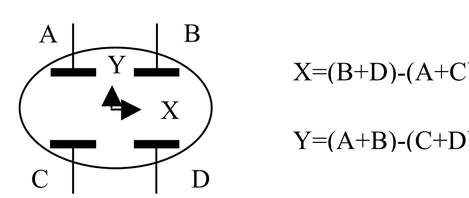

Figure 2: Sketch of a pickup sensor and combination of signals.

The problem of this method is the complex adjustment of signals in order to suppress the common mode components. Each power combiner/hybrid has its own delay and attenuation for each signal path and the straight forward combination of the signals is not good enough to detect the small amplitudes of the tune signals at BESSY.

The more effective and simpler method is to use the signals from just two stripline pickups. The difference

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signal of two diagonally arranged striplines contains information about x and y oscillations in the storage ring and it is easy to distinguish them in the spectra on the basis of their different frequencies. The careful equalizing and adjustment of the two stripline signals in relation to the stable "golden" orbit in the BESSY storage ring leads to a very high suppression of the common mode of the two signals (Fig. 3).

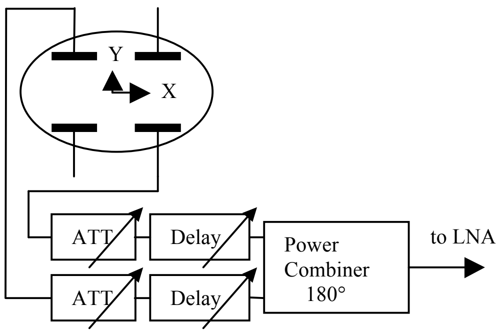

Figure 3: Voltage signals from two striplines are adjusted (in amplitude and phase) for suppression of the common mode with the power combiner.

As a consequence it is possible to amplify the resulting modulated RF signal without saturation. The filtered and amplified RF signal is mixed with the master clock (MC) of the machine down to base band up to half the revolution frequency, $f_{rev}/2$ (Fig. 4).

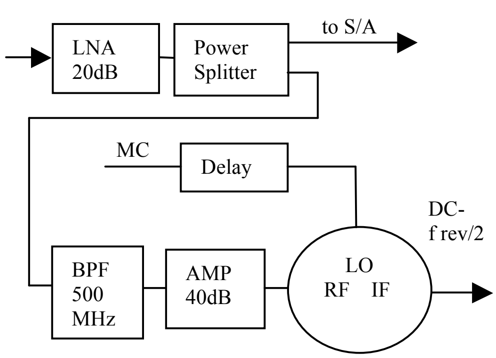

Figure 4: The filtering, amplification and down mixing of the resulting RF signal with the 500 MHz-master clock.

As shown in Fig. 5, the down mixed signal is sampled with a 20-bit ADC card. A PXI controller with LabVIEW generates a FFT spectrum from 32k data samples. In order to increase the speed of the data transfer the spectra are reduced to a 16k long 8-bit array. The program "CA_Lab" [3] is the interface between LabVIEW and EPICS which is used in our control system.

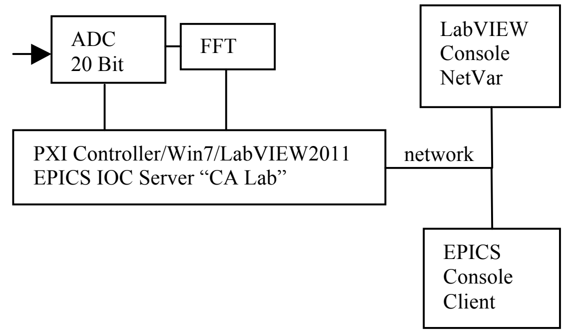

Figure 5: The PXI controller drives the ADC, creates the FFT, and prepares the spectra for data transfer via the network.

TUNE FREQUENCY AND MULTIBUNCH MODES

It is possible to measure the tunes in a very wide spectral range. The δ-function-like pulse from the short bunches as picked up by the stripline, corresponds to a fence-like spectrum with lines at multiples of the revolution frequency. In the case of M equally spaced bunches circulating in the storage ring the spectra has spectral lines, $f_{spectra}$, given by [4]:

$$f_{spectra} = n \cdot f_{RF} \pm (m \cdot f_{rev} + f_{tune})$$

where n is an integer number, f_{RF} is the bunch repetition frequency, m is the mode number (m=0, 1, …, M-1) with $m/M \cdot 2\pi$ the phase between the motion of neighbouring bunches, f_{tune} is the tune frequency, and f_{rev} is the revolution frequency in the storage ring.

The spectral range of interest can be restricted to below $f_{rev}/2$. All basic beam motions can be observed in this region. The bandwidth (BW) is given by the required sampling speed and the 32k limit of the data buffer. A better signal-to-noise ratio with an even higher sensitivity for the detection of the tune signal would be achieved by further reducing the bandwidth. The beam motion detected with our set of parameters is shown in Fig. 6.

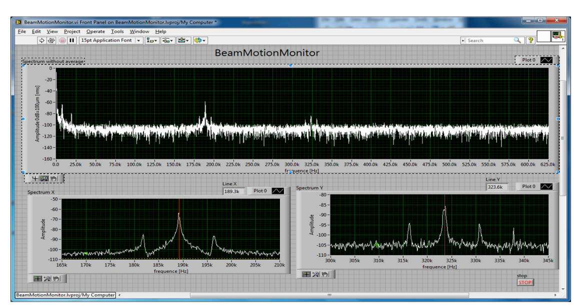

Figure 6: Top - beam motion from 0 to $f_{rev}/2$. Bottom - averaged spectra showing the betatron tunes. A sharp betatron line at the center, and two synchrotron satellites are clearly visible.

In order to observe coupled–bunch instabilities, called multi–bunch modes, the signal from the output of the splitter can be used (Fig. 4). The band up to $f_{RF}/2$=250 MHz includes all possible 400 multi-bunch modes at the

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BESSY storage ring [4]. For a rough examination of beam instabilities with modes m>0 a spectrum analyzer with a step size of 1.25MHz=f_{rev} for the centre frequency is very practical and an example is shown in Fig. 7.

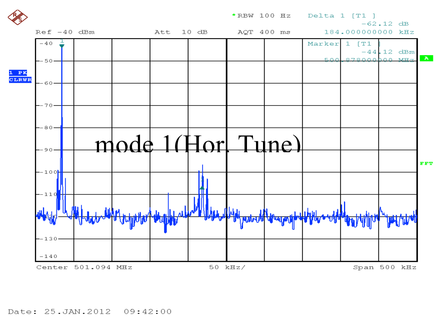

Figure 7: The horizontal tune observed at the mode m=1 with the spectrum analyzer.

An alternative method would be to increase the band width of the FFT spectrum by a higher sampling rate of the ADC at the cost of amplitude resolution. From our experience at the BESSY storage ring, the monitoring of two modes of beam motion is a good compromise between accurate tune determination and the observation of beam instabilities (Fig. 8, 9).

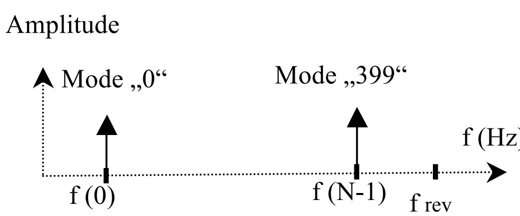

Figure 8: The two neighbouring multi bunch modes for tune measurements and the detection of beam instabilities in a spectral band from 0 to f_{rev}.

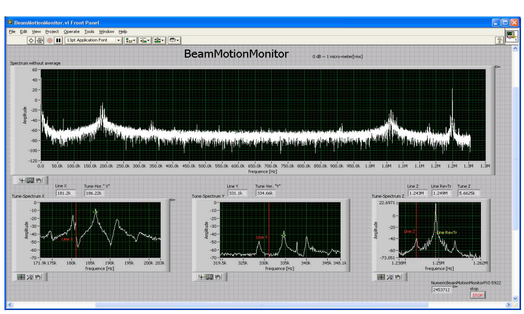

Figure 9: Top - the m=0 and the m=399 as seen by the BMM. Bottom - averaged spectra of the two transverse and the longitudinal tunes as delivered by the BMM.

CALIBRATION OF BMM

The calibration of this system down to fractions of a µm is done in the following way. We use the signal from one stripline pickup in order to determine the amplitude of the beam motion. Because the tune signal in this case is too small an external excitation of the beam with white noise is needed. For example, the 1 µm oscillation of the beam is equal to a carrier-to-sideband ratio of about -86 dB, between the amplitude of the carrier at f_{RF} =499.665MHz and the amplitude of the sideband, the tune line at $f_{RF} \pm f_{tune}$. The FFT spectra of the BMM are measured simultaneously. Based on this comparison the spectra are normalized to the current in the storage ring and then scaled to 0 dB corresponding to 1 µm of beam motion.

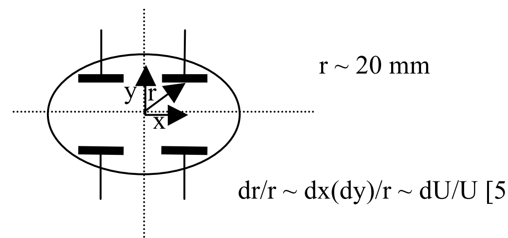

Figure 10: Calibration of BMM to µm. For -86dB (20log dU/U) is dx(dy) ~ 1 µm [rms].

SUMMARY

The betatron tune measurement based on the very sensitive beam motion monitor (BMM) is a powerful diagnostics tool and very helpful for the optimization of the overall performance of a modern synchrotron facilities. The possibility to measure the tune without exciting the beam allows a real-time monitoring of the working points without deteriorating the beam quality and supports beam studies for different physics experiments. The fast update rate of the FFT spectrum and the simultaneous averaging for noise reduction is the best combination for detecting beam motions down to smallest amplitudes and their changes. The permanent tune monitoring of the machine simplifies the work of the control room operator. The BMM opens the way for future developments of the storage ring.

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