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RESONANT SPIN DEPOLARISATION MEASUREMENTS AT THE SPEAR3 ELECTRON STORAGE RING

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Abstract

Accurate electron beam energy measurements are valuable for precision lattice modelling of high-brightness light sources. At SPEAR3 the beam energy was measured using the resonant spin depolarisation method with striplines to resonantly excite the spin tune and a sensitive NaI scintillator beam loss monitor to detect resulting changes in Touschek lifetime. Using the combined apparatus an electron beam energy of $2.997251\ (7)$ GeV was measured, a relative uncertainty of 3×10^{-6}.

The measured momentum compaction factor was found to be in close agreement with the numerical model value using rectangular defocussing gradient dipoles with measured magnetic field map profiles. In this paper we outline the chosen experimental technique, with emphasis on its applicability to electron storage rings in general.

INTRODUCTION

Experimental verification of storage ring lattice models requires a very sensitive technique for beam energy measurement. As the highest available precision technique, resonant spin depolarisation was successfully employed for the beam energy measurement of the Australian Synchrotron storage ring [2]. We apply this measurement apparatus and technique to the SPEAR3 electron storage ring at SLAC.

THEORY

With specific reference to the literature review of Mane [1], much of the relevant theory for this resonant spin depolarisation experiment at SPEAR3 is the same as for the experiment at the Australian Synchrotron [2].

Serendipitously, the polarisation of electron beams in storage rings is a diagnostic tool we get for free. A beam of electrons with spins of random orientations develops polarisation under the Sokolov-Ternov effect [3]. The polarisation of the ensemble of spins develops with time, in addition to precession about the polarisation axis - normally in the direction of the main dipole field.

The polarisation time of electrons in an isomagnetic lattice is described in SI-units by [3]

$$(\tau_{ST})^{-1} = \frac{5\sqrt{3}}{8}\frac{1}{4\pi\epsilon_0}\frac{e^2\hbar}{m_e^2c^2}\frac{\gamma^5}{\rho^3}, \qquad (1)$$

where ρ is the bending radius, γ the relativistic gamma, m_e the electron rest mass, and all other symbols have their usual electromagnetic meanings [4]. The SPEAR3 racetrack lattice is configured with bending magnets of different bending radii, as well as reverse bends in a long canted-undulator straight. Integrating all bending fields over one turn of the non-isomagnetic ring [1],

$$\frac{1}{\rho^3} = \frac{1}{2\pi R}\oint \frac{1}{|\rho(s)^3|}ds. \qquad (2)$$

This is equivalent to the third synchrotron radiation integral divided by the circumference of the ring.

METHOD

Storage Ring Lattice and Beam

The SPEAR3 storage ring is a 3 GeV storage ring light source, with DBA lattice cells. The racetrack lattice is composed of 14 main arc cells, and 4 matching cells. Several important design parameters are summarised in Table 1. A normal user beam fill pattern was used, and all insertion devices were open for this measurement of the bare lattice.

Table 1: SPEAR3 Storage Ring Design Parameters

Parameter			**Value**	**Units**
Beam energy		E	3.00	GeV
Relativistic γ		γ	5871	-
Bending radius	- arc	ρ	8.14	m
	- match	ρ	8.25	m
Circumference		C	234.143	m
RF frequency		f_{RF}	476.30	MHz

Depolarisation Kicker and Polarimeter

Vertical betatron tune striplines were used to excite the spin tune resonance. Scanning over the baseband spin tune resonance, the excitation frequency was approximately 250 kHz.

The beam loss monitor was a 50 mm NaI scintillator and photomultiplier tube. The detector was installed adjacent to the scraper defining the minimum energy aperture of the SPEAR3 storage ring, to maximise the count rate. This is immediately downstream of the central focussing quadrupole, which is the point of maximum horizontal dispersion in one of the double-bend achromat arc cells. The

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scintillator was installed in the orbit plane of the ring, on the inner side of the vacuum chamber.

Data Acquisition System

The data acquisition system used at the Australian Synchrotron [2] was employed for this measurement. Using EPICS, the frequency of time-stamped data acquisition was approximately 1 record per second.

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.

RESULTS

Polarisation Time

The beam loss apparatus was used to measure the polarisation time. The injected beam was initially unpolarised. The measured normalised loss rate illustrated in Figure 1 was fitted for the Sokolov-Ternov polarisation time given in Equation 1. Using Equation 1 and parameters in Table 1 we also calculated the model value. The results are summarised in Table 2 below.

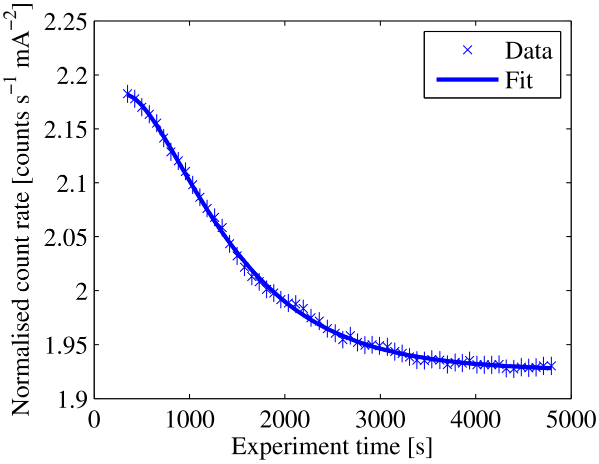

Figure 1: Measurement of polarisation time. Fit to normalised count rate gives $\tau_{pol} = 840 \pm 16$ s.

Table 2: Polarisation Time

Parameter		Value	Units
Measured	τ_{ST}	840 (16)	s
Model	τ_{ST}	1005	s

The 20% difference between the measured and model polarisation time has not yet been resolved.

Beam Energy

Resonant spin depolarisation of a stored, polarised electron beam can be achieved with excitation at any fractional spin tune sideband to the revolution harmonic. Designed for baseband tune excitation, the ampilifier and kicker were excited at frequencies of approximately 240-260 kHz. A radial field was used for the depolarisation.

Illustrated in Figure 2 below are resonant spin depolarisations of the measured beam energy. The real changes in beam energy during this measurement correspond to changes in the sum of horizontal corrector magnets, as fast-orbit feedback was operating. A change in the corrector sum of less than 2 A corresponded to a change in deflection angle of 0.1 mrad, and in depolarisation frequency of approximately 100 Hz.

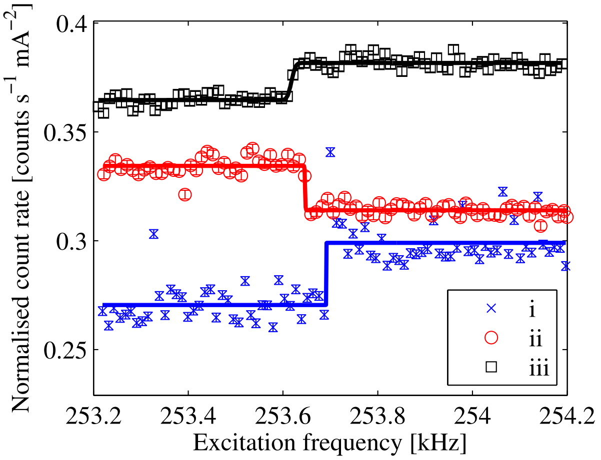

Figure 2: Three separate resonant spin depolarisations. Fast-orbit feedback was on during these measurements.

We can determine the beam energy from any single resonant spin depolarisation. For an RF frequency of 476,310,497 Hz and harmonic number 372, the resonant depolarisation shown in Figure 2 (iii) had a fitted mean depolarising frequency of 253.618 (7) kHz. This corresponded to a spin tune of 6.801923 (6), a beam energy of 2.997251 (7) GeV.

The measured beam energy was predicted in previous modelling [5]. Modelling the storage ring using field maps for the dipole and quadrupole magnets, it was postulated that the energy was 0.1 % lower than the design 3 GeV. Adding the contribution of the sum of horizontal corrector magnets as a net kick of -0.54 mrad at the time of measurement, the predicted energy at the time of measurement was 2.9971 GeV. The beam energy was measured to fluctuate within the range 2.9972-2.9973 GeV with the fast orbit feedback, during the time of measurement.

Spin Tune Synchrotron Sidebands

In locating the spin tune by scanning the excitation frequency, one can excite at the synchrotron sidebands to the spin tune and mistake this depolarisation for the spin tune.

The amplitude of synchrotron sidebands was observed to be lower than the central spin tune. Illustrated in Figure 3 are two excitation sweeps across the real spin tune harmonic at gap voltages of 2.65 and 2.45 MV. This reduction in gap voltage reduces the synchrotron frequency from 11.5 kHz to 11.0 kHz. As the measured depolarisation frequency does not change by 500 Hz with the change in gap voltage, this is a depolarisation of the spin tune and not a synchrotron sideband.

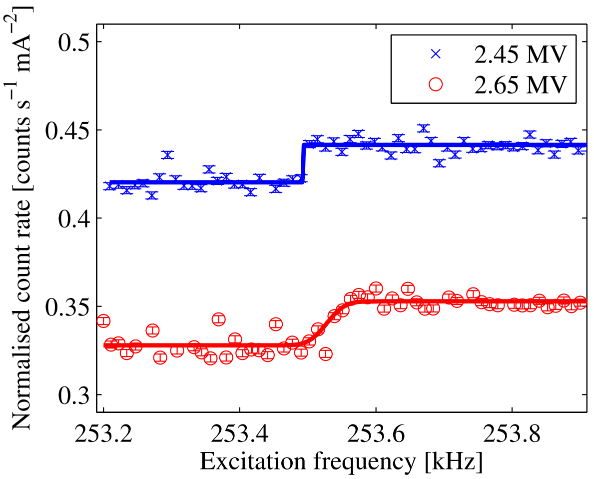

Figure 3: Resonant spin depolarisation at various gap voltages.

Momentum Compaction Factor

The momentum compaction factor – the change in circumference wchange in energy – was measured. The RF frequency provides an accurate constraint on the orbit circumference, and the spin tune an accurate measurement of beam energy. RF frequency feedback and fast-orbit feedback were turned off. Small changes in the RF frequency of 500 and 1000 Hz resulted in small changes to the stored beam energy. The corresponding change in spin tune was measured, as illustrated in Figure 4 below.

DISCUSSION

Measurement of the momentum compaction factor provides a precision calibration of the lattice dispersion. The momentum compaction factor fitted in Figure 4 was compared with different models of the SPEAR3 storage ring. Results are summarised in Table 3 below. This measurement of the momentum compaction factor demonstrates that the more appropriate choice of model for the lattice dispersion is the numerical integration of simulated field maps.

Table 3: Momentum Compaction Factor

Momentum compaction factor, α_c	**Value**
Measured	0.001637(3)
Field-map model [5]	0.001650
Single-bend AT model	0.001621

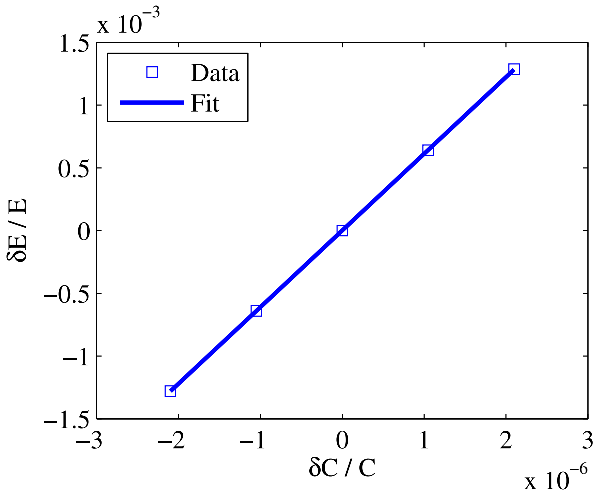

Figure 4: Measured momentum compaction factor.

CONCLUSION

Spin resonant depolarisation has been successfully used at the SPEAR3 electron storage ring. The beam energy has been measured as 2.997251 (7) GeV, representing a relative uncertainty of 3×10^{-6}. Beam energy and momentum compaction factor predictions from the field-map model are in excellent agreement with these measurements of the ring.

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