A Polarized electron beam in the pulse stretcher ring PSR-2000.

Andrey Zelinsky, Ivan Karnaukhov, Alexander Shcherbakov

Kharkov Institute of Physics and Technology, 310108, Kharkov, Ukraine

Abstract

The scheme of producing the longitudinal polarized beam at Kharkov Accelerator Storage Ring Complex LA-2000-PSR-2000 is presented. The spin rotator which makes it possible to change the spin direction in the energy range from 0.6 to 2.95 GeV is described The calculation results for the equilibrium degree of polarization and the depolarization time in the pulse stretcher ring in the energy range from 0.6 to 2.95 GeV with taking into account the reference orbit distortion and corrections are given. The influence of spin-orbit resonances on the beam polarization value during slow extraction is discussed.

The calculations were performed with the DeCA code.

1. INTRODUCTION

An electron-beam pulse stretcher ring (PSR-2000) with an operating energy range between 0.5 and 3 GeV has been designed at the Kharkov Institute of Physics & Technology (KIPT)[1]. This machine is intended to produce an electron beam with an emittance of $\sim 10^{-8}$ m$*$rad and an energy spread of ~ 0.1%. Among the problems, for the solution of which the PSR-2000 would be constructed, of primary importance would be the investigations of experiments on the interaction between the continuous longitudinally-polarized electron beam and a polarized target material, and the interaction of a circular electron beam with the jet target substance.

To carry out the necessary experiments, the PSR-2000 design provides for the corresponding modes of operation, i.e., slow extraction and storage ring operation conditions. For the latter case, we have calculated, the equilibrium degree of the electron beam polarization in the ring to the linear approximation with taking into account reference orbit perturbations . To produce a continuous, longitudinally-polarized electron beam, it was necessary to design a spin rotator which would ensure spin flipping from the longitudinal direction to the vertical and vice versa throughout the operating energy range.

In future, special attention will be given to the problems of polarized beam injection and extraction with the compensation of polarization losses in the processes.

2. THE POLARIZED ELECTRON BEAM IN THE STORAGE RING OPERATION CONDITIONS

It is known that in the electron storage rings the beam gets self-polarized (Sokolov-Ternov effect [2]). The particle spins are aligned antiparallel to the induction vector of the guiding magnetic field. The electron spin polarization is characterized by the degree of polarization P, i.e., the ratio of the number of electrons whose spins are oriented antiparallel to the induction vector of the guiding magnetic field to the total number of electrons. This ratio can be calculated as:

$$P=P_{max}/(1+\tau_p/\tau_d)$$

where $P_{max}=92.4\%$ is the highest possible degree of electron beam polarization in the storage ring;

$\tau_p=99(s)\cdot R(m)\cdot \rho^2(m)/E^2(GeV)$ is the time of beam self-polarization in the storage ring;

τ_d — time of electron beam depolarization;

$R(m)$ — average radius of the ring;

$\rho(m)$ - average bending magnet radius;

$E(GeV)$ - beam energy;

For the PSR-2000 the time of polarization varies from $8.83005*10^7$ sec for 0.5 GeV to $1.09845*10^4$ sec for 3 GeV.

Fig. 1 shows the equilibrium degree of polarization (EDP) versus the electron beam energy for the PSR-2000 lattice under storage ring operation conditions. The lattice is characterized by the following parameters: Calculations were made using theDeCA code [3]. Curve 1 shows the EDP with due account of the reference orbit perturbations and without orbit correction. The RMS errors of lattice elements alignment were estimated to be $x=10^{-4}$ m, $x'=10^{-4}$ rad, $z=10^{-4}$ m, $z'=10^{-4}$rad, $s=10^{-4}$ m, $s'=10^{-4}$ rad. In this case the RMS orbit displacement was $x=6*10^{-4}$ m, $z=2*10^{-4}$ m. Curve 2 shows the EDP after correcting the reference orbit by the Hereward-Baconiery method.

After correction, the RMS orbit displacement was found to be $x = 10^{-4}$ m, $z = 2 \cdot 10^{-5}$ m.

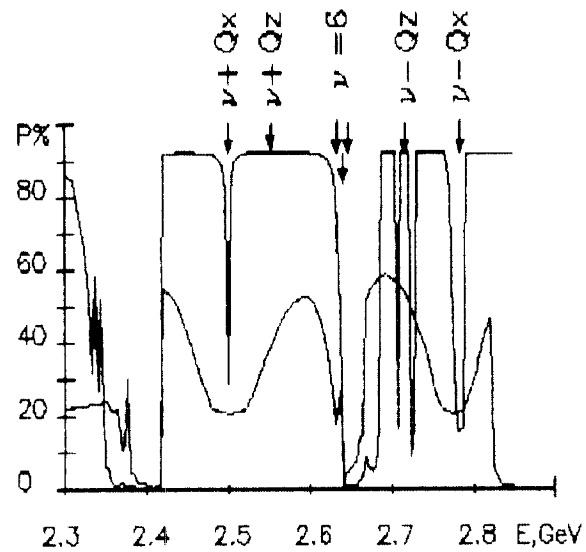

Fig.1 The equilibrium degree of polarization versus the electron beam energy

It is evident that the EDP is substantially improved after performing correction in the regions close to depolarizing resonances, the positions of which are indicated in the figure by arrows. Each resonance (n · is the integer) is surrounded by six sideband resonances (n · $Q_{x,z,s}$ is the integer). In the figure, the integer resonance and its two nearly synchrotron resonances are seen to merge on the strength of their proximity.

Based on the EDP calculations, we can conclude that the PSR-2000 lattice ensures, after performing correction of the reference orbit, a high degree of polarization (from 85 to 92 %) throughout the operating energy range in the regions distant from the depolarizing resonances. The width of the sideband depolarization resonances is not greater than 10^{-3} n, and this allows the beam operation in a wide range of energies.

3. THE EXTRACTED LONGITUDINALLY-POLARIZED ELECTRON BEAM IN THE ACCELERATOR-STORAGE RING COMPLEX LA-PSR-2000

For the accelerator-storage ring complex LA-PSR-2000 we have closen the following scheme of polarized beam transport. First, the longitudinally-polarized electron beam is accelerated in the linac LA-2000. The longitudinal direction of polarization in the accelerator has been chosen because of the fact that the focusing elements in the LA-2000 are the solenoids, and with this direction of polarization they do not lead to the beam depolarization. Then, in the injection channel the spin rotator changes the spin direction into the vertical one and the beam is injected into the ring with the vertical direction of polarization. After a slow extraction in the transport channel the spin direction is again changed from vertical to longitudinal by the use of the spin GaAs photocathode with NEF (Negative Electron Facility) is envisaged to be used as a polarized beam source. The source provides the beam with the degree of polarization ~ 40% and ~80% for the tensioned structure[4].

In the transport channels of the LA-PSR-2000 we shall use solenoidal spin rotators which allow the spin flop in a wide energy range. The device, which deflects the beam by one and the same angle value, irrespective of the energy, and changes the spin direction from vertical to longitudinal, is shown in Fig.2. The spin rotator consists of two bending magnets and two solenoids. The ratio of the forces of the two solenoids is a free parameter. As the beam energy changes, the magnetic field in the bending magnets changes so that the previous geometry of beam passage remains the same. The fulfilment of the law of spin direction transformation is provided by varying the forces of the both solenoids.

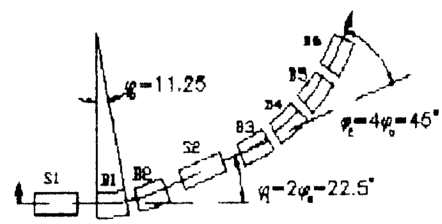

Figure 2. The scheme of spin rotator

Fig. 3. depicts the operating energy range (the range, where the fulfilment of the assigned law of spin direction transformation is possible) of the spin rotator as a function of the bending angle in the first bending magnet ϕ_1 for a fixed bending angle in the both magnets $\phi_1+\phi_2=\phi_0=66.25$ deg. The bending angle $\phi_1=22.5$, 45 deg corresponds to the PSR-2000 operating energy range.

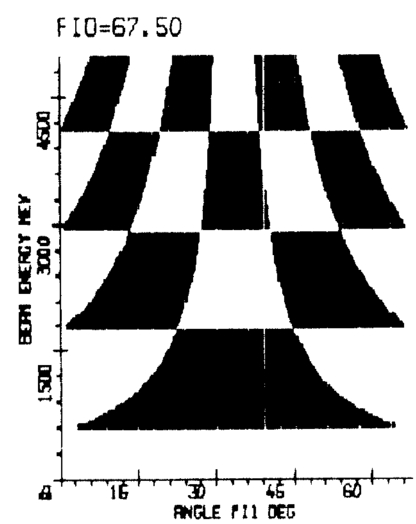

Figure 3. The operating energy range of the spin rotator

The spin rotator devised for the PSR-2000 transport channels has the following parameters:

- the operating energy range is between 0.6 and 2.935 GeV;

- the bending angles are 22.5 deg before ϕ_1 (two 11.25 deg standard magnets of the PSR-2000) and 45 deg before ϕ_2 (four 11.25 deg standard magnets of the PSR-2000);

- The product of the magnetic field strength in the solenoid by its length, H•l, is shown in Fig.4 as a function of the beam energy, for the first and the second solenoids of the spin rotator.

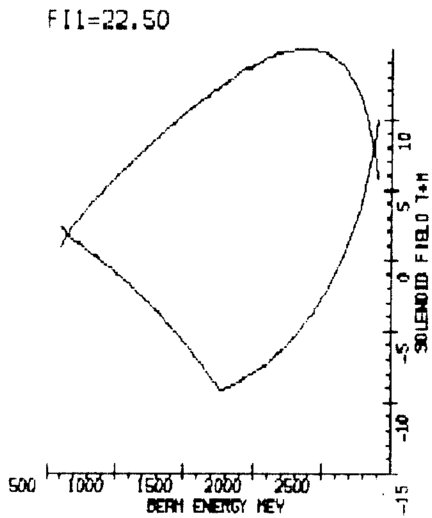

Figure 4. The strength of solenoids versus the beam energy

- Each of the spin rotator solenoids includes two one-meter sections separated by a set of six quadrupole lenses compensating the coupling of oscillations introduced by the solenoids [5]. These solenoidal "inserts" are placed in achromatic sections to exclude the influence of the solenoids on the dispersion functions of thetransport channel (i.e., to preclude possible vertical dispersion). The unit transport matrix has been realized for the spin rotator "insert".

The preliminary estimates of polarization losses during transport, injection and extraction of the polarized beam indicate that at a distance from depolarization resonances there are no polarization losses and the degree of beam polarization on the target is determined by the electron source.

REFERENCES

1. Gladkikh P.I., Gonchar V.Yu., Grigor'ev Yu.N. et.al."PSR-2000. The pulse stretcher ring for the Kharkov linear electron accelerator", Preprint KFTI 90-22, Moscow, TsNIIAtominform,1990, 34 p.
2. Sokolov A.A., Ternov I.M. " About polarized and spin effects in the synchrotron radiation theory", DAN SSSR , Moscow, 1963, v.153, N 5, pp. 1052-1054 .
3. Gladkikh P.I., Zelinsky A.Yu., Strelkov M.A. "DeCA - Code for analysing and designing cyclic Accelerators", Proceeding of the EPAC - 2, vol. , pp , 1991.
4. Agranovich V.L., Glamazdin A.V., Gorbenko V.G. " Status of Kharkov linac polarized electron source', Proceedings of the 9th International Symposium, Bonn, FRG, September, 1990, v.2, pp. 17-20 .
5. Zelinsky A.Yu., Karnaukhov I.M., Shcherbakov A.A. " Compensation of the oscillations coupling introduced by the solenoids" , Preprint KFTI 88-47, Moscow, TsNIIAtominform,1988,p.12.