Acceleration of Polarized Electrons in ELSA

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Abstract

The stretcher ring ELSA[1] at Bonn University provides external electron beams with high duty factor with energies between 0.5 and 3.5 GeV. New medium energy physics experiments starting in 1998 (e.g. to measure the GDH–sum rule) will require a polarized electron beam. The polarized electrons are produced in a dedicated source using the photo effect with circularly polarized laser light on a GaAs superlattice crystal. To conserve the polarization level throughout the energy ramp up to maximum beam energy it is necessary to cross and correct for several depolarizing resonances. Recently polarized electrons have been accelerated up to 2.0 GeV. The achieved polarization level is sufficient for the planned experiments. Details of the measurements concerning depolarizing resonances are given and compared to simulations with emphasis on the effects due to synchrotron radiation.

1 INTRODUCTION

The electron stretcher ring ELSA is operational since 1987, both as a continuous beam facility for external fixed target experiments and as a synchrotron light source. The accelerator complex consists of a linac, equipped with one source for polarized and one for 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 between some pA and 50 nA. Slow resonance extraction on a third integer resonance is used. The extraction time can be varied between 20 ms and some minutes.

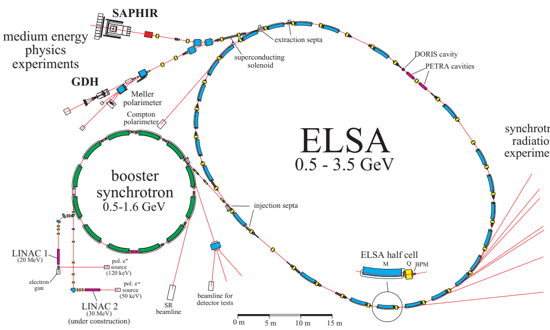

Figure 1: The ELSA facility at Bonn University.

Starting in the next months experiments with longitudinally polarized electrons or circularly polarized photons (produced by Bremsstrahlung) will be carried out. Since the experiments at ELSA require an external beam, the production of polarized electrons using the self polarization due to the Sokolov-Ternov effect would yield insufficient intensities. Instead, a low energy polarized electron source is used. With a GaAs superlattice crystal a polarization level of about 66% at the source has been achieved [2].

In order to preserve the polarization level to the experimental target, several depolarizing resonances have to be crossed and corrected for. This has been routinely done in several proton accelerators but to our knowledge never been used before for physics experiments at an electron storage ring. Some measurements will be presented and compared to simulations to show the differences between the electron and the proton case.

2 DEPOLARIZING RESONANCES

In a flat ring only the vertical component of the polarization is preserved. Every spin vector precesses around this direction and the precession frequency only depends on the particle energy: $Q_{sp} = \gamma a$, where Q_{sp} is the spin tune, γ the relativistic Lorentz factor and a the gyromagnetic anomaly ($1.16 \cdot 10^{-3}$ for electrons). Depolarizing resonances arise from resonant coupling of the spin precession to periodic horizontal magnetic fields. They can be divided into two main categories: intrinsic resonances due to the vertical betatron oscillations in quadrupoles and imperfection resonances due to vertical closed orbit distortions caused by magnet and alignment errors.

The change in polarization level after the linear crossing of an isolated resonance (with equal strength for all particles) is given by the Froissart-Stora equation [3]

$$\frac{P_f}{P_i} = 2 \cdot \exp\left(-\frac{\pi \mid \epsilon_r \mid^2}{2\alpha}\right) - 1, \qquad (1)$$

where ϵ_r is the resonance strength and α the crossing speed ($\alpha = \frac{\dot{\gamma} a}{\omega_{rev}}$ for imperfection and $\frac{\dot{\gamma} a}{\omega_{rev}} \pm \frac{\dot{Q}_z}{\omega_{rev}}$ for intrinsic resonances).

2.1 *Imperfection Resonances*

Earlier measurements [4] had shown that the depolarization in the booster below 1.32 GeV was small. Since there is no space for new elements and no suitable beam diagnostics available in the booster to correct the depolarizing resonances at higher energies, the injection energy of ELSA has to be kept below this value. Therefore the first important resonance in the relevant energy region of ELSA is the imperfection resonance at 1.32 GeV ($\gamma a = 3$). A measurement of the polarization level of the extracted beam below this energy yielded 63% in good agreement with the polarization of 64% at the injection into the booster, confirming the weak depolarization in the booster up to this energy [5].

[1] Electron Stretcher Accelerator

To study the imperfection resonance at 1.32 GeV in detail the injection energy of ELSA was set to 1.2 GeV and the extraction energy to 1.37 GeV. Therefore only this resonance was crossed during ramping. The ramping speed was varied between 0.1 and 7 GeV/s. In Fig. 2 the change in polarization due to the resonance crossing for different ratios of resonance strength to resonance crossing speed and the prediction of the Froissart-Stora equation (Eq. 1) are shown [5]. The error bars indicate statistical errors only. The systematic uncertainty is negligible owing to cancellations in the ratio of polarizations before and after resonance crossing.

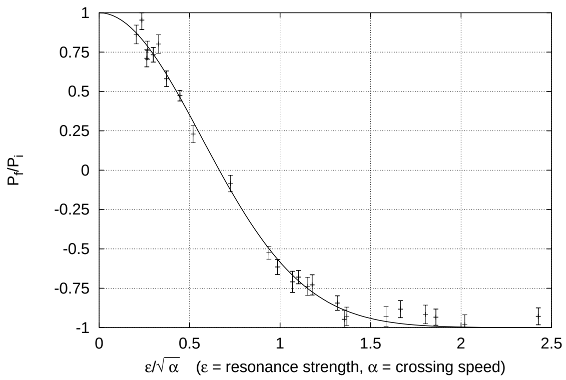

Figure 2: Change in polarization level due to crossing of the imperfection resonance at 1.32 GeV.

The dependence of the measured values on the ramping speed is in agreement with the predictions of the Froissart-Stora equation. Furthermore, the result of the fit (i.e. the resonance strength) is consistent with calculations using the measured closed orbit[2] (see Tab. 1). As expected from the simulations [6] there is no noticeable influence of synchrotron radiation.

Table 1: Comparison of calculated and measured strength of depolarizing resonances in ELSA

γa	E (GeV)	$\lvert\epsilon\rvert$ $[10^{-5}]$ (calculated)	$\lvert\epsilon\rvert$ $[10^{-5}]$ (measured)
$Q_z - 2$	1.14	6	4 $\pm$ 1
3	1.32	100	108 $\pm$ 3
$8 - Q_z$	1.5	4	9 $\pm$ 1
4	1.76	160	150 $\pm$ 20
Q_z	2.0	87	60 $\pm$ 20

To minimize the loss of polarization due to this imperfection resonance a harmonic correction with two vertical orbit bumps was carried out (Fig. 3). Coincidentally one of the bumps was in phase with the driving term of the resonance, so only the amplitude of this bump is shown on the plot. The points represent resonance strengths as calculated from the measured change in polarization due to resonance crossing. The fit (giving a residual resonance strength corresponding to a depolarization of about 2% at maximum ramping speed) is a hyperbolic function with three parameters. The dashed line indicates the resonance strength as calculated using the measured closed orbit and is in good agreement with the depolarization measurements.

[2]measured using beam based alignment techniques

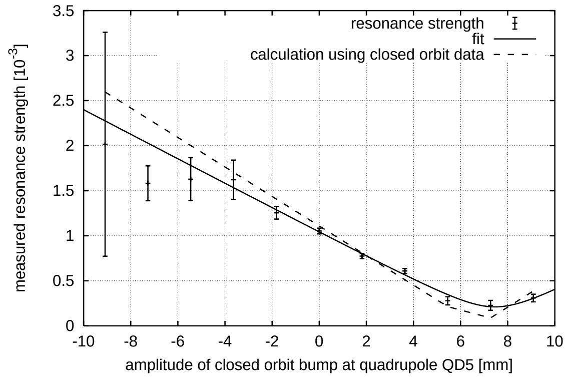

Figure 3: Harmonic correction of the imperfection resonance at 1.32 GeV using a closed orbit bump.

2.2 *Intrinsic Resonances*

The intrinsic resonances at 1.14 GeV ($\gamma a = Q_z - 2$) and 1.5 GeV ($\gamma a = 8 - Q_z$) were also investigated. They both turned out to be weak, as expected from calculations (Tab. 1). Therefore they require no correction for ramping speeds above 2 GeV/s; routine operation will be at about 6 GeV/s.

However, strong depolarization occurred at the intrinsic resonance at 2.0 GeV ($\gamma a = Q_z$). Even with an emittance coupling of only 1%, nearly 2/3 of the polarization were lost. As shown in Tab. 1, this resonance was expected to be the first strong intrinsic resonance in ELSA. Due to the synchrotron radiation emitted by electrons (see section 2.3), which makes it impossible to use the spin flip mechanism [6], the only feasible way to avoid depolarization at this resonance is to use a pulsed betatron tune jump quadrupole (cf. section 3) in contrast to the situation at proton accelerators where various other methods can be used, e.g. [7].

2.3 *Synchrotron Radiation Effects*

The imperfection resonance at 1.76 GeV ($\gamma a = 4$) showed a behaviour fundamentally different from that of imperfection resonance at 1.32 GeV. The change in polarization does not follow the Froissart-Stora equation but shows strong effects of synchrotron radiation. Therefore a complete spin flip is impossible at this resonance (about 15% depolarization in the best case, see Fig. 4). It must be corrected using the harmonic correction method. However, the strength of the resonance is in good agreement with the calculations based on closed-orbit data (see Tab. 1).

2.4 *Spintracking Studies*

To study the influence of synchrotron oscillations and synchrotron radiation on the spin motion and to make reliable predictions of the polarization behaviour in ELSA at energies where it is currently impossible to measure this behaviour due to the strong depolarization at 2.0 GeV, a spin-tracking program (SPTRACK) has been written. It is based on the approach of spinor transfer maps, which has been used earlier for the case of protons [8].

In the proton case one turn transfer maps were used, since all relevant processes there are slow compared to the revolution frequency. Unfortunately, for electrons a large number of photons is radiated during one revolution so that this approach is not applicable. Instead a full tracking of the motion in the longitudinal phase space has been implemented. Individual transfer maps for each dipole of ELSA are used and the energy loss due to synchrotron radiation is calculated between each of these transfer maps. The Monte-Carlo generator for the spectrum of the synchrotron radiation is the routine described in [9].

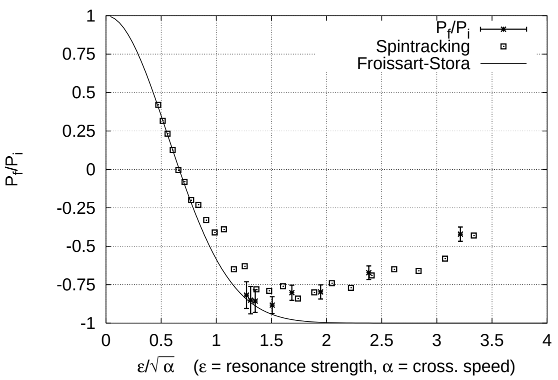

Figure 4: Change in polarization level due to crossing of the imperfection resonance at 1.76 GeV.

Using SPTRACK to simulate the crossing of depolarizing resonances gives results in good agreement with the measurements (Fig. 4). However, to reach this agreement an additional coherent synchrotron oscillation with an amplitude of about twice the equilibrium energy spread had to be included into the tracking. Indeed, these oscillations have been observed during the measurements and may be attributed to longitudinal multibunch modes and synchro-betatron resonances during ramping. The amplitude needed to reproduce the effect in the tracking is in rough agreement with the amplitude measured in the longitudinal bunch spectrum.

3 TUNEJUMP QUADRUPOLES

Even at maximum ramping speed and with emittance coupling ratios of 1%, three of the intrinsic resonances at ELSA are sufficiently strong to cause a significant depolarization. Since synchrotron radiation effects prevent an application of the spinflip technique (cf. section 2.3), the crossing speed has to be increased. For this purpose a system of pulsed Panofsky type quadrupoles with ferrite yokes has been designed that shifts the vertical tune rapidly during resonance crossing [10].

The design was optimized with respect to the inductance of the magnet and the multipole composition of the field. The main problem causing higher multipole components is the skin effect (the rise time of the magnet is 10 μs). This has been simulated and a coil arrangement was chosen to minimize the unwanted multipoles. The field map and the inductance of the magnet have been measured in detail. The field gradient is 1.2 T/m with two windings at 500 A, the higher multipoles are negligible and the inductance is about 9 μH [11]. Measurements with beam will start next month.

4 SUMMARY

Polarized electrons have been produced and accelerated at ELSA. A time averaged beam intensity of 0.5 nA has been achieved at the target. The obtained maximum polarization was 63% at 1.27 GeV. Until now a polarization of 45% has been preserved up to 1.9 GeV correcting the resonances in between.

The behaviour of the polarization after crossing the imperfection resonance at 1.32 GeV showed good agreement with predictions of the Froissart-Stora equation. Using the measured closed-orbit distortions for the calculation, the measured resonance strength is consistent with the simulation. A harmonic correction of this resonance has been successful at preserving more than 95% of the initial polarization. At the imperfection resonance at 1.76 GeV the effects of synchrotron radiation become visible. The measured depolarization agrees with the predictions of a spin-tracking program.

Strong depolarization occurred at the intrinsic resonance at 2.0 GeV. This will be cured by fast tune jump quadrupoles. The design and construction of the tune jump quadrupoles has been completed and first tests without beam were carried out.

5 REFERENCES

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