

IMPROVEMENTS OF THE SET-UP AND PROCEDURES FOR BEAM ENERGY MEASUREMENTS AT BESSY II*

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Abstract

With a 7 T - wiggler in operation all attempts to detect the resonant depolarization of the electron spins were unsuccessful at BESSY II. This was attributed to the severely reduced degree of spin polarization of the electrons moving in the alternating fields of the strong wiggler which on the other hand nearly doubles the radiation loss per turn. The key to a clear detection of the depolarization is the improvement of the sensitivity of the polarimeter, based on the spin dependent Touschek scattering cross section and the more effective and thus full depolarization of the beam. With these improvements the high precision beam energy determination can again be performed in parallel to the normal user operation and without any noticeable perturbations to the beam.

INTRODUCTION

Even with the successful operation of the Metrology Light Source (MLS) [1] the 1.7 GeV third generation synchrotron radiation source BESSY II is still used as the European source of calculable photon flux in a wide range of photon energies by the Physikalisch Technische Bundesanstalt, PTB [2]. One of the crucial parameters in these calculations is the knowledge of the energy of the circulating electrons. Two techniques were available for the measurement of the energy, however, the Compton backscattering apparatus [3] was moved to the MLS and only the resonant spin depolarization set-up was left at BESSY. Since the last report on this system [4] additional insertion devices (IDs) were installed in the storage ring. When the 7 Tesla superconducting 19 pole wiggler went into operation, in spite of many attempts, the resonant depolarization of the spins was no longer observable. Therefore, this study was undertaken in order to investigate the problem in more detail.

There is also an interest in precise measurements of the energy at other light sources such as Soleil and Diamond. The knowledge of the energy of the beam would allow for a comparison of the actual fields of the (dipole) magnets with the field measurements before their installation. Even after careful modeling of the linear optics, very often discrepancies are found in the averaged K-values of the quadrupole magnets. These offsets could stem from an error in the assumed energy of the beam so a direct measurement of the energy would be desirable.

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EFFECT OF INSERTION DEVICES ON BEAM PARAMETERS

Most of the IDs at BESSY are based on permanent magnets with a maximum fields of usually ~1 Tesla and the impact on the spin dynamics and polarization is quite small. This is not true for the impact of the four superconducting (sc) IDs. There are two 7 Tesla wavelength shifters (WLS) for material science and protein structure analysis, a 4 Tesla WLS is used for lithography, and the 7 Tesla wiggler is employed primarily for both material science and the studies of magnetic properties.

Strong field IDs can substantially influence beam parameters like the energy spread, the transverse emittance, the damping times and the spin polarization. Here we are only interested in the latter effect. The Sokolov-Ternov polarization time, τ_{pol} , due to radiation is given by [5]:

$$\frac{1}{\tau_{pol}} = \frac{5 \cdot \sqrt{3}}{8} \frac{h \cdot r_e}{2\pi \cdot m_e c} \frac{c}{C} \gamma^5 \left(\frac{e}{p_0 c} \right)^3 \oint |B|^3 ds.$$

The symbols have their usual meaning. C is the circumference of the ring and B is the bending field. Any additional ID increases the amount of synchrotron radiation and therefore the rate of polarization, $1/\tau_{pol}$. In an ideal planar machine the asymptotic level of polarization is given by:

$$P_{\infty} = \frac{8}{5 \cdot \sqrt{3}} \frac{\oint B^3 ds}{\oint |B|^3 ds}.$$

Thus any additional ID reduces this level. In general, the spin polarization, P, of the circulating electrons builds up as a function of time, t, according to:

$$P(t) = P_{\infty} \cdot \frac{\tau_{eff}}{\tau_{pol}} \cdot \left(1 - e^{-t/\tau_{eff}} \right). \quad \text{With the effective}$$

polarization time given by $1/\tau_{eff} = 1/\tau_{pol} + 1/\tau_{dep}$. τ_{dep} describes the depolarizing effects of field perturbations. They also reduce the asymptotic level of polarization: $P(t \rightarrow \infty) = P_{\infty} \cdot \tau_{eff}/\tau_{pol}$.

Based on simple field models for the sc IDs at BESSY their impact on the spin dynamics has been estimated and results are given in Table 1. The asymmetric WLSs [6] reduce the polarization time with little influence on the asymptotic level of polarization. On the other hand, the symmetric wiggler speeds up the polarization too,

however, significantly reduces the equilibrium polarization level. This is the main problem for the detection of the spin resonance at BESSY.

Table 1: Impact of sc IDs on Spin Dynamics

Configuration	Polarization Time, τ_{pol}/h	Polarization, $P_{\infty}/\%$
Bare lattice, $\rho=4.35m$	1.316	92.4
+ 1 x 7 T - WLS	0.883	89.2
+ 2 x 7 T - WLS	0.664	87.6
+ 4 T - WLS	0.633	87.0
+ 7 T - wiggler	0.296	42.0
only with 7 T - wiggler	0.392	29.1

EXPERIMENTAL PROCEDURE

The layout of the experiment and the requirements were already presented in 2000 [4]. In summary: For a successful experiment one needs the polarization of the electrons, a spin sensitive device for the detection (polarimeter), and a depolarizer for the resonant destruction of the spin orientation.

Depending on the ID-configuration, spin polarization will build up if depolarizing field perturbations are small. This is usually the case for well aligned and adjusted synchrotron light sources as many successful experiments have shown [7, 8]. In all these cases, the polarimeter is based on the spin dependent Touschek scattering loss rate (or the lifetime). In 3rd generation light sources the short Touschek lifetime is usually a disadvantage, here it allows for a simple detection of the resonant destruction of the spin polarization. The loss rates go up (lifetime goes down) if the ensemble of particle is depolarized. Depolarization is achieved with a radial time varying field whose frequency is slowly swept up and down over the resonance. The field is created with a set of four strip lines, two at the top and two at the bottom of the vacuum chamber. Nowadays they are powered with four individual and quite small amplifiers ($P_{max}=50$ W, bandwidth=1–3 MHz). Their relative phases can be chosen such that any desired field configuration can be realized: radial, vertical, and skew quadrupole. The integrated on-axis radial field strength is around $5 \cdot 10^{-6}$ T·m at 2.37 MHz.

This system was successfully used for the parasitic measurement of the energy during user runs without any noticeable perturbations for users. After the 7T-wiggler went into operation the signal indicating the depolarization could no longer be detected.

Improvements

In earlier experiments the beam was neither fully polarized nor totally depolarized: the time between resonance crossings (~2500 seconds) was shorter than the polarization time and the depolarizing resonance was

crossed with 3.2 Hz/s, too fast for full depolarization. High precision measurements were nevertheless possible even during user runs with many ID changes which can cause similar signal variations as the depolarization itself.

In order to nearly double the sensitivity of the polarimeter the coupling was reduced in machine development shifts thereby increasing the spin dependent Touschek losses. Also the sweep speed through the depolarizing resonance was reduced by a factor of 8. Even if the response of the spins to the radial excitation would have been reduced we still expect to fully depolarize the spins. As before one sweep took 2500 s which is as large as the expected polarization time with the 7 T - wiggler. After this optimization the resonant spin depolarization could be detected easily. Changing the location of the beam loss monitors was not as helpful as initially thought.

Results

Fig. 1 shows the result of a measurement under these optimized conditions, still without the 7 T - wiggler in operation. Nearly 300 mA distributed over 350 bunches were injected initially. At the beginning of the plot the current was 245 mA with a lifetime of 8 h. The successful depolarization is evident from the sudden increase of the loss rate and the corresponding reductions of the lifetime. The loss rate, dN/dt , is normalized by multiplication with the measured vertical beam size, σ_v , and divided by the square of the beam current I : $dN/dt_{norm}=dN/dt \cdot \sigma_v / I^2$. Both, the loss rate and the product, $I \cdot \tau$, of current and lifetime, τ , in Fig. 1 are displayed as a function of time and relative to their values at time $t=0$.

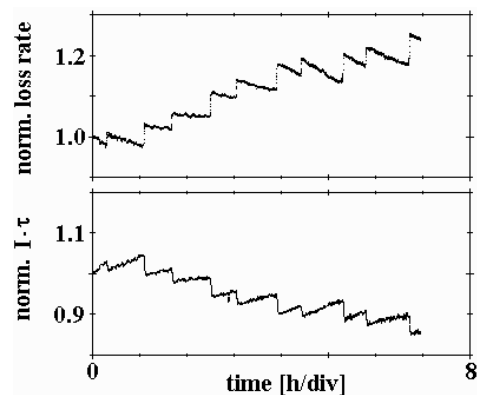


Figure 1: Normalized signals during the energy measurement with optimized sensitivity with all WLSs in operation but without the 7 - Tesla wiggler.

In Fig. 2 the normalized loss rate of this measurement is shown as a function of the depolarizing frequency. Different colors help to distinguish the up- and down scans. There is a small downward shift of the resonance as a function of the beam current. This is more clearly seen in Fig. 3, where the frequency of the spin resonance is shown together with the spin tune, ν_s , the number of spin precessions per turn. Since we know that the energy is around 1.7 GeV and because the amplifier performs

best at around 2-3 MHz, the spin tune is given by $\nu_s = 2 + F_{dep} / F_{rev}$, with F_{rev} , the revolution frequency. This small shift is always present. We suspect it is related to thermally induced horizontal orbit shifts. Without the closed orbit control the energy variation would be much larger.

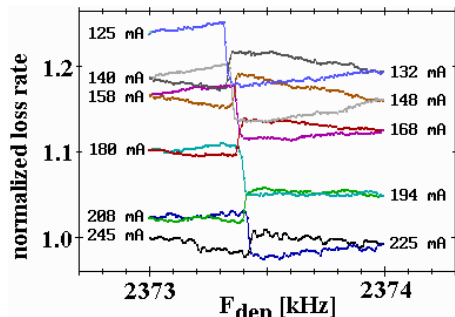


Figure 2 (color): Same conditions as in Fig. 1, however normalized loss rate vs. the frequency of the depolarizer.

If the signals can be normalized properly, the effective polarization time, τ_{eff} , can be found from the temporal behavior of the lifetime or the loss rate [8]. In our case only a coarse estimate can be given: $\tau_{eff} = 1.0 \text{ h} \pm 0.3 \text{ h}$. This has to be compared to $\tau_{pol} = 0.633 \text{ h}$ from Table 1. Therefore, depolarizing effects must be very small.

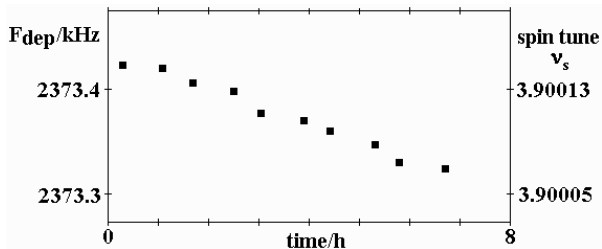


Figure 3: Shift of the energy ($E = \nu_s * 440.65 \text{ MeV}$) as a function of time which is related to the beam current.

Even under the normal coupling conditions and during normal user runs with the 7 T - wiggler operational the parasitic high precision energy determination was possible. In Fig. 4 a comparison of the average of 10 resonance crossings with and without the 7T - wiggler is shown. As expected the signal step is a factor of 4 smaller: a factor of nearly two is attributed to the smaller Touschek loss rate and the rest is explained by table 1. The energy shows very similar shifts as depicted in Fig. 3. There is no significant variation of the energy as the 7 T - wiggler is turned on and off and even over longer periods of time the energy is always around $1718.6 \text{ MeV} \pm 0.1 \text{ MeV}$. If a higher precision is required the measurement has to be performed in situ.

SUMMARY AND OUTLOOK

The 7 T - wiggler severely reduces the achievable level of polarization. Clear signals indicating the depolarization of the spins were only obtained after a careful optimization of the beam loss monitor signal by: a)

reducing the scan speed to allow for full depolarization and b) by waiting sufficiently long between resonance crossings in order to let the ensemble build up a sufficient level of spin polarization. In the optimization process it was helpful to increase the Touschek losses by reducing the coupling and/or increasing the charge per bunch. It remains to be shown, that the technique of resonant spin depolarization for the high precision determination of the beam energy is also applicable in case of continuous injections during top-up operation which is foreseen to start at BESSY at the beginning of 2012.

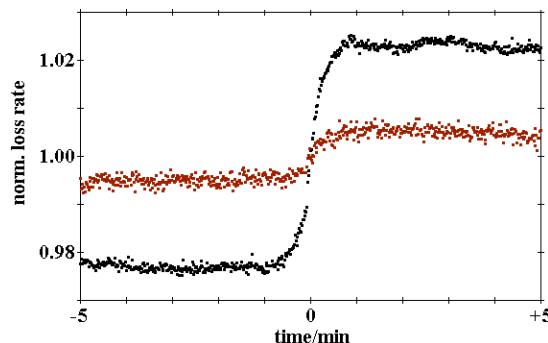


Figure 4 (color): Increase of the relative loss rate during the crossing of the spin resonance: black - without the 7 T wiggler and red - with the 7 T - wiggler in operation.

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