ELECTRON BEAM ENERGY MEASUREMENT AT THE AUSTRALIAN SYNCHROTRON STORAGE RING

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Abstract

The technique of resonant spin depolarisation was used to precisely measure the electron beam energy in the storage ring at the Australian Synchrotron. A detector and data acquisition system dedicated to the measurement were developed. Using the system, the long term energy stability of the storage ring was monitored and a mechanical realignment of the ring was clearly seen in the energy measurement. Details of the parameters used to optimise the measurement are also discussed.

INTRODUCTION

The highest precision technique available for the measurement of the stored electron beam energy is that of resonant spin depolarisation. The technique was used to calibrate beam energy measurements for LEP [1]. Our method of polarising and observing the depolarisation follows the technique used at BESSY I [2], BESSY II [3], ALS [4], SLS [5], and ANKA [6].

THEORY

A thorough review of theory and experiments with polarised beams of protons, electrons and muons was undertaken by Mane [7]. We will consider the development of radiative polarisation of electron beams, adiabatic resonant spin depolarisation, and Møller scattering cross-section polarimetry.

Radiative Polarisation

Radiative polarisation develops in an initially unpolarised electron beam by the Sokolov-Ternov effect [8]. While travelling through a uniform magnetic field, such as a bending magnet of a storage ring, the spins of electrons will undergo both polarisation in the direction of the field, and precession about the polarisation axis. The polarisation of the beam develops with time approximately by [7],

$$P\left(t\right) = P_0\left(1 - exp\left(\frac{t}{\tau_{ST}}\right)\right) \tag{1}$$

$$\tau_{ST} = \frac{8}{5\sqrt{3}}\frac{m_e\rho^2 R}{\hbar\gamma^5 r_e} \tag{2}$$

where ρ is the mean bending radius, R the mean ring radius and m_e, r_e the classical electron mass and radius. The polarisation $P\left(t\right)$ approaches an equilibrium polarisation P_0 [3]:

$$P_0 = \frac{8}{5\sqrt{3}}\frac{\oint B^3 ds}{\oint |B^3| ds} \tag{3}$$

which approaches a maximum for a storage ring without reverse bends or wiggler insertion devices.

Resonant Spin Depolarisation

The number of spin precessions per revolution of the storage ring, the spin tune ν_{spin}, is given by [1],

$$\nu_{spin} = \left(\frac{g-2}{2}\right)\frac{E}{m_e c^2} \equiv a\gamma \tag{4}$$

where E is the beam energy, m_e the mass and g the gyromagnetic factor of the electron. The gyromagnetic factor g for electrons has been measured to precision within the 12^{th} significant figure [9]. Hence measurement of the spin tune ν_{spin} gives a direct measurement of the beam energy, with uncertainty corresponding to uncertainty in the measurement of the spin tune.

Spin transport and precession is described by the Thomas-BMT equation [7]. We remark that the spins initially polarised normal to the plane of the ring can be rotated away to random orientations, by a series of transverse magnetic kicks resonant at the spin tune.

Møller Scattering Polarimetry

Polarimetry is performed by investigation of the Møller scattering cross-section. The particle loss rate dN/dt is described in terms of the polarisation $P(t)$ by [7]:

$$\frac{dN}{dt} = -\frac{N^2 c}{\sqrt{2}\gamma^2\sigma_{x'}\sigma_{y'}}\left(f_1 + f_2 P(t)^2\right) \tag{5}$$

where f_1, f_2 are functions, which can be treated for this measurement as constants. Importantly, a normalised loss rate can be defined as:

$$R_{norm} = \frac{1}{I(t)^2}\frac{dN}{dt} \propto f_1 + f_2 P(t)^2 \tag{6}$$

where $I(t)$ is the stored beam current at time t.

METHOD

Storage Ring Lattice and Beam

The Australian Synchrotron is a 3 GeV storage ring light source, composed of modified Chasman-Green lattice

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cells. Several important design parameters are summarised in Table 1. All results presented are for the bare storage ring lattice, with 0.1 m distributed dispersion, and high transverse chromaticities of $\xi_x = 3, \xi_y = 13$. The storage ring

Table 1: AS Storage Ring Design Parameters

Parameter		Value	Units
Beam energy	E	3.00	GeV
Relativistic gamma	γ	5871	-
Bending radius	ρ	7.69	m
Circumference	C	216.00	m
RF frequency	f_{RF}	499.67	MHz

was configured such that the Touschek lifetime dominated the beam lifetime. Skew quadrupoles normally used to increase betatron coupling (and accordingly lifetime) were unpowered, to give a beam with transverse emittance ratio of about 0.1% [10]. The fill pattern was reduced from a user fill of 300 bunches, to about 75 bunches in 360 buckets.

These optimisations improved the signal to noise ratio in the initial observation of the resonance. Once identified, the resonance was observable under normal user fill settings, with insertion devices closed.

Depolarisation Kicker and Polarimeter

Vertical betatron tune striplines were used to excite the resonance.

The beam loss monitor was a 75 mm NaI scintillator and photomultiplier tube. Various locations around the storage ring circumference were tested, but the observation of the depolarisation signal was largely insensitive to the circumferential positioning of the detector. The scintillator was installed in the orbit plane of the ring, on the inner side of the vacuum chamber.

Data Acquisition System

As Equation 4 highlights, the important parameter in this measurement is the accurate determination of the spin tune. Hence, the measurement of the depolarising excitation frequency and revolution frequency are the two important parameters.

A Struck 3820 scaler was used to count the excitation frequency, as well as the counts from the beam loss monitor. The scaler features a 50 MHz internal reference clock, for accurate determination of the integration period (typically 1 s). The revolution frequency was determined from the RF frequency, and the stored beam current from the DCCT readback records.

RESULTS

Polarisation Time

The polarisation time was measured. The beam was initially fully depolarised by resonant excitation at the spin tune. With the excitation switched off, the beam was allowed to develop radiative polarisation. The measured normalised loss rate was fitted by Equations 1 and 6. Using Equation 2 and parameters in Table 1 we calculate the model value. The results are summarised in Table 2 below.

Table 2: Polarisation Time

Parameter		Value	Units
Measured	τ_{ST}	806 (21)	s
Model	τ_{ST}	807	s

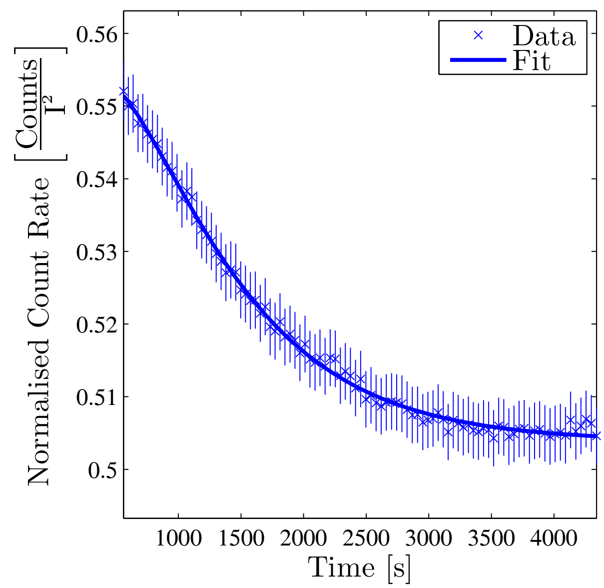

Figure 1: Measurement of polarisation time. Fit to normalised count rate gives $\tau_{pol} = 806 \pm 21$ s.

Beam Energy

A spin-polarised electron beam can be resonantly depolarised at any spin tune sideband to the orbit harmonic. The choice of sideband was determined by the bandwidth of the excitation system, particularly the amplifier and kickers. The resonance was excited at 17.81977(4) MHz. This corresponded to a beam energy of 3.013408(8) GeV.

Illustrated in Figure 2 are two excitation sweeps across the spin tune harmonic. Scanning from both above and below the spin tune places tight constraints on the uncertainty in beam energy fitted.

Spin Tune Synchrotron Sidebands

Resonant spin depolarisation is observed by exciting synchrotron tune sidebands of the spin tune. The amplitude of synchrotron sidebands was observed to be lower than the central spin tune. During this measurement, the cavity voltage was 2.873 MV.

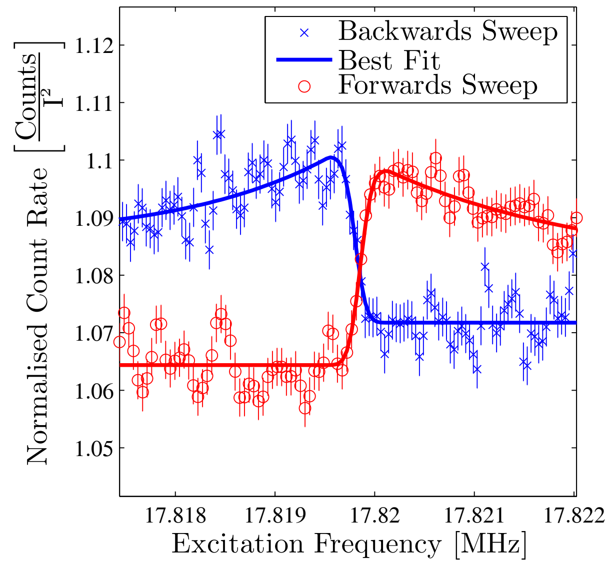

Figure 2: Resonant spin depolarisation at spin tune.

Table 3: Synchrotron Tune for $V_G = 2.873$ MV

Parameter		Value	Units
Measured	f_s	14.54(10)	kHz
Model	f_s	14.51	kHz

Momentum Compaction Factor

The momentum compaction factor was measured. Small changes in the RF frequency of 500 and 1000 Hz in 500 MHz resulted in small changes to the stored beam energy. The corresponding change in spin tune was measured. Results are summarised in Table 4 below.

Table 4: Momentum Compaction Factor

Parameter		Value
Measured	α_c	0.00211(5)
Model	α_c	0.00211

Energy Stability

Over the period of a shift, the beam energy was measured repeatedly. For a polarisation time of approximately 15 minutes, an interval of 30 minutes was appropriate for the radiative development of polarisation. Results are presented in Figure 3 below.

Long term energy stability is presented in Table 5 below.

DISCUSSION

The measurement of the beam energy has been a useful confirmation of the storage ring parameters. Several photon beamlines desire an online measurement of the beam energy, for calibration of absolute photon flux. We plan to provide this online measurement in anticipation of top-up operation.

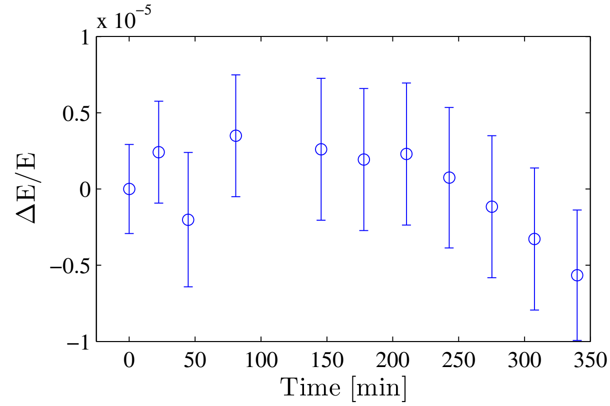

Figure 3: Energy drift with time.

Table 5: Long Term Energy Stability

Date (2010)	Mean energy [GeV]
20^{th} June	3.013418(4)
21^{st} June	3.013379(3)
28^{th} June	3.013171(3)
4^{th} July	3.013188(4)
18^{th} July	3.012996(5)
29^{th} August	3.012974(4)
17^{th} September	3.013332(5)
20^{th} September	3.013270(5)

CONCLUSION

Spin resonant depolarisation has been successfully used at the Australian Synchrotron storage ring. The beam energy has been measured within an uncertainty of 10^{-5}.

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