ENERGY CALIBRATION OF THE ANKA STORAGE RING

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Abstract

The ANKA electron storage ring operates in the energy range from 0.5 to 2.5 GeV. An energy calibration using the method of resonant spin depolarisation yields the exact beam energy of ANKA. In addition this method allows to determine other parameters such as nonlinear momentum compaction factor and incoherent synchrotron tune with extraordinary precision. This paper discusses experimental set-up and energy measurements. The reproducibility of the ANKA beam energy is addressed as well as energy drifts caused by thermal expansion of the floor.

INTRODUCTION

Investigations of the ANKA storage ring optics have revealed the normalised quadrupole gradients to be systematically increased by about 1 $\%$ [1]. This could be explained if the true beam energy was about 1 $\%$ lower than its nominal value. The verification of this deviation in beam energy was the initial motivation for an energy calibration using the method of resonant spin depolarisation (RDP).

An asymmetry in the spin-flip probability due to the emission of synchrotron radiation leads to the buildup of transverse polarisation in electron storage rings which was first described by Sokolov and Ternov [2]. Initially the polarisation level increases exponentially with time with a build up time of about 10 minutes in the case of the ANKA storage ring at top energy.

The spin vector of a relativistic electron precedes in the presence of electric and magnetic fields with a frequency related to the beam energy [3, 4]. The average over all particles of the number of spin oscillation per revolution is defined as the spin tune $\nu = a\,\gamma$ with $a = (g_e - 2)/2 = 0.001159652193(10)$ [5] and $\gamma = E_{\rm beam}/m_0c^2$.

The Touschek effect can be used to detect a change in polarisation level [6, 7]. The cross-section for Touschek scattering depends on the electron beam polarisation. For a higher polarisation level, a slightly longer lifetime and therefore a smaller counting rate of a loss monitor is expected than for an unpolarised beam. A change in loss rate therefore corresponds to a change in polarisation level.

To measure the spin precession frequency a magnetic field generated by a strip line perpendicular to the bending field rotates the spins by small amounts. For a certain phase relation between the kicks of the depolariser and the spin tune the small spin rotations add up coherently from turn to turn and the polarisation is destroyed. The resonance condition for spin rotations is

$$f_{\rm dep} = (k \pm [\nu]) \cdot f_{\rm rev} \qquad (1)$$

where $f_{\rm rev}$ is the revolution frequency and k an integer. The non-integer part of the spin tune is represented by $[\nu]$. To determine the spin tune, the frequency of the depolariser field is slowly varied with time over a given frequency range. If a depolarisation occurs during such a scan, spin tune and beam energy can be determined from the corresponding frequency bin.

EXPERIMENTAL SETUP

Several different setups of detectors were used for the resonant depolarisation studies performed at ANKA. The first attempts were done with a detector consisting of two scintillators with photo multiplier tubes mounted at one end separated by lead sheets to suppress the contribution of synchrotron radiation to the counting rate [8]. The final setup consists of a single Pb-Glass block with a photo multiplier (see Fig. 1) located in a region sensitive to Touschek losses. The detector pulses are converted into NIM signals and counted with a data acquisition system using a custom made interface to the serial port of a Linux PC.

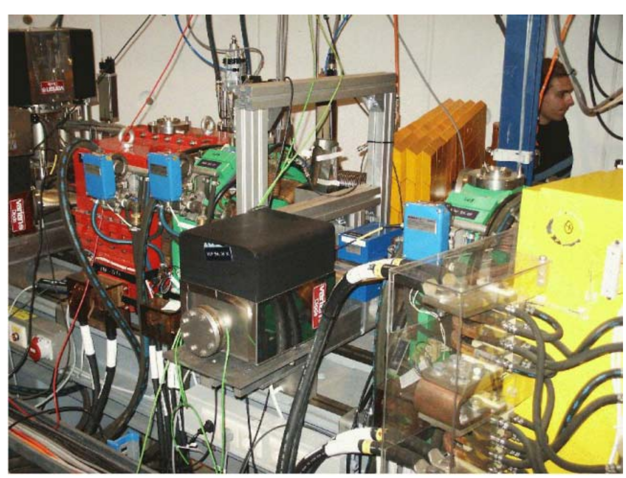

Figure 1: Picture of the Pb-Glass detector showing its location in the storage between two sextupoles (green), close to the maximum of the dispersion. The position of the detector is denoted by its aluminium frame mounting.

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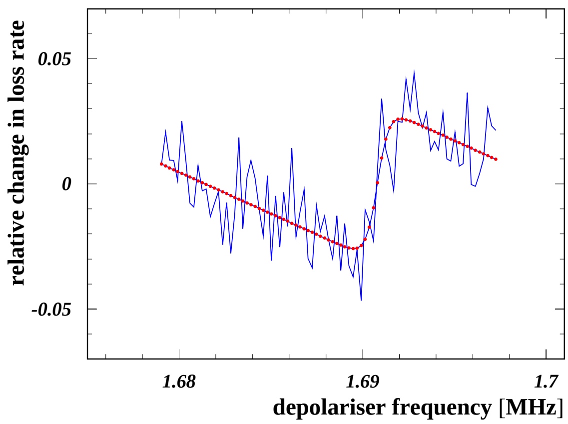

Figure 2: Relative change in loss monitor counting rate as a function of the depolariser frequency. The sudden jump in counting rate indicating the occurrence of a depolarisation is clearly visible. The measured rate is overlayed by the results of a fit (red points) according to Eq.(2).

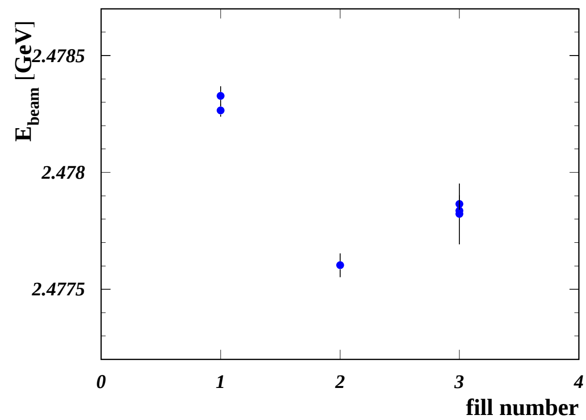

Figure 3: Results of the energy determinations at ANKA for different fills. It is clearly visible that reproducibility within fills is much better than between fills.

MEASUREMENT AND FITTING PROCEDURE

During a scan to find the depolarising resonance the frequency of the strip line's RF field is varied over a given range with a certain speed. It is important that the speed is sufficiently slow to make depolarisation - a statistical phenomenom - possible. At the same time the speed should be fast enough to minimise the effect of immediate repolarisation which will make the observation more difficult. For our experiments a speed of 6.49 MeV per 1800 s turned out to be reasonable for large range scans. For scans of a smaller energy range a speed of 2.80 MeV per 1200 s was used.

The loss rate during a depolarisation scan shows a monotonous decrease (from the decrease in beam current) overlayed by a sudden jump that marks the occurrence of (partial) depolarisation. The loss rate's behaviour can be described by the following effective relation:

$$r = a - \frac{\partial r_I}{\partial t} t + \frac{\Delta r}{1 + \exp\left\{ - \frac{t - t_d}{\sigma_d} \right\}} \tag{2}$$

where the parameters a and $\partial r_I / \partial t$ describe the monotonous decrease, Δr is the the size of the change in loss rate, σ_d the resonance width and t_d the time after beginning of the scan at which the resonance occured. Typical relative energy uncertainties determined from the width σ_d are of the order of $2 \cdot 10^{-5}$. A systematic uncertainty of the same order of magnitude comes from the determination of the starting time of the actual depolariser scan.

RESULTS

Several series of energy determinations using the method of resonant depolarisation have been done at ANKA. It could be confirmed that the beam energy is indeed about a percent lower than estimated from the dipole calibrations. The results of the various measurement are summarised in Fig. 3 for different fills (a fill denoting the time span between injection and beam dump including the ramp from 0.5 to 2.5 GeV). The fill-to-fill reproducibility is only of the order of 10^{-4}. This could be due to varying warming-up behaviour of the dipoles, which are operated close to saturation for top energy. The scatter of the energy measurements within a fill however is much smaller, of the order of 10^{-5}, and consistent with the precision of the energy determination itself. This indicates that any thermal or other drifts within fills are well understood and compensated. This is done by constantly monitoring the shift of the horizontal closed orbit (change of orbit length) which provides a measure for a change in beam energy $\Delta E/E$ since

$$\frac{\Delta E}{E} = -\frac{1}{\alpha_c}\frac{\Delta C}{C} = -\frac{1}{\alpha_c}\frac{(f_{RF} - f_{RF}^c)}{f_{RF}} \tag{3}$$

where C is the storage ring circumference, f_{RF} the frequency of the RF system, f_{RF}^c the central frequency and α_c the momentum compaction factor. A change in orbit length is immediately compensated by the an automatic closed orbit correction program by modifying the RF frequency. The same is obviously true for a real change in circumference, e.g. due to thermal expansion of the building's floor caused by outside temperature changes. To estimate the order of magnitude of these changes, the temperature on the concrete floor of the ANKA building has been monitored for over one year. The temperature measurements together with the RF frequencies adjusted by the automatic closed orbit correction to match the central frequency are displayed in Fig. 4. The summer/winter differences are easily visible as is the anti-correlation between temperature and frequency. Furthermore the aforementioned compensation for the warming-up of the dipoles after ramping by an adjustment of the RF frequency shows in the behaviour of the frequencies.

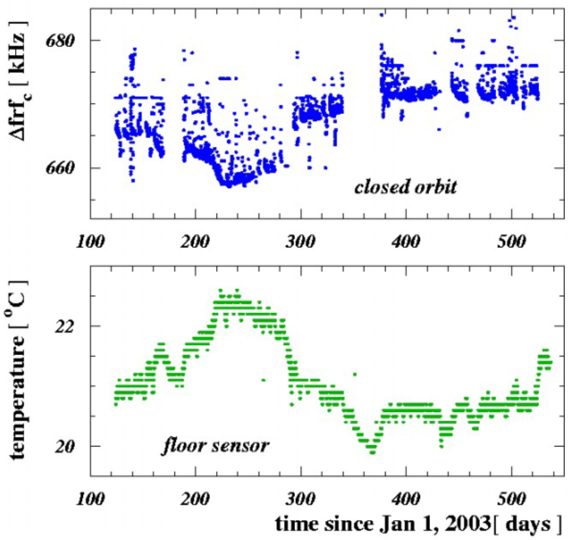

Figure 4: Upper plot: RF frequencies adjusted by the automatic closed orbit correction to match the central frequency as a function of time in days since January 2003. Lower plot: Temperature measured on the concrete floor of the ANKA building for the same period. The summer/winter differences are easily visible as is the anti-correlation between temperature and frequency.

Incoherent Synchrotron Tune

A depolarisation can occur not only at the true depolarisation resonance $f_{\rm dep}$ but also on its synchrotron side bands. Due to the single particle nature of the depolarisation process, this happens at kicker frequencies $f_{\rm dep}$ with

$$\frac{f_{\rm dep}}{f_{\rm rev}} = [\nu] \pm Q_s^{\rm inc} \qquad (4)$$

where $[\nu]$ stands for the fractional part of the spin tune, $f_{\rm rev}$ for the revolution frequency and $Q_s^{\rm inc}$ for the incoherent synchrotron tune. A simultaneous measurement of $Q_s^{\rm coh}$ therefore allows a direct assessment of the ratio of coherent and incoherent synchrotron tune that in turn allows to determine the amount of bunch lengthening with current [9]. The incoherent synchrotron tune is given by the difference of the depolariser frequency for depolarisation on the side band and the energy depolarisation frequency. Figure 5 shows the measurements of the incoherent tune as a function of the coherent tunes obtained from a beam frequency spectrum.

Momentum Compaction Factor

Using Eq.(3) it is straightforward to determine the momentum compaction factor for different RF frequencies. Details about this study can be found in [10]. The linear term of the momentum compaction factor was found to be $(7.39 \pm 0.01) \cdot 10^{-3}$. This is in reasonable agreement with the theoretical expectation of $7.2 \cdot 10^{-3}$.

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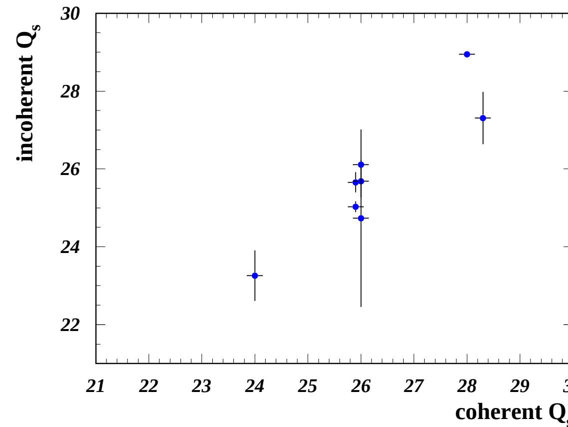

Figure 5: Incoherent synchrotron tune at a beam energy of about 2.5 GeV as a function of the coherent synchrotron tune. The incoherent tunes were determined from resonant depolarisation scans for different RF voltages, the coherent tunes were obtained from a beam frequency spectrum measured with a strip line.

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