MEASUREMENT AND CORRECTION OF THE LONGITUDINAL AND TRANSVERSAL TUNES DURING THE FAST ENERGY RAMP AT ELSA

M. Eberhardt*, F. Frommberger, A. Roth and W. Hillert
Electron Stretcher Accelerator ELSA, University of Bonn, Germany

Abstract

At the electron stretcher accelerator ELSA of Bonn University, an external beam of either unpolarized or polarized electrons is supplied to hadron physics experiments. In order to correct dynamic effects caused by eddy currents induced during the fast energy ramp, the transversal tunes have to be measured in situ with high precision. These measurements are based on the excitation of coherent betatron oscillations generated by a pulsed kicker magnet. Horizontal oscillations were excited using one of the injection kicker magnets. Since its installation in 2009 a newly designed kicker magnet enables measurements in the vertical plane as well. Betatron oscillation frequencies are derived from a fast Fourier transform of the demodulated BPM signals, showing a well pronounced peak at the tune frequency. Using this technique, tune shifts were measured and corrected successfully during the fast energy ramp.

Measurement and correction of coherent synchrotron oscillations is feasible as well, utilizing a quite similar technique. Coherent synchrotron oscillations are excited by a phase jump of the acceleration voltage using an electrical phase shifter in the reference RF signal path.

INTRODUCTION

The ELSA facility of Bonn University [1] consists of a 50 keV source of polarized electrons [2], two thermionic electron guns, two injector LINACs, a booster synchrotron and the 3.5 GeV stretcher ring delivering beam for several experiments on baryon spectroscopy (Fig. 1).

In order to supply a nearly continuous electron beam to these hadron physics experiments, multiple injections from the synchrotron are accumulated in the stretcher ring at a typical energy of 1.2 GeV, post-accelerated to the extraction energy of maximal 3.5 GeV and extracted slowly by means of resonance extraction, yielding a macroscopic duty faktor of $>70\%$. An additional external electron beamline for detector tests will become available to users in 2010.

The hadron physics program at ELSA is mainly focused on double polarization experiments utilizing tagged photons (linearly or circulary polarized) and a polarized frozen spin target [3]. In order to successfully conduct this scientific program, a high and reliable degree of electron beam polarization is required. During the fast energy ramp (typically 4 GeV/sec, maximal 7.5 GeV/sec) a sophisticated scheme for the correction of depolarizing resonances is mandatory: e.g. for compensation of depolarizing intrinsic resonances driven by vertical betatron motion the crossing speed is enhanced with the help of two pulsed betatron tune jump quadrupoles, thereby shifting the vertical betatron tune by $\Delta Q_z \approx 0.1$ [4]. Prerequisite for these techniques is an accurately stabilized vertical betatron tune during the fast energy ramp. In order to avoid significant beam loss when jumping on a betatron resonance both the horizontal and the vertical tune have to be shifted in the resonance diagram during acceleration in an appropriate way to enlarge the distance to the nearby resonances.

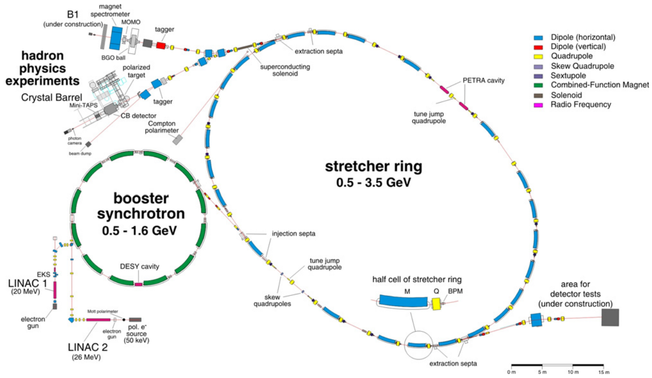

Figure 1: The ELSA facility.

TUNE MEASUREMENT AT ELSA

During the fast energy ramp eddy-currents are induced in the thin walls (0.3 mm) of the vacuum chamber built from stainless steel. These currents cause additional magnetic fields, causing shifts of the betatron tune. In order to correct for these shifts the horizontal and vertical tune have to be measured in situ on the energy ramp with high precision and short time intervals.

Excitation of coherent oscillations is necessary due to damping effects caused by decreasing coherence and synchrotron light radiation. The measurement of betatron tunes is based on an excitation of coherent betatron oscillations by pulsed kicker magnets during the fast energy ramp. Measurement of the synchrotron tune is also possible based on an excitation of coherent synchrotron oscillations by a phase jump of the acceleration voltage. Vertical, horizontal and longitudinal beam oscillations are measured

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* eberhardt@physik.uni-bonn.de

using three standard beam position monitors (BPMs) and dedicated electronics. Data acquisition of the demodulated BPM signals and spectral analysis of the measured betatron oscillations are performed by a pc system set up for fast analog-digital conversion and fast Fourier transformation. The Fourier spectrum of the acquired data shows immediately a well pronounced peak and the tune can be extracted from the position of the peak with a precision of 10^{-3}. The tune measurement system described in the following chapters is dedicated to measure the horizontal, vertical and longitudinal tune during the fast energy ramp every 20 ms. It is also used to determine the correct timing sequence of the tune jump quadrupoles when crossing intrinsic resonances.

HORIZONTAL BETATRON TUNE CORRECTIONS

Horizontal coherent betatron oscillations can be excited with one of the injection kicker magnets. The Fourier spectrum of excited coherent oscillations shows a charcteristic peak at the fractional part of the betatron frequency, from which the horizontal tune can immediatly be extracted. Using this data, it is feasible to correct the horizontal tune with a precision of 10^{-3} during the fast energy ramp. Horizontal tune shifts are measured and corrected every 20 ms routinely during accererator operation. An appropriate correction of the horizontal tune is demonstrated in Fig. 2.

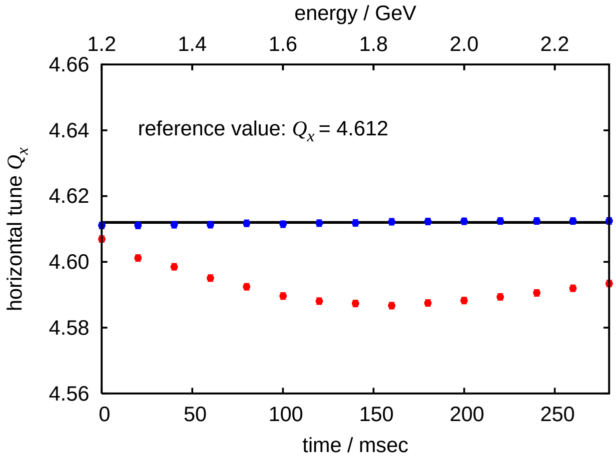

Figure 2: Compensation of horizontal tune shifts caused by dynamic effects (e.g. the generation of eddy currents) during the fast energy ramp. The blue points were measured when correcting the shifts, the lower red points were measured without correction.

VERTICAL BETATRON TUNE CORRECTIONS

A kicker magnet needed for the excitation of vertical coherent oscillations was installed at ELSA in fall 2009 (see Fig. 3). The design is adapted from a pulsed ferrite-based window frame magnet with a pulse length of approx. 500 ns and a peak current of 400 A. The kicker magnet performance characteristics given in table 1 correspond to the excitation of vertical coherent betatron oscillations with a maximum amplitude of about 5 mm at the BPM over the full energy ramp of ELSA.

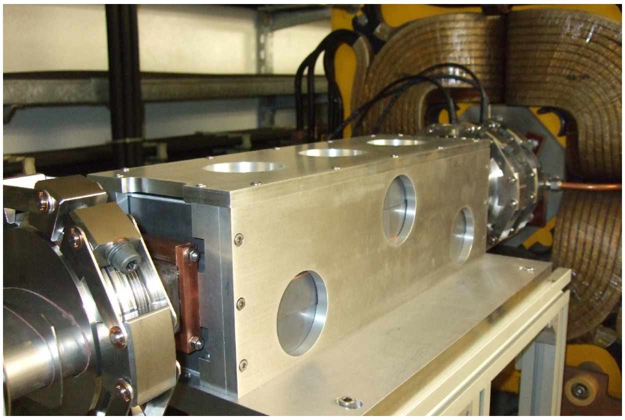

Figure 3: Picture of the newly installed kicker magnet used for excitation of vertical coherent betatron oscillations.

Table 1: kicker magnet performance charcteristics

maximum current amplitude	$I_{\text{peak}} \approx 400$ A
charging voltage	$U_C < 1800$ V @ 400 A
pulse length	$t_{\text{pulse}} \approx 500$ ns
pulse repetition rate	$t_{\text{PRR}} \leq 50$ Hz
pulse form	half sine
rise time 0% - 100%	$t_{\text{rise}} \approx 250$ ns
fall time 100% - 0%	$t_{\text{fall}} \approx 250$ ns
inductance	$L \approx 0,5$ µH
kick angle	$\alpha_{\text{kick}} \approx 350$ µrad

The vacuum chamber of this window frame magnet is made of fiberglass-reinforced plastics to avoid eddy currents induced by the pulsed magnetic field. The inner surface is coated with titanium to carry the beam induced image current. The power supply generates a pulse with a half sine shape, a rise time of approx. 250 ns and a peak current of 400 A.

This kicker magnet allows for the measurement and correction of the vertical tune in the same manner as it is performed for the horizontal tune. The vertical tune shifts are measured and corrected for routinely when operating the accelerator with polarized beam. An appropriate compensation of the vertical tune shifts is demonstrated in Fig. 4.

LONGITUDINAL SYNCHROTRON TUNE MEASUREMENT

Phase focusing in circular accelerators leads to incoherent energy oscillations of circulating electrons (synchrotron oscillations). Coherent oscillations can be excited by a

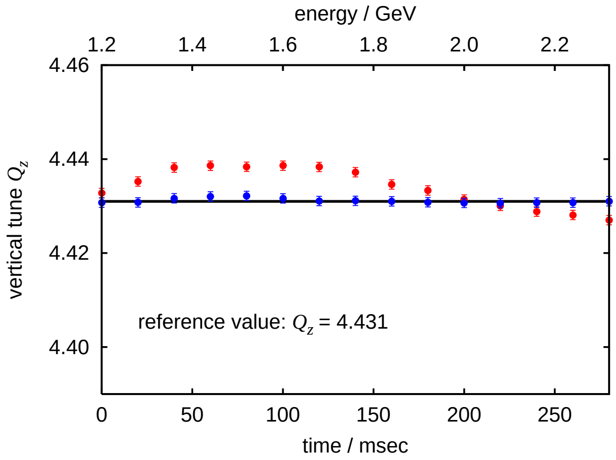

Figure 4: Compensation of vertical tune shifts caused by dynamic effects during the fast energy ramp. The blue points were measured when correctiong the shifts, the red points were measured without correction.

phase jump of the accelerating voltage applied via an electrical phase shifter in the reference RF signal path.

The synchrotron tune Q_s follows the equation

$$Q_s = \sqrt{\frac{\alpha h e}{2\pi}\frac{U_0}{E}\left(-\cos\psi_s\right)}\,, \qquad (1)$$

where α is the momentum compaction factor of the ring, h the harmonic number, U_0 the amplitude of the RF acceleration voltage, E the beam energy and ψ_s the synchronous phase with $\frac{1}{2}\pi < \psi_s < \frac{3}{2}\pi$. At constant U_0 the synchrotron tune decreases during acceleration (see Fig. 5). Adequate adjustment of the maximum acceleration voltage allows a stabilized synchrotron tune on the fast energy ramp.

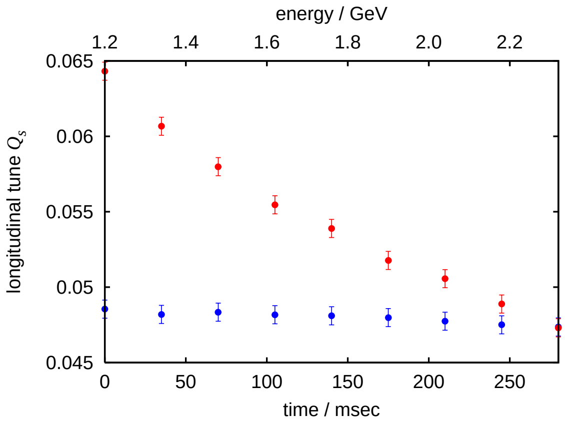

Figure 5: Synchrotron tune during the fast energy ramp. The red points were measured with constant amplitude of the RF accelerating voltage, the blue points were measured when adjusting the RF amplitude adequately.

CONCLUSION

Measurement and correction of both the horizontal and vertical tune is essential for the acceleration of a polarized electron beam. For this reason a new tune measuremant system was commissioned at ELSA. Coherent betatron oscillations can be excited with one of the injection kicker magnets and a newly designed vertical kicker magnet. Excitation of coherent longitudinal oscillations by a phase jump of the acceleration voltage is feasible as well. Data acquisition of the demodulated BPM signals and spectral analysis of the measured betatron oscillations are performed by a pc system set up for fast analog-digital conversion and fast Fourier transformation. Measurements demonstrate the successful operation of the tune measurement system. Using the measured data, an effective correction of the tunes during acceleration is possible.

ACKNOWLEDGEMENTS

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