PRECISE BEAM ENERGY CALIBRATION AT THE SLS STORAGE RING

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Beam energy calibration measurements by means of resonant spin depolarization are very precise. Knowledge of the SLS Storage Ring beam energy with a precision of $\frac{\Delta E}{E}$ = 10^{-5} can be utilized to determine the momentum compaction factor and its non-linearity [1]. In an attempt to standardize and simplify the measurement procedure the application APE was written; it has been tested and used successfully to calibrate the beam energy and determine the momentum compaction factor.

INTRODUCTION

As first mentioned by Ternov, Loskutov and Korovina in 1961 electrons gradually polarize in storage rings due to spin-flip synchrotron radiation. However, spin-flip radiation is accompanied by depolarizing effects (for example from perpendicular fields) and therefore beam polarization must be understood as an equilibrium state which is approached exponentially with a build-up time constant τ and an equilibrium polarization level P_0 [2]:

$$P_{tot}(t) = P_0 \left(1 - \exp\left(-\frac{t}{\tau}\right)\right)$$

where P_0 is a function of τ (see Fig. 1).

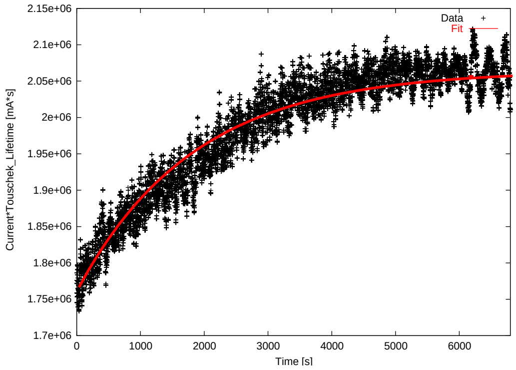

Fig. 1: Polarization build-up and fit. The fit parameter for the characteristic build-up time is 1837 s corresponding to an equilibrium polarization of 91%.

By using a filling pattern with a high single bunch current (≈1.2 mA/s) Touschek limitation of the beam lifetime was ensured [3]. Due to the polarization dependency of Touschek scattering, changes in beam lifetime can be identified with changes in the polarization level without requiring new dedicated hardware. The spin $\vec{S}$ of an electron at rest in a magnetic field precesses according to the Larmor equation. Using Lorentz transformations one can rewrite the equation of motion for highly relativistic electrons moving in the electromagnetic field of an accelerator, which, when substituted into the Larmor equation is called the Thomas-BMT Equation. The electron spin precession frequency is given by:

$$\vec{\Omega}_{sp} = \frac{e\vec{B}_\perp}{m_e c\gamma} \cdot a\gamma = \vec{\omega_0} \cdot \nu \qquad (1)$$

where a is the anomalous magnetic moment of the electron, $\vec{\omega_0} = e\vec{B}_\perp / m_e c\gamma$ the revolution frequency in the storage ring and $\nu = a\gamma$ the *spin tune* ($a\gamma$ = 5.45 in the SLS at E = 2.4 GeV). The polarization builds up with respect to the spin component $\vec{S_z}$ leading to an equilibrium polarization anti-parallel to the main bending field $\vec{B}_\perp$. If a time-varying radial magnetic field is applied in resonance with $\vec{\Omega}_{sp}$ the mean spin vector can be tilted into the horizontal plane which (in conjunction with spin diffusion) leads to zero polarization. Thus finding the resonant depolarization frequency is equivalent to finding the beam energy (Eq. 1).

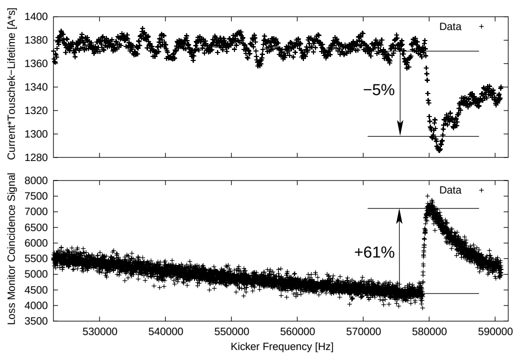

Fig. 2: The resonant depolarizing frequency is reached at 580 kHz.

In the experimental setup a sinusoidal signal is fed into a vertical kicker magnet. The frequency of this signal is swept over pre-defined intervals. As soon as the sweep frequency hits the resonant depolarizing frequency and the beam gets depolarized, the product of beam current and lifetime drops and loss monitor (a pair of scintillators installed downstream of the in-vacuum undulator U24) coincidence signals rise due to an increased number of pairs of Touschek scattered electrons (see Fig. 2).

Due to the high precision of the energy measurements the presented technique can be used to obtain the momentum compaction factor α and its non-linear component α_1.

$$-\frac{\Delta f_{rf}}{\Delta f_{rf}} = \alpha\left(\frac{\Delta E}{E}\right) + \alpha_1\left(\frac{\Delta E}{E}\right)^2$$

After changing the RF main frequency the shift in energy can be measured.

MEASUREMENT PROCEDURE

An application (APE) has been implemented in order to have a well defined measurement procedure requiring only a minimum of user interference. The Tcl/Tk code serves as a wrapper for several UNIX shell scripts. Fitting is accomplished by calls to GNUplot; the GUI was written using the BLT widget. APE not only allows data acquisition but also online data analysis in real time. Data acquisition procedures receive values like beam current, lifetime and loss monitor coincidence signals from EPICS channels within the SLS control system through a CORBA interface [4] and archive these values with a time stamp to data files. APE can visualize the acquired data in 2-D plots, show parameter read-back values, fit parameters to data (like equilibrium polarization, resonant depolarizing frequency and momentum compaction factor) and change machine parameters (like the RF main frequency or the sweep frequency). All user input to APE is done through a simple GUI running on a console in the SLS control room. APE has been tested and used successfully during machine shifts. It allows the operator to perform the energy calibration and momentum compaction factor measurements.

MEASUREMENT RESULTS

Several measurement runs have shown that high polarization levels can be reached in the SLS storage ring with tunes ν_x = 20.38, ν_y = 8.16, ν_{ST} = 5.45. After performing vertical Beam Based Alignment (BBA) [5] levels of polarization close to the theoretical maximum of 92.4% were reached (see Fig. 1).

The beam energy can be obtained from a fit using the Froissart-Stora equation for isolated resonance crossing (see Fig. 3). In early 2002 a series of energy calibration measurements was performed [1] revealing E = (2.4361$\pm$0.00018) GeV with an uncertainty of $\frac{\Delta E}{E}$ = 7$\cdot$10^{-5}. The energy calibration results were supported by independent measurements [6] of characteristic line spectra of undulator U24 revealing E = (2.44$\pm$0.02) GeV which is in excellent agreement with the presented measurements. Recent measurements however indicate that the energy has shifted to E = (2.41135$\pm$0.00002) GeV corresponding to a frequency change of $\Delta f_{RF} \approx$ 3 kHz; an explanation for this shift has not yet been found.

Measurements of the momentum compaction factor with $(\Delta f_{RF})_{max}$ = $\pm$600 Hz have revealed α = 6.3$\cdot$10^{-4}. In order to measure α_1 with sufficient precision the RF main frequency has to be shifted by larger values like $(\Delta f_{RF})_{max}$ = $\pm$2 kHz. This remains to be done. Presently the non-linear fit with α = 6.3$\cdot$10^{-4} to data is consistent with the non-linear component α_1 = 4.56$\cdot$10^{-3} determined from the machine model (see Fig. 4).

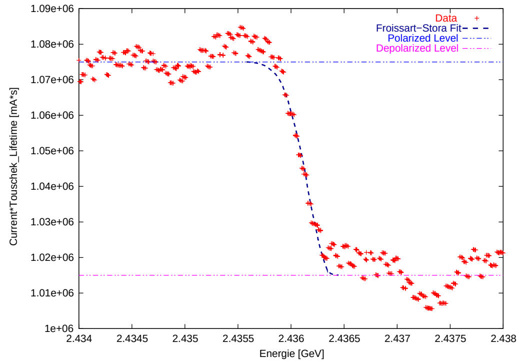

Fig. 3: Resonance with fit according to the Froissart-Stora equation for isolated resonance-crossing.

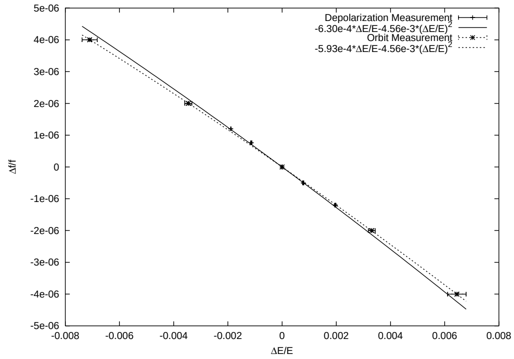

Fig. 4: Measurement of the momentum compaction factor through off energy orbits and resonant spin depolarization and corresponding fits.

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