

HIGH PRECISION DETERMINATION OF THE ENERGY AT BESSY II*

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Abstract

The energy of electrons stored in the light source BESSY II is measured by resonant spin depolarisation. Precise knowledge of the energy is required in order to use BESSY II as a primary source of calculable spectral photon flux. The experimental arrangement is presented: Polarisation of the electron spins builds up within a few hours through the emission of synchrotron radiation. The degree of polarisation is determined from the spin dependence of the Touschek effect and the polarisation is destroyed by exciting the beam resonantly with strip lines. In the measurements the excitation is swept slowly back and forth through the depolarising resonance and lost particles are counted. On resonance the loss rate increases and the energy can be determined with very high accuracy from the resonance frequency. During the user runs the energy was measured every hour with an uncertainty of 10^{-5} . Due to modifications of the horizontal orbit correction algorithm the long term stability of the energy could be improved from $\pm 7 \cdot 10^{-4}$ to $\pm 3 \cdot 10^{-4}$.

1 INTRODUCTION

BESSY II is a 1.7 GeV electron storage ring optimised for a third generation VUV light source in operation since the beginning of 1999[1]. This facility serves the Physikalisch-Technische Bundesanstalt, PTB, as a source of calculable photon flux in a wide range of photon energies[2]. Thus among other parameters, the energy of the stored electrons has to be known with an accuracy of at least 10^{-4} . At BESSY II this parameter is determined by two different techniques. The first approach uses Compton scattering of a CO_2 -laser beam and the sharp high energy cut-off of the back-scattered photons[3]. This technique has the advantage not to require a spin-polarised beam. On the other hand the accuracy is limited. In the second approach, the resonant depolarisation of the electron spins is used[4]. Here the accuracy is very high, however, a polarised beam is needed, which is difficult to achieve at too low beam energy.

This paper presents the first successful high precision measurements of the energy at BESSY II with this

technique. The general layout of the experiment is reviewed only briefly since the apparatus has been presented at an earlier conference[5]. Emphasis is put on those details which have changed since then. Results on the stability of the energy and their improvements are presented.

2 LAYOUT OF THE EXPERIMENT

The resonant spin depolarisation technique for the high precision energy measurement is based on the fact, that according to the Thomas-BMT equation[6], the spin tune, ν_s , the number of spin precessions per revolution, is energy dependent: $\nu_s = a \cdot \gamma$. With a the gyromagnetic anomaly of the electron, $a=1.1596522 \cdot 10^{-3}$, and the relativistic factor γ .

The resonant spin depolarisation technique requires:

- Spin polarisation of the beam
- The polarimeter in order to measure the polarisation
- The depolariser as a means to depolarise the beam resonantly.

2.1 Polarisation build up

Under certain conditions the beam in a storage ring polarises naturally through the emission of synchrotron radiation by the Sokolov-Ternov effect with a typical time constant for second and third generation light sources of the order of 1 hour[7]. The polarisation time for BESSY II running at 1.7 GeV is 1.4 h. Waiting for a few hours can lead to a vertically polarised beam with 92.4% of the spins oriented antiparallel to the bending fields.

2.2 Polarimeter

Touschek scattering, the collision of electrons within one bunch, does depend on the spin orientation of the colliding particles. Thus measurable quantities which are sensitive to this effect, like the loss rate of particles or the lifetime of the beam, can be used as a polarimeter[8]. In the Touschek scattering process transverse momentum, primarily from the horizontal plane, is transferred into the longitudinal plane and this longitudinal momentum is boosted up by a factor γ in the lab frame. Touschek losses are higher if the beam is not polarised. The sensitivity of this polarimeter increases with the energy acceptance of the ring: The higher the transferred momentum the more important is the spin orientation.

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Lost particles hit the vacuum chamber walls and produce showers of low energy photons and particles. These showers are monitored by 4 NaI-scintillation detectors mounted external to the vacuum chamber. The detectors are placed where many off-energy particles are lost. In the future the NaI-crystals will be replaced by plastic scintillators because of the very high count rates and the much shorter pulses which can be obtained with this material. The output pulses of the photomultipliers are amplified, shaped, discriminated, and finally counted.

2.3 Depolarizer

The beam can be depolarised by a set of four 50 cm long 50 Ω strip lines. The strip lines have a T-type cross section and are installed in slots of the vacuum chamber. The T-type structure was selected for mechanical reasons and the dimensions of the strip line and the slot size were chosen in order to achieve the desired impedance. All 4 strip lines are connected in series to the high power amplifier and the 50 Ω -load such that a large radial field component is produced. The maximum on axis integrated field strength was estimated to be $4.7 \cdot 10^{-6}$ T·m/A. The strip line ensemble was placed at the beginning of the straight section where the maximum efficiency of the depolarising field is achieved. The depolarisation time, τ_{dep} , is proportional to the modulation bandwidth of the depolariser, $\Delta\omega_{dep}$, and with this arrangement is given by:

$$\tau_{dep} = \Delta\omega_{dep} \cdot 0.63 \text{ A}^2 \text{ s}^2 \cdot Z/P \quad (1)$$

Where Z is the impedance of the strip line and P is the output power of the amplifier. With $\Delta\omega_{dep} = 2\pi \cdot 520$ Hz and $P = 1$ kW the expected depolarisation time is 100 s.

3 RESULTS

3.1 First Experiments

The first experiments were performed in the following way: Polarisation can build up for 4 hours during a normal user run. By that time the beam current has decayed from approximately 150 mA down to 50 mA. Now the normalised signals, i.e. detector count rates divided by the square of the beam current, are comfortably large: ≈ 10 kcounts/s/ mA² at around 100 mA and even larger at smaller beam currents, so that the expected small signal changes as the beam is depolarised can be measured within a 1 second time interval. During the earlier measurements the frequency of the depolarising field was swept back and forth over ± 260 Hz around the centre frequency with a sweep frequency of 10 Hz. Every 5 minutes the centre frequency was stepped up (or down) by 0.5 kHz. This step size allows for the desired 10^{-4} accuracy of the energy. During the actual measurement the detector count rates were collected together with the beam current and if required together with other relevant storage ring parameters as a function of the excitation frequency. Usually the increase of the

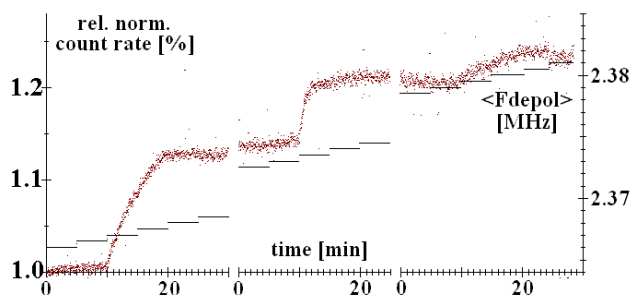


Fig. 1 (colour): Increase of count rate as the beam is depolarised. The count rate is normalised relative to the beginning of the measurement. The main resonance is shown in the middle. Depolarisation occurs also at synchrotron side bands. The average depolarising frequency increases stepwise.

signal as the beam is spin depolarised is visible from the raw data. The recorded data can be analysed in more detail off-line with additional software.

Fig. 1 shows the result of the first attempt to measure the energy of the beam. The experiment was immediately successful despite the necessarily large search interval. The beam was first depolarised at the lower synchrotron side band of the main resonance. This resonance is broadened due to the spread in synchrotron frequencies and the depolarisation rate is nearly an order of magnitude smaller than on the main resonance. Since the beam was fully polarised the signal increased by 13%. The scan was continued and 1 hour later the next depolarisation occurred at a frequency 6.5 kHz higher. This is the synchrotron frequency. The resonance frequency corresponds to an energy of $E=1.7186(1)$ GeV. On the main resonance the depolarisation time is 50 s with a power of 1 kW. This is faster than expected from equation (1). The increase of the normalised count rate is 6.5 % and now the beam is completely depolarised during the 5 minute interval. After 1 more hour, which is only 70% of the polarisation time, the higher synchrotron side band resonance is hit. The signal increases again by 4%. It is obvious, that neither full polarisation nor complete depolarisation are required in order to detect the resonance.

3.2 Later Experiments

During later experiments the fast 10 Hz sweep of the excitation frequency was abandoned completely because inevitable power supply noise and small 50 Hz-ripples would result in many resonance crossings and would lead to the spin depolarisation of the ensemble of particles any way. This was first successfully tried out at the ALS [9] and according to equation (1) the power requirements are drastically reduced. RF-power of 100 W is sufficient to detect the depolarising spin resonance. By sweeping through the resonance up- and down-wards, it was verified, that at this power level the resonance was not

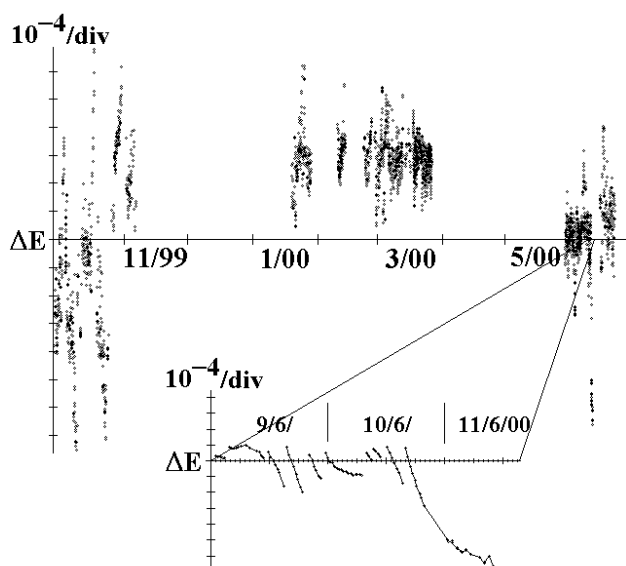


Fig. 2: Relative energy shifts and drifts during normal user runs from September 1999 until June 2000. Uncompensated horizontal closed orbit distortions are responsible for the observed variations.

shifted nor broadened. Power broadening is a common problem in resonance experiments.

At around 100 mA the signal due to depolarisation increases by 2%. The step becomes larger and the normalised count rates increase at smaller beam currents. In nearly all cases the spin polarisation did build up and clear signals could be detected. The fast transverse and longitudinal feedback system have no impact on the polarisation of the spins. There was one situation where the lately installed Landau cavities excited the beam and no depolarisation could be seen.

3.3 Stability of the Energy

Since September 1999 the energy is monitored during normal user runs. The increase of the Touschek loss rate due to the depolarisation of the beam every 30 minutes has only a small impact on the overall lifetime which is still dominated by the vacuum conditions. This will only be true while new small gap insertion device vacuum chambers are installed frequently. The analysis can not be automated since insertion device gap changes lead to count rate variations very similar to the depolarisation.

The results are displayed in Fig. 2. In the beginning the stability of the energy was rather poor. All energy drifts could be correlated with orbit shifts induced thermally. Terrestrial tides would produce smaller variations. In order to keep the energy stable, the orbit correction algorithm[10] must adjust the RF-frequency such, that the integrated vertical fields on the closed orbit are constant. This improved the stability at the end of October 1999. In the user run starting in June 2000 the average energy was reduced by $3 \cdot 10^{-4}$ because of a new reference orbit which

lead to a different averaged setting of the horizontal steering magnets.

Part of the results can be seen with higher resolution in the insert in Fig. 2: Short term energy variations follow the pattern of injections and the mode of operation. If the closed orbit is corrected, which takes place every 2 to 4 hours between 7 am and 11 pm during normal user runs, the original beam energy is recovered. In between these intervals the energy is drifting downwards due to the fact that the floor of the storage ring tunnel is warming up by $0.05^\circ\text{C}/\text{day}$ because these days were very hot in Berlin. At the same time the RF-frequency had to be reduced by 210 Hz/day. At 11 pm on the 10th of June, the end of this user run during this week, the orbit continued to drift freely and so did the energy. The stability of the energy can be further improved to the desired 10^{-4} level if the orbit is corrected continuously.

4 SUMMARY

A set up for the high precision measurement of the energy of the stored electron beam has been designed, built, improved, and successfully operated at BESSY II. The measurement is based on the resonant depolarisation of the spins. The energy has been measured during user runs. The stability of the energy was improved from $\pm 7 \cdot 10^{-4}$ to $\pm 3 \cdot 10^{-4}$. A further reduction of these energy drifts can be expected if thermally induced horizontal orbit shifts are suppressed either at the source or by correcting the orbit continuously.

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