Beam induced depolarizing resonances in the HERMES hydrogen/deuterium target

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Abstract. Nuclear polarized hydrogen and deuterium gas targets employed in high-energy storage rings have become an important tool in the study of spin dependent processes in nuclear and particle physics. A severe problem in the use of this type of targets in bunched beams is the nucleon depolarization which can take place when the transient magnetic fields generated by the beam interact with the polarized nucleons and change their spin state. These depolarization processes can be studied experimentally with a fully operational target installed in a storage ring. This is the case of the HERMES target (at HERA - DESY) where this effects have been extensively studied in the past with H longitudinally polarized with respect to beam axis. In the presentation, besides of the results related to the past longitudinal running, the new problematics related to the present running with transversally polarized H will be addressed.

INTRODUCTION

The HERMES gaseous polarized hydrogen/deuterium internal target is operational since 1996 in the HERA electron storage ring at DESY[1]. The polarized gas, produced by an atomic beam source (ABS), is injected into a storage cell[2] through which the 27.5 GeV HERA electron beam passes. The target atomic polarization is measured by a Breit-Rabi polarimeter[3]. A magnet surrounding the storage cell provides a holding field defining the polarization axis and preventing spin relaxation by effectively decoupling the spin of electrons and nucleons. The orientation of the field, longitudinal to the electron beam axis from 1996 to 2000, was switched to transverse in 2001.

A potential source of target depolarization is related to the interaction of the transient magnetic fields generated by the bunched electron beam with the polarized nucleons of the target. This effect has been studied with both field orientations and beam induced depolarizing resonances have been clearly seen. The occurrence of new densely spaced resonances makes this problem particularly critical in the transverse case, where it can be avoided only by designing a very uniform target magnetic field.

THE HERMES TARGET POLARIMETER

The atomic polarization is constantly monitored by a Breit-Rabi polarimeter (BRP) (fig. 1). A sample of target gas leaving the storage cell enters the BRP encountering first two hyperfine transition units and then a sextuple magnets system. A flux composed by the two (three) upper hyperfine states of atomic hydrogen (deuterium) is focused
into a quadrupole mass spectrometer (QMS) and detected by a Channeltron. A beam blocker placed inside the sextuple system ensures that no atoms in the lower states can reach the QMS. The background measurement is carried out by using a chopper which periodically shuts the flux in front of the QMS. A differential pumping system keeps the pressure in the detector chamber at $1 \cdot 10^{-10}$ mbar.

For any given ABS injection status, the BRP transition units are operated in at least four (six) different modes in the hydrogen (deuterium) case. In this way, a number of signals equal to or larger than the number of hyperfine levels can be collected. Knowing the efficiencies of the transitions units and the relative transmissions of the sextupole system for different hyperfine states, the four (six) hyperfine populations can be calculated. Finally, applying the knowledge of the target field intensity, the polarization of the sampled atomic beam is computed. The standard acquisition time for a polarization measurement lasts roughly 60 s for hydrogen and 90 s for deuterium.

The BRP calibration is carried out by operating the transition units in all possible ways. By doing so for different ABS injections modes, it is possible to collect a number of signals larger than the number of unknown (efficiencies, transmission ratios and hyperfine populations) and therefore determine the transition units efficiencies and the sextupoles transmission ratios.

The BRP sextupole system has been recently optimized by replacing its magnets. Due to this improvement, the current statistical uncertainty for 60 s polarization measurement is less than 0.5%. The systematic error is in the order of 1%.

Because of its capability of measuring the individual hyperfine populations, the Breit-Rabi polarimeter is particularly suited for identifying the different kinds of transitions caused by the beam induced time dependent fields.

**FIGURE 1.** Schematic of the BRP. The light grey elements are the two transition units. As in the ABS case, the strong field transition (SFT) needs to be replaced and the medium field transition (MFT) retuned when switching between hydrogen and deuterium. The dark grey elements are the sextupoles. The beam shutter is used to measure the hydrogen contribution coming from dissociative water.
TARGET DEPOLARIZATION BY BEAM INTERACTION

Bunch field induced resonant depolarization in the HERMES target may originate when the frequency of an rf-harmonic induced by the HERA e-beam matches the frequency difference between two different hyperfine states present in the storage cell. The probability of such an event is proportional to the square of the beam current. In order to determine for which values of the target field this mechanism can take place, one has to study the harmonic structure of the time dependent magnetic field induced by the 220 bunches of the electron beam. As the distance between two adjacent bunches is $\tau = 96$ ns, the frequency spacing between two harmonics is given by $\nu = \frac{1}{\tau} = 10.41 \text{ MHz}$. Since the width of the gaussian shaped bunch is very narrow ($\sigma_t = 37.7$ ps), a huge number of harmonics with non-negligible amplitude (more than 400 within one sigma of the Fourier spectrum) can contribute to induce rf-fields.

Depending on the pair of hyperfine states involved, transitions are distinguished between $\pi$, occurring when the rf-field component is perpendicular to the static one, and $\sigma$, taking place when the two fields are parallel. Around the working point of the target magnet (300 to 340 mT), the $\pi$ resonances are easily avoidable with a field uniformity of the percent level. This is unfortunately not the case for the $\sigma$ resonances, whose spacing is only 0.37 mT. The resonance conditions for the hydrogen case are shown in figure 2. For deuterium the spacing between two $\sigma$s of the same kind is again 0.37 mT, but the situation is complicated by the presence of two possible transitions ($|2\rangle \leftrightarrow |6\rangle$ and $|3\rangle \leftrightarrow |5\rangle$). On the other hand, the interval between two $\pi$s is larger in this case.

Due to the relative orientations of the beam induced magnetic field and the static holding field...
field, the $\sigma$ transitions are present in the transverse case only.

THE MEASUREMENTS

Beam induced depolarizing resonances have been observed in the HERMES target during measurements taken in 1997 with the longitudinal hydrogen target[4], and in 1999 during a transverse target test run[5].

In the longitudinal case, the field was produced by a superconducting solenoid capable of an intensity up to 400 mT and a uniformity better than 2%. During normal condition the field strength was set to 335 mT, between two $\pi$ resonances. For the observation of the depolarizing resonances two different techniques were applied. In both cases hyperfine states $|3\rangle$ and $|4\rangle$ produced by the ABS were injected into the storage cell. The first method, called flip-in, was designed to detect the two possible $\pi$ transitions $|1\rangle \leftrightarrow |2\rangle$ and $|3\rangle \leftrightarrow |4\rangle$ in the target field range between 220 to 400 mT. During a slow field scan, the polarimeter was arranged to detect the presence of states $|2\rangle$ and $|3\rangle$ only. The position and shape of each resonance in that field range could be observed, as it is shown in the left plot of figure 3. In the second approach, the field was scanned within the range of the $62^{th}$ harmonic, and the BRP arranged to perform a complete polarization measurement at each step. The right plot of figure 3 shows the loss of nuclear polarization of the target atomic sample during this measurement.

Similar measurements were taken during a special run in 1999 using a transverse conventional dipole magnet capable of a field intensity up to 180 mT and a uniformity along the longitudinal direction $z$ of 0.6 mT (at 150 mT). The $\pi$ resonances were observed using the flip-in technique in a field range between 110 and 162 mT. Unfortunately, due to the non-uniformity of the field and to a failure of the QMS of the polarimeter, the individual $\sigma$ resonances could not be seen and their effect could not be measured.

FIGURE 3. Beam induced depolarizing resonances observed in the HERMES longitudinal hydrogen target. The left plot shows the results of the flip-in measurement. The signal peaks cause by the harmonics number 60 to 62 are caused by $\pi$ $|1\rangle \leftrightarrow |2\rangle$ resonances, whereas the 75 and 76 are due to the $\pi$ $|3\rangle \leftrightarrow |4\rangle$. The arrow shows the working point of the longitudinal magnet. In the right plot, the polarization measurement within the field range of the $62^{th}$ harmonic is displayed. The fit represents the depolarization calculated taking into account the atomic density distribution inside the target cell, the expected resonance probability and the target field shape[6].
THE TRANSVERSE MAGNET DESIGN

In 1999, the HERMES collaboration decided to run with a transverse polarized hydrogen target starting from 2001. For this purpose, a new target dipole magnet was constructed. The most severe field requirement which had to be faced was related to the problem of the possible beam induced depolarization via $\sigma$ transitions. In order to avoid any resonance inside the target cell, a field uniformity better than 0.14 mT was requested. On the other hand, in order to maintain the atomic polarization above 85% and the total polarization relative uncertainty below 4.5%, a field strength of around 300 mT was necessary. Moreover, a requirement on the maximum applicable field originated from the bending of the HERA electron beam passing through the vertical field and the resulting emission of synchrotron radiation towards the HERMES spectrometer. An estimation showed that the e-beam trajectory could have been compensated up to 340 mT target field by using two correction magnets already existing upstream and downstream of the target. The emitted synchrotron light would not have hit the HERMES detector. Due to geometrical constraints imposed by the HERMES setup, the design of a magnet fulfilling all the listed requirements was not possible. At a field intensity of $B=297$ mT, uniformities of $\Delta B_z=0.05$ mT, $\Delta B_y=0.15$ mT, $\Delta B_x=0.60$ mT were achieved in the cell volume ($z$ is the longitudinal direction, while $y$ and $x$ are the two transverse ones). The magnet was installed in the HERMES hydrogen target in July 2001. Due to the poor performance of the HERA machine after the startup in September 2001, a serious study of beam induced depolarization, with particular concern for the highest non-uniformity along $x$, has not been possible up to now. A solution making use of two correction coils embedded inside the storage cell support structure is currently under test.

CONCLUSION

Beam induced resonant depolarization has been observed in the HERMES target. The problem turns to be particularly critical for the recently installed transverse polarized target, where it can be suppressed only with a holding field uniformity at the edge of the technical feasibility.

REFERENCES

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