〔A18p01〕

A Study of Spin Depolarizing Resonances at 3.5 GeV Electron Stretcher Accelerator (ELSA)

S. Nakamura[1,2], W. v. Drachenfels[2], D. Durek[2], F. Frommberger[2], M. Hoffmann[2], D. Husmann[2], B. Kiel[3], F. Klein[2], F. J. Klein[2], D. Menze[2], T. Michel[3], T. Nakanishi[1], J. Naumann[3], S. Okumi[1], T. Reichelt[2], H. Sato[4], B. Schoch[2], C. Steier[2], K. Togawa[1], T. Toyama[4], S. Voigt[2], M. Westermann[2]
(1) Nagoya University, (2) Universität Bonn, (3) Universität Erlangen, (4) KEK

Abstract

Polarized electrons was accelerated in the 3.5 GeV electron stretcher accelerator ELSA. The polarization of the electron beam produced by a polarized electron source was measured up to 2.1 GeV by a Møller polarimeter. By optimizing the ramping speed to cross several depolarizing resonances, a polarization of 45% could be preserved up to 1.9 GeV. Strong depolarization occurred at 2.0 GeV (intrinsic resonance). Therefore the construction of fast tune jump quadrupoles are in progress to conserve high polarization above 2.0 GeV.

1 INTRODUCTION

The Bonn accelerator facility consists of a linac, equipped with sources of both polarized and unpolarized electrons, a fast cycling booster (50 Hz), and the storage ring ELSA (Fig. 1) [1]. External beams can be provided between 0.5 and 3.5 GeV with currents ranging from a few pA to 100 nA using a slow resonance extraction method.

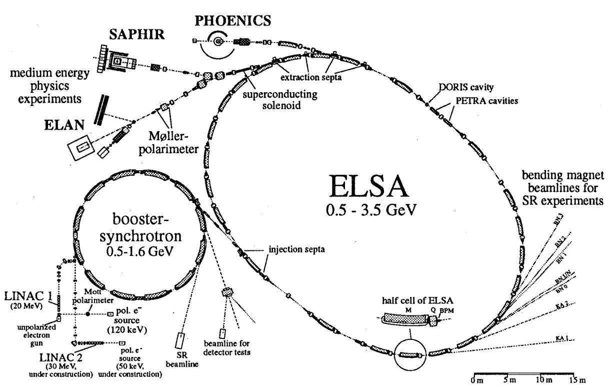

Fig. 1: Site plan of the ELSA facility at Bonn University

The GDH experiment with circularly polarized photons using polarized electrons is planned [2][3]. The intensity requirement at an external target is about 1 nA with a high duty factor and a polarization degree of at least 40%. Polarized electrons are produced at low energies in a polarized electron source to fulfill the intensity requirements of the experiment [4][5].

In a flat ring only the vertical component of the polarization is preserved. The spin vector of each particle precesses around this direction, and the precession frequency depends only on the energy of the considered particle: $Q_{sp} = \gamma a$, where Q_{sp} is the spin tune (i.e. the number of precessions in the rest frame of the particle in one turn), γ is the relativistic Lorentz factor and a is the gyromagnetic anomaly (1.16×10^{-3} for electrons). Depolarizing resonances arise from resonant coupling of the spin precession to periodic horizontal magnetic fields of quadrupoles which depend on the individual vertical trajectory followed by the electrons. The resonances can be divided into two main categories:

1. intrinsic resonances due to the vertical betatron oscillations. The resonance condition is $\gamma a = kP \pm Q_z$, where k is an integer, P is the super-periodicity of the ring ($P=2$ for ELSA) and Q_z is the vertical betatron tune ($Q_z = 4.6$ for ELSA);
2. imperfection resonances due to the vertical closed orbit distortions caused by magnet misalignments and field errors. The resonance condition is $\gamma a = k$.

In order to preserve the polarization to the experiment, several depolarizing resonances must be corrected for during acceleration in ELSA. Therefore studies for the acceleration of the polarized beam at ELSA were carried out.

2 PRODUCTION OF POLARIZED ELECTRONS

The source for polarized electrons at ELSA uses the photoemission from a highly p-doped direct bandgap III-V semiconductor (GaAs-like materials) irradiated by circularly polarized light. The surface is treated with C_S and O_2 to obtain the negative electron affinity (NEA) [6]. An AlGaAs-GaAs superlattice photo-cathode was used in this experiment owing to its high polarization and high quantum efficiency [7]. The polarized electrons emitted from the superlattice cathode were accelerated up to 120 keV in the gun chamber and injected to the linac. The gun chamber consists of an ultra high vacuum (UHV) support unit and a high voltage (HV) accelerating section [4][5].

The polarization degree at 120 keV was measured with a polarimeter [8] using Mott scattering on thin gold foils [9]. The maximum polarization of (63.6± 0.4 stat.±3.4 sys.)% was obtained at a wavelength of 750 nm.

Important parameters of the source for polarized electrons used at ELSA are listed in Table 1.

repetition rate	50 Hz
pulse length	1 μs
electron energy	120 keV
laser spot size on the cathode	≤ 10 mm
polarization degree	$\geq 60\%$
pulse intensity	$1\times10^{11} - 6\times10^{11} e^-$ (peak current of 20 - 100 mA)

Table 1: Parameters of the source for polarized electrons.

3 ACCELERATION OF POLARIZED ELECTRONS

3.1 Beam Acceleration

The polarized electrons were accelerated in the linac to 20 MeV, injected into the booster synchrotron, and accelerated to 1.2 GeV. The injection energy of ELSA was set to 1.2 GeV, staying below the stronger depolarizing resonances in the booster at 1.32 GeV [10]. The beam was accumulated in ELSA during 21 cycles of the booster, and then accelerated to higher energies. The ramping speed for the acceleration in ELSA was changed between 0.1 and 7 GeV/s to study the resonances in detail. The slow extraction lasted about 1 s. The length of the acceleration cycle varied between 1.6 and 2.1 s according to the final energy and the ramping speed.

3.2 Spin Manipulation

For the polarization measurements, the spin direction was changed from vertical to longitudinal after extraction out of ELSA. First the vertical polarization was rotated into the accelerator plane by the use of a superconducting solenoid (maximum integrated field 12.5 Tm). Then the spin precessed in the two bending magnets downstream (see Fig. 1) into the longitudinal direction via Thomas precession.

3.3 Møller Polarimeter

The polarization of the beam was determined by a Møller polarimeter through a counting-rate asymmetry measurement using a target (40 μm Vacoflux: composition 49% Fe, 49% Co, 2% V) containing polarized electrons and both helicity states of the beam [11]. The spin polarization of the target foil was $8.27 \pm 0.26\%$ at saturation (10mT). The Levchuk effect [12] on the effective target polarization is less than 1.3% (relative) for all kinematics. The intensity of the extracted beam was kept between 0.2 and 0.5 nA resulting in a nearly background-free Møller signal in the time-of-flight spectra.

3.4 Experimental Results

First the extraction energy of ELSA was set to 1.27 GeV, so that no depolarizing resonances in ELSA were crossed. A maximum value of (62±2 stat.±3 sys.)% was obtained without significant depolarization.

The extraction energy of ELSA was then set to 1.37 GeV so that only the third imperfection resonance at 1.32 GeV ($\gamma a = 3$) was crossed during ramping of ELSA. Fig. 2 shows the change in polarization degree due to the resonance crossing for different ratios of resonance strength (ε) [13] to the square root of resonance crossing speed (α). The error bars indicate statistical errors only. By varying the ramping speed between 0.1 and 7 GeV/s, one half of the measurements were done without closed orbit correction (ε_1, spin flip domain) and one half with a fixed closed orbit bump for the harmonic correction, reducing the resonance strength significantly (ε_2). The resonance strength of each of the settings was calculated by fitting the Froissart-Stora equation [14] to the measured values (the resonance strength is the only fit parameter for the various crossing speeds).

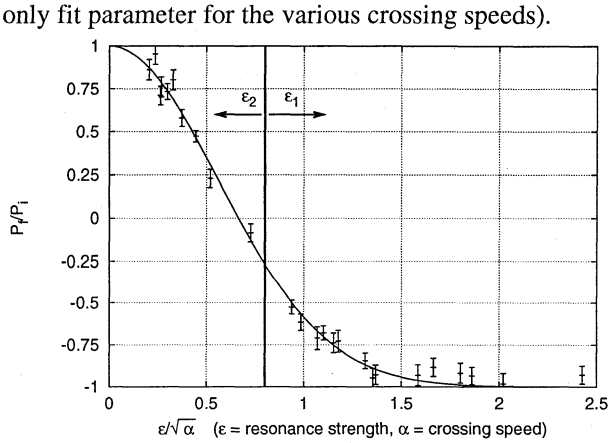

Fig. 2: Ratio of the polarization before and after crossing of the third imperfection resonance versus $\varepsilon / \sqrt{\alpha}$.

The resonances at 1.14 GeV ($\gamma a = Q_z - 2$), 1.5 GeV ($\gamma a = 8 - Q_z$), 1.76 GeV ($\gamma a = 4$) and 2.0 GeV ($\gamma a = Q_z$) were also investigated by varying the crossing speed. The measured resonance strengths of the five depolarizing resonances are summarized in Table 2, together with the calculated values. The measured and the calculated values are in good agreement.

Q_{sp}	E (GeV)	$\lvert\varepsilon\rvert$ (calculated)	$\lvert\varepsilon\rvert$ (measured)
$Q_z - 2$	1.14	6.8×10^{-5}	$(4 \pm 1) \times 10^{-5}$
3	1.32	1.0×10^{-3}	$(1.08 \pm 0.03) \times 10^{-3}$
$-Q_z + 8$	1.5	3.9×10^{-5}	$(9 \pm 1) \times 10^{-5}$
4	1.76	1.6×10^{-3}	$(1.5 \pm 0.2) \times 10^{-3}$
Q_z	2.0	8.7×10^{-4}	$(6 \pm 2) \times 10^{-4}$

Table 2: Comparison of calculated and measured strength of depolarizing resonances in ELSA.

The resonances at 1.14 GeV and 1.5 GeV were wake. They require no correction for ramping speeds above 2 GeV/s. At the fourth imperfection resonance at 1.76 GeV, a complete spin flip was impossible (about 25% of the polarization was lost in the best case), although the resonance strength is larger than at the third imperfection resonance. It seemed to be that the depolarization arises from the multiple crossings due to synchrotron oscillations and the spin diffusion during the spin flip [15][16]. The polarization after crossing the intrinsic resonance at 2.0 GeV ($\gamma a = Q_z$) showed a similar tendency. Consequently, nearly 2/3 of the polarization were lost.

4 CONCLUSION

Polarized electron beams were produced and accelerated at the Bonn accelerator facility. The polarized electron source operates reliably together with the accelerator complex. A beam intensity of up to 0.5 nA was achieved at the target.

The beam polarization was conserved from the source to the target at 1.27 GeV without crossing the resonance. The polarization after crossing the third imperfection resonance at 1.32 GeV with various crossing speeds showed good agreement with the Froissart-Stora equation. The harmonic correction scheme was attempted to reduce the resonance strength. Consequently more than 95% of the initial polarization was preserved. The result showed that the fast crossing using the harmonic correction scheme is feasible in ELSA to overcome the imperfection resonance.

The further depolarizing resonances in ELSA up to 2.0 GeV were experimentally studied. The resonance strengths were determined by measuring the final polarization after crossing the resonance by varying the crossing speed. The obtained values are good agreement with the calculated values. However, the final polarization after crossing the resonances at 1.72 GeV and 2.0 GeV showed a deviation from the Froissart-Stora equation in large $\varepsilon / \sqrt{\alpha}$ region, which is expected from the spin diffusion during the spin flip due to the synchrotron radiation [15][16]. In general, a large value of $\varepsilon / \sqrt{\alpha}$ is required to carry out the adiabatic spin flip for the intrinsic resonance compared with the imperfection resonance, because the electrons with small betatron amplitudes encounter not strong perturbation fields. On the other hand, in large $\varepsilon / \sqrt{\alpha}$ region, the spin diffusion during the spin flip might strongly affect on the depolarization. Experimental results show that the spin flip scheme seemed to be difficult in ELSA to preserve the polarization at high energies. The fast crossing is the only feasible way to overcome both the imperfection resonances and the intrinsic resonances in ELSA.

The beam polarization of 45% was obtained using the spin flip method up to 1.9 GeV. Below this energy the polarized beam fulfills the minimum requirements for the GDH experiment. The best way to avoid the depolarization at the intrinsic resonance at 2.0 GeV is to use the fast crossing using pulsed betatron tune jump quadrupoles, because the spin flip mechanism seems to be impractical in higher energies due to the synchrotron radiation. Two pulsed quadrupoles with ferrite yokes are currently being installed [16][17].

5 REFERENCES

[1] K.H. Althoff and D. Husmann, internal report, Bonn-IR-87-30, Bonn, 1987.
[2] G. Anton on behalf of the GDH collaboration, Prog. Part. Nucl. Phys. 34 (1995) 173.
[3] K. Helbing, Ph.D. thesis, Bonn-IR-97-14, Bonn, 1997.
[4] S. Nakamura, Ph.D. thesis, in preparation.
[5] S. Voigt, Ph.D. thesis, Bonn-IR-96-09, Bonn, 1996.
[6] D.T. Pierce, F. Meier and P. Züricher, Appl. Phys. Lett. 26 (1975) 670.
[7] T. Nakanishi et al., preprint DPNU 97-38, Nagoya Univ., 1997 (to be published in AIP conf. proc. of 7th Int. Workshop on Polarized Gas Targets and Polarized Beams).
[8] W. Hanke, diploma thesis, Bonn-IB-95-33, Bonn, 1995.
[9] T.J. Gay and F.B. Dunning, Rev. Sci. Instr. 63 (1992) 1635.
[10] W. Brefeld et al., Nucl. Instr. and Meth. 228 (1985) 228.
[11] H.A. Olsen, Applications of Quantum Electro-dynamics, Springer Tracts in Modern Physics, Vol. 44, 1968.
[12] L. G. Levchuk, Nucl. Instr. and Meth. A 345 (1994) 496.
[13] E.D. Courant and R.D. Ruth, BNL-51270, Brookhaven, 1980.
[14] M. Froissart and R. Stora, Nucl. Instr. and Meth. 7 (1960) 297.
[15] K. Yokoya, Part. Acc. 14 (1983) 39.
[16] C. Steier and D. Husmann, Correction of Depolarizing Resonances in ELSA, Proc. 1997 Particle Accelerator Conf., Vancouver.
[17] T. Toyama, C. Steier et al., internal report, Bonn-ME-97-01, Bonn, 1997.