Polarization Study in TRISTAN

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Abstract

The study on the electron beam polarization in the TRISTAN storage ring has been continued since the first observation of a significant level of the spin polarization. The extensive work on the radiative polarization is focused on high resolution measurements for depolarization resonances and compensation of depolarizing effects. A comprehensive study reveals the radiative polarization in the high energy storage ring.

1 INTRODUCTION

It is well known that electrons are transversely polarized anti-parallel to the guiding magnetic field in a storage ring by emission of spin-flip synchrotron radiation, known as the Sokolov - Ternov effect [1]. Glancing of recent results of the polarization measurements in high energy storage rings [2], it seems to be difficult to obtain a high degree of polarization because of strong depolarizing effects originating not only from magnetic imperfections and misalignments but also from a spread of the beam energy unless sophisticated optics design and corrections would be employed. Observation of a significant level of the spin polarization at TRISTAN [3] has brought us to a comprehensive study of the radiative polarization. Since attempts at SPEAR [4] and PETRA [5], no experimental work appears on the beam polarization in the high energy storage rings. It is important to accomplish an experimental study using the existing accelerator in order to give proof of the depolarization theories and the compensation schemes of depolarizing effects. The results may provide useful techniques achieving a high polarization level in large e^+e^- or ep colliders, and developing a polarized beam in the future linear colliders. Without any depolarizing effects, the maximum degree of the polarization shoud be able to be 92.38 % in the buildup time of $\tau_p = 98.66(\rho^2 R/E^5)$ s at the beam energy E in GeV, where ρ is the bending radius in meters and R is the machine mean radius. In TRISTAN the natural polarization time is $\tau_p = 2.88 \times 10^9/E^5$ s, typically 2 minutes for 30 GeV. This fast polarization time is helpful for the experiment.

The polarization study in TRISTAN is described: (1) The first step is to have a fast precision polarimeter. We have employed the Compton polarimeter using circularly polarized photons from a laser. The polarimeter development has been in progress toward a high precision system with capability of measuring the spin polarization vector and a very fast system using a high intensity laser. (2) High resolution measurements of depolarizing resonances are carried out around 29 GeV. The strength and causes of depolarizing resonances are investigated. (3) The experiments are carried out in order to examine the depolarizing mechanism due to the closed orbit distortions, the solenoid fields in the colliding detectors, the beam-beam interaction, the energy spread and so on. (4) Compensation of depolarizing effects is attemted with the correction technique based on the harmonic spin matching scheme. (5) A precise energy calibration of the electron beam can be performed using depolarizers.

2 POLARIMETERS

2.1 *Compton polarimetry*

We employ the Compton polarimeter, based on Compton scattering of circularly polarized photons from a laser on a polarized electron beam. The laser allows us to develop a fast precice measurement of high-energy electron polarization. The differential cross section for Compton scattering of a polarized photon by a polarized electron is expressed in the electron rest system as [6]

$$\frac{d\sigma}{d\Omega} = (r_e^2/2)(q/q_0)^2\big[1+\cos^2\vartheta + (q_0 - q)(1-\cos\vartheta) + \xi_1 \sin^2\vartheta - \xi_3(1-\cos\vartheta)(\mathbf{q}_0\cos\vartheta + \mathbf{q})\cdot\mathbf{P}\big], \quad (1)$$

where $r_e = e^2/mc^2$ is the classical electron radius, q_0 and q are the initial and final energies of the photon in units of the electron rest mass mc^2, $\mathbf{q}_0$ and $\mathbf{q}$ are the incident and scattered photon momenta, ϑ is the scattering angle, $\xi_1 = +1$ refers to linear photon polarization perpendicular to the scattering plane, $\xi_3 = +1$ refers to left circular photon polarization, and $\mathbf{P}$ is the polarization vector of the initial electron.

In the laboratory system, Compton scattering of circularly polarized light by a transversely polarized electron produces the left-right asymmetry in the distribution of backscattered photons on the horizontal axis for $P_x \neq 0$ and the up-down asymmetry in the distribution on the vertical axis for $P_y \neq 0$. The transverse components of the polarization vector can be definitely extracted from measurements of the horizontal and vertical distribution of scattered photons for the left handed ($\xi_3 = +1$) and right handed ($\xi_3 = -1$) circularly polarized light. The longitudinal component P_z of the electron polarization is also obtained from measuring transverse distribution of photons for two states of the circularly polarized light with the photon energy cut. With an unpolarized electron beam, one may determine the linear component ξ_1 of the photon polarization. The degree of the polarization is basically determined by asymmetry of Compton gamma rates, the analyzing power Π and the photon polarization ξ_3 for each case as

$$P_e = 1/(\xi_3\Pi)(N_+ - N_-)/(N_+ + N_-), \qquad (2)$$

where N_+ and N_- are the number of gamma events counted by the detector for the two photon helicities with $\xi_3 > 0$ and $\xi_3 < 0$.

2.2 *Single-photon polarimeter*

The single-photon counting method uses a low power, high repetition rate laser pulse. Each backscattered photon is detected by the position sensitive detector and the calorimeter. The polarimeter we have first installed in TRISTAN is based on the single photon method using a cavity-dumped argon-ion laser of a 514.5 nm line. The cavity-dumped pulses with the pulse width of 15ns (FWHM) and a peak power of 50 W are synchronized with the 200 kHz beam crossing frequency in two-bunch mode to illuminate the electron bunch at each crossing. The linearly polarized laser light is converted to either left or right circularly polarized light with Pockels cell and a quarter wave plate. The laser beam is guided through the 38 m long transport optics towards the interaction point where the laser light crosses the electron beam at an angle of 8 mrad in the horizontal plane and is focused with a rms spot size of approximately less than 1 mm. The backscattered gamma rays travel along with the electron beam, then leave the beam pipe at the end of the main dipole and finally reach the gamma detector located 40 m downstream from the interaction point. The photon trigger is provided by a coincidence among two scintillation counters and a lead glass calorimeter with a cut of the photon energy. Electron-positron pairs created in the tungsten converter are detected by the silicon microstrip detector and recorded in 12 bins of a 1 mm width to determine the vertical position of a converted photon. In the upgraded single-photon polarimeter, we use the "gamma ray imager" consisting of 64 scintillating fibers with a 1 mm × 1 mm cross section as a position sensitive detector. The photon energy is measured by the pulse height proportional to the energy deposited in a lead glass counter.

2.3 *Multi-photon polarimeter*

The multi-photon technique uses a high peak power laser to produce numerous gamma rays per interaction. We will install the multi-photon system employing a Nd:YAG laser at 532 nm, which generates a 7 ns long, 550 mJ pulse at a 10 Hz repetition rate. When the laser light is transported by the same optics as the single-photon system, a laser pulse should be able to generate $\sim 6 \times 10^5$ photons with energy range of $2 - 15$ GeV per interaction with a 1 mA electron bunch in the TRISTAN ring at a 29 GeV beam energy. Thus this system allows us to make measurement of the asymmetry with a statistical error of 0.1 % in a 3 s run. The gamma rays are detected by the silicon microstrip detector consisting of 96 microstrips with a 125 μm pitch.

3 POLARIZATION MEASUREMENTS

3.1 *Measurement of the asymmetry*

The operation of the polarimeter begins with adjusting alignment of the laser beam to search for optimum overlap of the laser spot and the electron beam in both space and time. Then the photon polarization is tuned by adjusting the Pockels cell bias control so that the extinction ratio is maximized by measuring the minimum and the maximum power throughputs for two linearly polarized states of the Pockels cell by means of a quarter-wave plate and a polarizer. In asymmetry measurements, data on the transverse and energy distributions of gammas are accumulated for two photon states, (+) and (−), depending on the Pockels cell setting and the laser-off state (0). Three laser modes are alternately switched by the Pockels cell voltage and the laser trigger pulse at a rate of approximately 10 Hz. From these measurements, the asymmetry is deduced for each detector channel as

$$A = (n_+ - n_-)/(n_+ + n_- - 2n_0), \qquad (3)$$

where n_+, n_- and n_0 are the respective event rates corresponding to (+), (−) and (0) laser modes. The transverse asymmetry can be detected as a shift of the center of gravity of the vertical profile of the backscattered gammas for two helicities:

$$\Delta(Y) = -P_y\xi_3\Pi, \qquad (4)$$

where Π is the analyzing power of the polarimeter, which is determined only by the detector distance from the interaction point and the cut-off energy of gammas. The analytic calculation for 28.863 GeV gives $\Pi = 134 \pm 10$ μm.

3.2 *Measurement of depolarizing resonances*

A resonant depolarization occurs at the condition

$$\nu = n \pm k\nu_x \pm l\nu_y \pm m\nu_s \qquad (5)$$

where $\nu = \gamma(g-2)/2 = E/(0.440652 \text{ GeV})$, the so-called spin tune, and ν_x, ν_y, ν_s are the horizontal, vertical and synchrotron tunes, and k, l, m are integers. The dominant resonances are integer resonances, $\nu = n$, and the first order betatron and synchrotron resonances, $\nu = n \pm \nu_{x,y,s}$. Behavior of these depolarizing resonances is examined by a energy scan of the polarization measurements, since depolarizing effects indicate strong energy dependence. The energy scan was made in the energy range of 28.863 - 29.083 GeV corresponding to the spin tune, 65.5 - 66. A series of asymmetry measurements was carried out for the experimental solenoids and their skew quadrupoles switched off while the beam energy was changed in 5 - 10 MeV step, remaining the machine tunes unchanged. During the measurment, the vertical closed orbit distortions was about

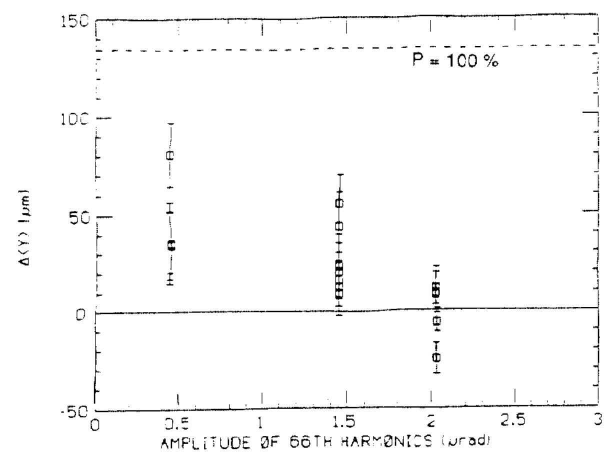

Figure 1: Results of the harmonic orbit correction in terms of a mean shift $\Delta\langle Y\rangle$ as a function of the amplitude of the 66th harmonics.

1.2 mm r.m.s. while the vertical dispersion was as small as about 7 cm r.m.s..

3.3 *Compensation of depolarization*

The vertical closed orbit distortion causes the spin to deviate from the vertical direction of the magnetic field so that the depolarization occurs due to a reduction of the Sokolov-Ternov effect. The deviation of the spin vector n from the vertical axis is given by [7]

$$|\delta \mathbf{n}| = \frac{1+\nu}{2(1-\cos 2\pi\nu)}\Big[\big(\sum_{i=1}^{N}\Delta y_i' \sin\nu\alpha_i\big)^2 + \big(\sum_{i=1}^{N}\Delta y_i' \cos\nu\alpha_i\big)^2\Big] \quad (6)$$

where α_i is the deflecting angle of the beam after the bending magnet i, and $\Delta y_i'$ is the change of the angle of the closed orbit between two bending magnets. Since $\Delta y_i'$ is expressed as a Fourier-sum,

$$\Delta y_i' = \sum_{n=1}^{\infty}(a_n \cos\alpha n + b_n \sin\alpha n), \quad (7)$$

$\delta \mathbf{n}$ is proportional to $(a_k^2 + b_k^2)/(k-\nu)^2$ at $\nu = n + 0.5$. Thus the amplitudes of the Fourier harmonics $k = n$ and $k = n + 1$ strongly influence the depolarization. These dangerous harmonics should be corrected by a harmonic orbit correction scheme [5]. We attempted to apply this correction scheme to TRISTAN using the 8 vertical correction dipoles installed at symmetric positions in the octants. The correction was carried out at 28.863 GeV ($\nu = 65.5$) for the 66th harmonics. Before the correction the rms closed orbit distortion was corrected down to 0.3 mm without any improvement of the polarization level. The shift of the center-of-gravity of the vertical profile was moved up to 80 μm as the amplitude of the 66th harmonics decreased as shown in Fig. 1. After the correction the corresponding polarization level is estimated to be 75 % ± 15 % with ξ_3 of 0.8.

4 CONCLUSIONS

The status and plan of the study on the electron beam polarization in TRISTAN were described. The depolarizing resonances were found by the energy scan of the polarization measurements. The harmonic orbit correction gave us a strong indication of the polarization level improvements.

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6 REFERENCES

[1] A.A. Sokolov and I.M. Ternov, "On Polarization and Spin Effects in the Theory of Synchrotron Radiation", Sov. Phys. Dokl., vol. 8, pp. 1203-1205 June, 1964.

[2] J. Badier et al., "First Evidence of Transverse Polarization in LEP", in Proceedings of High Energy Spin Physics, Bonn, FRG, September 1990, vol. 2, pp. 84-89.

[3] K. Nakajima et al., "Measurement of Equilibrium Beam Polarization in the KEK e^+e^- Storage Ring TRISTAN", Phy. Rev. Lett, vol. 66, pp. 1697-1700 April, 1991.

[4] D.B. Gustavson et al., "A Backscattered Laser Polarimeter for e^+e^- Storage Rings", Nucl. Instr. and Meth., vol. 165, pp. 177-186, 1979.

[5] H.D. Bremer et al., "Beam Polarization at PETRA", Proceedings of High Energy Spin Physics, Brookhaven, USA, 1982, pp. 400-406.

[6] H.A. Tolhoek, "Electron Polarization, Theory and Experiment", Rev. Mod. Phys., vol. 28, pp. 277-298 July, 1956.

[7] R. Rossmanith and R. Schmidt, "Compensation of Depolarizing effects in Electron-Positron Storage Rings", Nucl. Instr. and Meth., vol. A236, pp. 231-248, 1985.