Correction of Depolarizing Resonances in ELSA

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Abstract

At the 3.5 GeV electron accelerator ELSA (Bonn University) an upgrade for polarized electrons is under way. A source of polarized electrons (GaAs crystal, electrons produced by photoeffect using circular polarized laserlight) is operational. Recently, studies have been started to minimize the losses in polarization level due to crossing of depolarizing resonances, which necessarily exist in circular accelerators (storage rings). Calculations concerning different correction schemes for the depolarizing resonances in ELSA are presented, and first results of measurements, done by means of a Møller polarimeter in one of the external beamlines, are mentioned.

1 INTRODUCTION

The electron stretcher ring ELSA[1] is operational since 1987, both as a continuous beam facility for external fixed target experiments and part of the time as a dedicated synchrotron light source. The accelerator complex consists of two LINACs, each equipped with sources of polarized and unpolarized electrons, a fast cycling booster (50 Hz) and the storage ring ELSA (Fig. 1). External beams can be provided beween 0.5 and 3.5 GeV with currents between some pA and 100 nA [1]. A slow resonance extraction on a third integer resonance excited by sextupoles is used. The extraction time can be varied between 20 ms and some minutes.

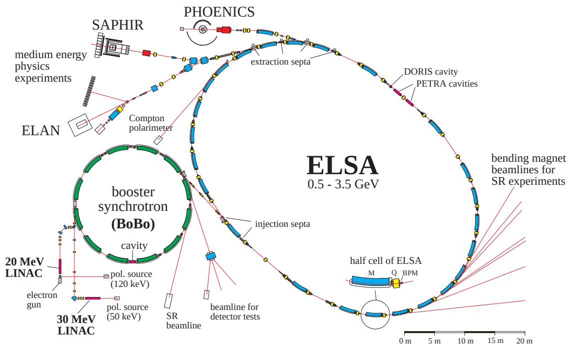

Figure 1: Site plan of the ELSA facility at Bonn University.

Starting 1997/1998 experiments with longitudinal polarized electrons or circular polarized photons (produced by bremsstrahlung) will be carried out. Because of the intensity requirements of an external target, the polarized electron beam cannot be produced by self polarization due to the Sokolov-Ternov effect. Instead, a low energy polarized electron source has to be used. With strained GaAs or superlattice crystals it is possible to achieve a polarization level of more than 70 % at the source.

In order to preserve the polarization level to the experimental target, several depolarizing resonances (both in the booster and in the storage ring) have to be crossed and corrected. This has been successfully done in several proton accelerators but not yet in an electron storage ring. Some calculations will be presented to show the differences. The applied correction techniques also differ from the scheme which is applied in high energy electron storage rings to obtain a high equilibrium polarization.

In a flat ring only the vertical component of the polarization is preserved. Every spin vector precesses around this direction and the precession frequency depends only on the energy of the corresponding particle: $Q_{sp} = \gamma a$, where Q_{sp} is the spin tune (i.e. the number of precessions in the restframe of the particle in one turn), 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:

1. intrinsic resonances due to the vertical betatron oscillations in quadrupoles and the resulting horizontal magnetic fields: Resonance condition is $\gamma a = kP \pm Q_z$, where k is an integer, P the supersymmetry of the ring ($P = 2$ for ELSA) and Q_z the vertical betatron tune;
2. imperfection resonances due to magnet errors and the resulting vertical closed orbit distortions: Resonance condition is $\gamma a = k$.

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 [2]

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

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 INTRINSIC RESONANCES

The strength of an intrinsic resonance is different for each individual particle and depends on its vertical betatron amplitude. To calculate the depolarization one has to integrate Eq. (1) over the vertical phase space. But since the resulting formula has the same qualitative behaviour, the following qualitative discussion can be carried out using Eq. (1).

[1]Electron Stretcher Accelerator

There are two possibilities to avoid depolarization: For small resonance strength or high crossing speed the polarization vector stays unchanged. For high strength or low crossing speed a spinflip (with conservation of the absolute value) is possible. For an electron accelerator like ELSA, the second possibility is not applicable for intrinsic resonances. At imperfection resonances the situation is somewhat different which will be discussed later.

To reduce the strength of intrinsic resonances, tests to decrease the emittance coupling have been done. A coupling ratio of less than 5 % could be achieved during the whole ramping phase (below 1 % during flat top). But even then, three of the intrinsic resonances are sufficiently strong to cause a significant depolarization. So additionally the crossing speed has to be increased. For this purpose a pulsed system of Panofsky type quadrupoles with ferrite yokes has been designed that shifts the vertical tune rapidly during resonance crossing [3].

The design was optimized with respect to the inductance of the magnet and the multipole composition of the field. For earlier designs of similar magnets (IUCF, KEK or ELSA) only two-dimensional simulations have been used. They underestimated the inductance of the magnet by more than a factor of two. We suspected the field of the conductor loops at the end of the magnet and the stray fields to be the source of the discrepancy. In a three-dimensional simulation both effects are included naturally. The result of a 3D simulation using MAFIA [4] for the inductance of our magnet was 14.4 μH in comparison to 6.4 μH from a 2D simulation. As a check for the validity of this result, we also did 3D simulations of several already existing ironless or ferrite quadrupoles and we could reproduce their measured inductances to about 10 %.

The main problem causing higher multipole components is the skin effect (the rise time of the magnet is 10 μsec and the peak gradient 1.2 T/m). This has been simulated and a coil arrangement was chosen to minimize the unwanted multipoles.

2.1 Ion Problems

Ions produced by scattering on the residual gas molecules can be captured in the electric potential of the beam. They introduce an additional space charge that results in a shift of the betatron tune. This problem does not exist for proton accelerators, where depolarizing resonances have been successfully crossed in the past.

Furthermore there can be a coherent instability between the captured ions and the electron beam if a certain threshold number of captured ions is reached. The instability strongly increases the emittance of the electron beam and causes a sudden change in the vertical tune (Fig. 2). This increases the strength of intrinsic resonances and requires the tune jump to be enlarged. For a homogeneous filling of ELSA, the instability threshold is reached for relatively low currents at injection energy. Therefore cures against the instability have to be applied [5].

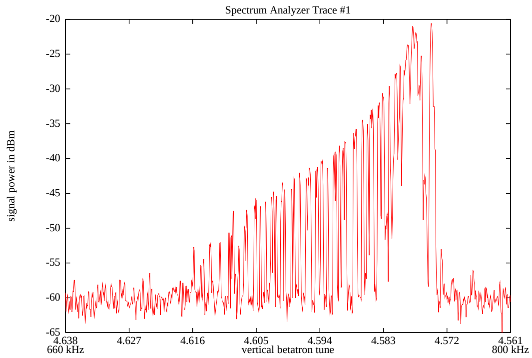

Figure 2: Spectrum of the coherent vertical oscillation of the beam (averaged over 10 sec) around the $5-Q_z$ betatron tune sideband ($Q_z^{nom} = 4.575$). No external excitation of the beam is applied.

At ELSA, first a gap in the filling structure (filling only 1/3 of the ring) was applied during synchrotron radiation runs. Later this has also been used for external experiments, but the gap has to be smaller in order to keep a high duty factor. A second possible cure is the application of beam-shaking (resonant vertical excitation of the beam close to a sideband of the vertical tune). This is now integrated into the routine operation with high currents below 1.6 GeV. Also clearing electrodes can be used. Their installation is under way and first tests have been carried out. Overall the coherent instability is suppressed for beam parameters relevant for polarized electron operation. Also the tuneshift could be kept at an acceptable level.

3 IMPERFECTION RESONANCES

The strength of imperfection resonances is roughly proportional to the average vertical closed orbit distortions. Unfortunately, the achievable overall orbit quality during ramping is not sufficient to avoid a significant depolarization. Therefore one concentrates on the closed orbit harmonic(s) that is (are) driving a specific resonance. Because the crossing speed of imperfection resonances is determined by the ramping speed only (which is more or less fixed), the only parameter to vary is the resonance strength.

3.1 Adiabatic Spinflip

The spin motion in an electron storage ring is strongly affected by the synchrotron motion and the stochastic emission of synchrotron radiation [6]. Therefore the dependence of the final polarization on the resonance strength is more complicated than in Eq. (1). To calculate this, one starts with the formula describing the spin precession close to a resonance in a spinor representation. Then one has to include the synchrotron oscillation, the emission of photons and the ramping into the terms containing γ. Afterwards it can be solved by pertubation methods and numerical integration.

These calculations show that it is possible to achieve a nearly perfect spinflip up to the 4th imperfection resonance

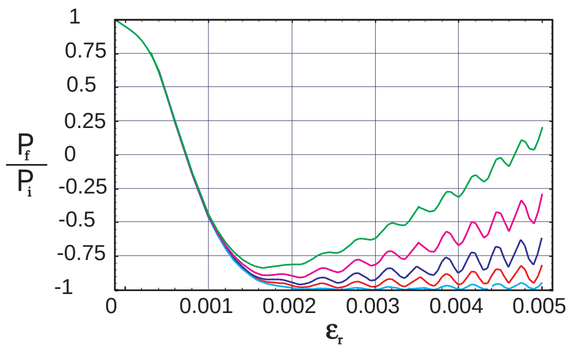

Figure 3: Simulation of depolarization due to crossing of the 3rd (lowest curve), 4th, 5th, 6th or 7th (top curve) imperfection resonance plotted against the resonance strength. The graphs have been calculated with ELSA standard beam parameters and a ramping speed of 6 GeV/s.

at ELSA (Fig. 3). The required resonance strength is about $2 \cdot 10^{-3}$. This can easily be achieved by the help of two existing correctors and the required closed orbit distortion will be safely inside the machine aperture. The advantage of a spinflip over a harmonic correction is the smaller sensitivity to corrector and measurement errors. Thus it is fast to optimize and should be very reproducible once established. At higher energies a spinflip is still possible, but is combined with significant depolarization. Therefore a harmonic correction scheme is planned for these resonances.

3.2 Harmonic Correction

The aim of the harmonic correction is the reduction of the degrees of freedom of the optimization problem by correcting only the closed orbit harmonics relevant for the actual resonance. Therefore it is possible to optimize the initial corrector settings calculated from closed orbit data by measurements of the actual depolarization. For simulations concerning different correction methods a program to calculate resonance strengths based on the Courant-Ruth formalism [7] (used in combination with MAD [8]) has been written. As a result, specifications for an upgrade of the corrector system have been formulated.

4 EXPERIMENTAL STATUS

A source of polarized electrons is operational and first tests with a superlattice crystal were carried out. A low energy Mott polarimeter downstream from the source and a high energy Møller polarimeter in an external beamline can be used for measurements. During several machine development runs longitudinal[2] polarization behind the storage ring has been measured[3] at 1.27 GeV with the Møller polarimeter. Currently several investigations are going on to optimize the polarization level at that energy.

Within this year an internal Compton polarimeter will come into operation at the storage ring. It will be calibrated by observation of the polarization build-up due to the Sokolov-Ternov effect. To choose suitable optics, tracking studies with SITROS [9] have been carried out. Afterwards each of the resonances will be studied in detail. The two tune jump quadrupoles will be installed in the end of 1997. An upgrade to improve the speed of the corrector dipoles will be carried out this year and also the beam position monitors are currently equipped with new electronics.

Beam based alignment measurements have been started (the k-values of all quadrupoles can be varied separately) in order to improve the precision of the closed orbit correction and to calibrate the optics model of ELSA [10]. First results indicate that the lattice errors are sufficiently weak, such that gradient error and other higher order depolarizing resonances cause no problems.

5 SUMMARY

The program to correct depolarizing resonances at ELSA has been started. To produce polarized electrons a GaAs-type source is used. A low and a high energy polarimeter are operational and first measurements of the polarization level behind the main ring have been done. Such studies of resonance crossing during ramping have not been performed at other electron storage rings yet. The design of a system of pulsed quadrupoles for the crossing of intrinsic resonances is finished. Cures for ion problems, which are specific of electron accelerators, are implemented. Simulations show that a spinflip can be achieved up to the 4th imperfection resonance to minimize depolarization. For higher energies synchrotron oscillations and synchrotron radiation become too strong. Therefore harmonic correction schemes have been simulated and upgrades of the corrector system with respect to the results are under way.

6 REFERENCES

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[2] In the external beamline the spin orientation is rotated from vertical to longitudinal.

[3] using a bulk GaAs crystal at the source