POLARIZED ELECTRONS IN THE AMPS STORAGE RING

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Abstract

AmPS is a 300-900 MeV electron ring. The machine was designed as a pulse stretcher to provide continuous external beams. After years of successful operation in this mode the nuclear physics program now concentrates on experiments with stored beams interacting with internal gas targets. These experiments require currents between 50 and 200 mA through 60 cm long 15 mm wide cylindrical target cells. Gas pressures in the open-ended cells correspond to target thickness of 10^{14} to 10^{16} atoms/cm^2. Strong stray fields from a spectrometer and from target holding fields disturb the closed orbit. Under operational conditions the linac provides a maximum energy of 700 MeV, so ramping is required to achieve 900 MeV. To further increase the luminosity at the target a reduced emittance lattice based on the existing magnet configuration has been designed. Late 1996 a polarized electron injector as well as a "Siberian Snake" to control the spin on the internal target became operational. The polarized injector delivers a few mA to the linac so stacked injection in the ring is required. With strained InGaAsP cathodes a polarization of 80 % was obtained. Test results, performance and prospects are presented.

1 INTRODUCTION

NIKHEF is a nuclear physics and high-energy physics research institute. The storage ring AmPS provides high duty factor (d.f.) beams for the in-house electron scattering experiments. The experiments use several detectors measuring in coincidence. The real to accidental coincidence ratio is directly dependent of the d.f. of the beam on target. In pulse stretcher mode the ring provides routinely external beams up to 10 μA @ 300 to 700 MeV. For experiments with internal targets up to 150 mA @ 300 to 700 MeV is available. An energy of 950 MeV was achieved in Spring 1997 during accelerator physics experiments. Details on the design and the performance of the ring were reported earlier, an extensive list of references is available [1]. A collaboration between NIKHEF, the Budker Institute of Nuclear Physics (BINP) and the Institute of Semi-conductor Physics (ISP) allowed to add a polarized electron source and a siberian snake to the AmPS accelerator facility. A first internal target (IT) experiment with polarized electrons was performed in Fall 1996 with on average a stored current of ~ 5 mA @ 650 MeV. Meanwhile systematic commissioning of key systems improved the cathodes lifetimes, the stored current and the polarisation degree.

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2 AmPS with POLARIZED ELECTRONS

2.1 Self polarization

Due to the emission of synchrotron radiation the electron spins will be aligned with the direction of the magnetic field (i.e. transverse polarization). The time constant of this 'Sokolov-Ternov effect' in practical units [2] is

$$\tau_0[hr] = 2.75\times10^{-2}\,\frac{\rho^2 R[m^3]}{E^5[GeV]}$$

The maximum polarization degree is about 92 %. Since the desired spin-orientation at the target location is longitudinal, an additional insertion device is needed to re-orient the spin. For AmPS at E = 800 MeV the self–polarization time $\tau_0 \approx 30$ hr, not very useful with gas IT's.

2.2 Injection of polarized electrons

Because of the long self-polarization time it was decided to inject polarized electrons directly into AmPS. In order to obtain the desired longitudinal polarization at the IT location, some spin manipulation is necessary.
The spin tune ν_0 is given by $\nu_0 = \gamma.a$, γ is the Lorentz factor and $a = (g – 2)/2$. In practical units this relation is expressed as ν_0 = E[MeV]/440.65. Only at energies being integer multiples of this 'magic energy' of 440.65 MeV will the spin tune be integer. At these energies a longitudinal polarization at the IT location will be maintained without additional insertions (assuming injection with the proper polarization direction!). At all other energies the spin tune is not integer and a special device, e.g. a Siberian Snake, is needed to make the spin tune integer. A Snake rotates the spin by p along the longitudinal beam axis, which introduces in the x–plane an additional spin rotation of $2(p – \nu_0/2)$; in one revolution the spin rotates by ν_0, so the net rotation per revolution is just 2p, independent of energy, see Fig. 1. To produce longitudinal polarization at the IT location, an energy–dependent polarization of the injected electrons is required, since ν_0 *does* depend on energy. To rotate the spin over π, a solenoid with a field integral of

$$\int \frac{B_s\,dl}{B\rho} = \pi \qquad (1)$$

is required. The total length of the AmPS solenoids is 1.624 m, so from (1) the field requirement follows:

$$B_S\,[T] = 6.45\,E[GeV].$$

Superconducting solenoids are needed to reach this field magnitude.

2.3 Beam optical effects

A solenoid will introduce strong coupling between the two transverse planes. In order to remove this coupling the solenoid has been split into two parts, and the total Snake includes two 45˚–rotated end quadrupole doublets and a strong central quad. This structure possesses the following transfer matrix:

$$M = \begin{pmatrix} -1 & 4.7 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 4.7 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

In the horizontal plane the Snake behaves as a 4.7–m drift space, with a tune advance of $\Delta\nu_X = 0.5$ (as $\cos\mu_X = -1$). Vertically the Snake is just a 4.7–m drift length. To first-order, the x–y coupling has been removed. When the Snake is operated, AmPS is run with a slightly modified lattice configuration, in order to compensate the additional horizontal tune shift.

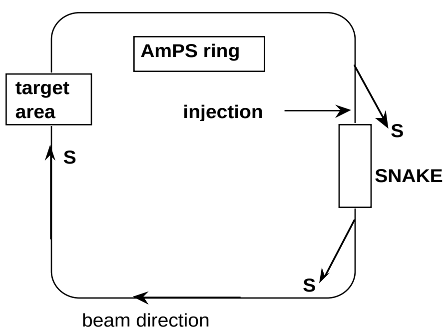

Fig. 1 Spin orientation in AmPS with Snake on.

3 THE POLARIZED ELECTRON SOURCE (PES)

PES mainly consists of a loading chamber, a preparation chamber, a 100 keV photo-cathode gun, a Ti:Sapphire laser with an optical circuit, a Z-shape spin manipulator, a Mott polarimeter and a 300 keV r.f. post-accelerator.
Cathodes are inserted into and extracted from the source UHV system through the loading chamber. With a magnetic manipulator cathodes can be exchanged between the loading and the preparation (prep) chamber. The prep chamber can store up to 4 cathodes. One cathode can be prepared to a Negative Electron Affinity (NEA) surface state at a time. Also the quantum efficiency and the lifetime (at He-Ne laser wavelength) can be measured in the prep. chamber. Cathodes are exchanged between the prep. chamber and the photocathode gun by means of 2nd magnetic manipulator, within a typical time of 15 min.
The photocathode gun is designed with double vacuum chambers and a double high voltage insulator [3]. The latter allows for the permanent connection of the preparation and loading chamber. The cathode operates at **-100 kV**. Pulsing this power supply with the injection frequency (typ. 1 Hz, max. 10 Hz) and with a pulse length of 600 µs increased the cathode lifetime from 4 to 180 h with respect to the former d.c. mode of operation. The photocathode is illuminated by Ti:Sapphire laser. Its wavelength range is from 700 to 850 nm at intensities up to 1kW per pulse. By means of an electro-optic pulse slicer, with a variable delay and width, the laser pulse length can be set in the range 0.4 - 4 µs. The laser produces linearly polarized light. A $\lambda/4$ plate converts the polarization to circular. The intensity of the pulses is adjustable by a rotatable Glanprism. The laser spot on the cathode can be adjusted by a variable diaphragm which is projected onto the cathode surface. The laser pulses are synchronized with the h.v. power supply pulses.
From the gun the 100 keV electrons are guided through two 45° bending magnets towards the Z-shape spin manipulator. Here the electron spin orientation can be adjusted by an arbitrary angle. The principle of the spin rotator is based on the Illinois-CEBAF design [4] . It precesses the spin such that the maximum longitudinal polarization can be achieved at the internal target location of the storage ring AmPS. To match the injection requirements of MEA the polarized electrons are accelerated to 400 keV by a post-accelerator. This accelerator consists of two 2856 MHz cavities, one for prebunching and one for acceleration. The beam is inflected in MEA by an α magnet. Fig. 2 shows a lay-out.

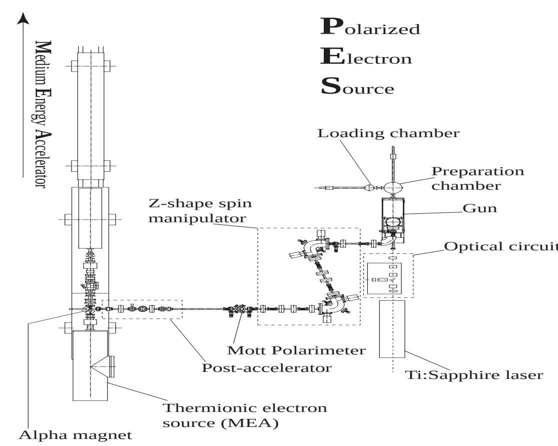

Fig. 2. Overview of the polarized electron source

Diagnostics: the polarization degree of the electrons is measured with a Mott polarimeter based on an existing design [5]. The polarimeter is positioned downstream of the Z-shape spin manipulator because the measurement is sensitive to the transverse polarization of the beam.
To determine the polarization degree the electrons are scattered on a 100 nm thick gold foil. Other foils with different thickness are used to calibrate the polarimeter. Four silicon surface barrier detectors detect the scattered electrons. Two detectors are mounted at +120° and -120° to measure the scattering asymmetry. The other two detectors are mounted at +50°, and -50° and monitor the instrumental asymmetries. The current transmission along the beampath of the source can be measured with 2 current transformers and also with a Faraday cup when the alpha magnet is not powered.

Six screens provide information on the beam shape and position along the beam path of the polarized electrons. Selection of the cathodes is a tedious job, especially since a high quantum efficiency is not necessarily related to a high current output. The best cathodes so far provided 30 mA at 50 % polarization and 10 mA at 70 % polarization. The transmission in to MEA is ~ 25 to 30 %.

4 SIBERIAN SNAKE

The snake consists of 2 mirror symmetric sections. Each section is composed of 2 “skew” (90°) quadrupoles, one superconducting (SC) solenoid and one “normal” quadrupole. The SC solenoids are warm bore types. Each solenoid consists of 5 coils that are connected in series. The inductance of a coil is ~ 450 mH and a 0.2 Ω resistor is externally connected across each coil giving an L/R of ~ 2 s. The maximum current is ~ 300 A yielding a field of 6.5 T , good for 1 GeV. NbTi (NT-50) wire with a ø of 0.85 mm is used for the coils as well as for the leads from the coils to the outside world. There is one cryostat that feeds both solenoids with liquid He. The ”heat” shields are now cooled by the return He gasflow reducing the consumption of He from the original 150 to 70 liter/24 h.

5 POLARIMETER

To measure the polarization of the stored electrons in the AmPS ring, a polarimeter based on spin-dependent Compton scattering has been designed and constructed. The cross section for elastic photon-electron scattering depends on the product of longitudinal electron polarization (P_z) and circular photon polarization (S_3) by:

$$d\sigma/dE = \sigma_0(1 + P_z S_3 \alpha_{3z})$$

where σ_0 is the unpolarized cross section and α_{3z} the analyzing power (which is of the order of 2% at 1 GeV). The polarimeter consists of a Argon-ion laser, an optical path for the laser beam, and a gamma-detector to measure the energy of the backscattered photons. The Argon-ion laser produces a CW beam of 10 W in TEM_{00} mode at 515 nm. The optical path contains remotely controllable mirrors to transport the laser light to the interaction region and lenses to maximize the density of the laser light. A Pockels cell and a quarter-wave plate are used to create left and right circularly polarized light. Photons which are Compton scattered, have energies up to 30 MeV and are detected with a pure CsI crystal of 10x10x24 cm^3. A lead shield surrounds the crystal, while a plastic scintillator is placed in front of the detector to veto charged particles. Initial tests with the polarimeter have shown that we can optimize the overlap of the electron and laser beam by means of the remote controlled mirrors. 88% of all detected photons originated from Compton scattering with a rate normalized to the beam current of 3.5 kHz/mA.

6 RESULTS

A current of 150 mA is routinely stored in AmPS by 3 turn injection and stacking of 2 mA polarized e^- pulses from the linac MEA. This was achieved by precise matching of the pulses of the 2 injection kickers.

The polarization life time of the electrons stored in AmPS was measured see fig. 3. These measurements indicate that the polarization life time is long enough to enable IT experiments using the polarized electron beam, because then the ring is refilled typically every 10 minutes. The measurements also show that there is no significant loss of polarization during injection, even with multi-turn injection and stacking.

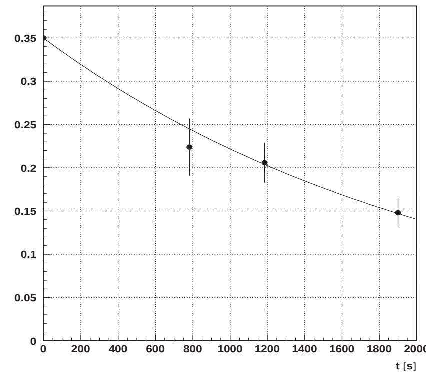

Fig. 3. Polarization (vertical axis) versus time [s]. Stored current at t = 0: 120 mA.

Due to a destructive quench of several of the SC leads to the solenoid coils the commissioning had to stop end of January 1997. One of the solenoids is still operational and it will be tried to maintain polarization in the ring with this solenoid. This only works well close to the magic energy of 440 MeV.

7 PROSPECTS

Internal target experiments with polarized electrons will be resumed early 1998, after the repair of the snake.

High-luminosity: a first lattice design [6] for a threefold reduction of the stored beam emittance proved extremely sensitive to some quadrupole settings. The design could be adapted allowing for “offsets” up to 3 % without deteriorating the reduced emittance nor the betafunction amplitude at the internal target. The emittance will be measured indirectly by measuring the size of the beam profile with a system based on compton scattering [7].

Ramping: starting from 650 MeV the energy could be successfully ramped to 950 MeV in 15 min. (without IT cell and with electrons from the thermionic gun). The current loss (includig lifetime effects) during ramping was typically 50 % with starting currents of 75 mA.

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