

# APPLICATION OF A BEAM BASED ALIGNMENT TECHNIQUE FOR OPTIMIZING THE ELECTRON SPIN POLARIZATION AT HERA

D. P. Barber, R. Brinkmann, E. Gianfelice, T. Limberg, N. Meyners, P. Schüler, M. Spengos  
DESY, Notkstrasse 85, D-22603 Hamburg,  
M. Böge, CERN, CH-2111 Genève 23

## Abstract

A new method for optimizing polarization by minimizing the rms value of the vertical orbit kick and relying on the beam position monitor readings has been successfully tested for the first time at the HERA electron ring. We summarize the results of measurements.

## 1 INTRODUCTION

Electron (or positron) beams in high energy storage rings can become spin polarized by the Sokolov-Ternov effect [1]. The direction of the polarization is dictated by the BMT equation [2]. The equilibrium polarization reached is limited mainly by the deviation  $\delta\hat{n}_0(s)$ , due to closed orbit distortions, of the actual polarization direction from the design direction  $\hat{n}_0(s)$ , which, in the arcs, should be as (anti)parallel as possible to the main bending field. The polarization direction in HERA-e is changed locally at the Hermes experimental area by "spin rotators" [6].

To maximize the equilibrium polarization one must minimize  $\delta\hat{n}_0(s)$  [7]. The contribution to  $\delta\hat{n}_0(s)$  coming from vertical closed orbit distortions may be written as [3], [4], [5]:

$$|\delta\hat{n}_0(s)| = \frac{1}{2 \sin \pi\nu} \left\{ \left[ \int_{s-L}^s ds' F(s) \cos(\nu\phi_B) \right]^2 + \left[ \int_{s-L}^s ds' F(s) \sin(\nu\phi_B) \right]^2 \right\}^{1/2}$$

where  $\nu$  is the spin tune (i.e. the number of precessions per revolution that a spin performs around  $\hat{n}_0$ ) and  $\phi_B(s)$  is the cumulative horizontal bending angle at the position  $s$ ;  $F(s)$  is given by:

$$F(s) = (1 + a\gamma) \left( Kz + \frac{1}{B\rho} \Delta B_x \right)$$

$K$  being the quadrupole strength and  $\Delta B_x$  the error horizontal field along the design orbit. This is in general the most important contribution to  $\delta\hat{n}_0$ . At a quadrupole displaced by  $\delta_Q$  wrt design orbit we have:

$$\frac{1}{B\rho} \Delta B_x = -K\delta_Q$$

The rms value of the tilt  $\delta\hat{n}_0$  depends on the energy and on the optic. In HERA-e, after normal closed orbit correction, it is typically of the order of 30 mrad. This is sufficient

to limit the polarization to no more than 10...20 % , and must therefore be corrected with special methods.

## 2 CORRECTION METHODS

The correction scheme used originally at PETRA [3] has been generalized to a machine including vertical bending magnets and other "exotic" magnets [5]. The tilt  $\delta\hat{n}_0$  is Fourier analyzed and the most important harmonics are minimized by using vertical closed bumps. This is the method currently used at HERA for polarization optimization [7]. The optimization is done empirically; simulations and experience have shown that only 4 harmonics must be compensated for improving polarization. Nevertheless the method is time consuming. So improved methods have been sought.

The "deterministic" harmonic bump method (applied at LEP [9] and TRISTAN [10]) samples the vertical closed orbit at the BPM's and therefore relies on a good knowledge of the BPM transverse offset (mechanical and/or electronic) with respect to the design orbit. As this is in practice not measurable with enough precision, the method needs well aligned and calibrated BPM's. This is not the case in the HERA electron ring where similar attempts for improving polarization have indeed failed.

## 3 POLARIZATION OPTIMIZATION BY KICK MINIMIZATION

An alternative method has been developed [8] which minimizes the source  $F(s)$  of spin disturbance itself. At those locations where a BPM, a correction dipole and a quadrupole sit close together we have:

$$\begin{aligned} F(s) &= Kz - K\delta_Q + \theta \\ &= K(z_M + \delta_M) - K\delta_Q + \theta \\ &= K(z_M + \delta_M^Q) + \theta \end{aligned}$$

where  $z_M$  is the actual BPM reading,  $\delta_M$  is the (mechanical) offset of the BPM wrt the design orbit,  $\delta_M^Q$  is the offset of the BPM wrt the quadrupole and  $\theta$  is the kick provided by the corrector. Thus the "rms kick minimization" method attempts to minimize the combined orbit kick given by quadrupole and the corrector. In this case it is important to know  $\delta_M^Q$ . This can be measured with good precision (down to 50  $\mu\text{m}$  for HERA-e) by Beam Based Alignment techniques[8].

For this purpose in the 1993/94 shut down the HERA electron ring was equipped with switches [13] allowing to control the strength of the individual quadrupoles of the regular FODO cells and the measurement procedure was completely automatized [11]. In 1994 and 1995 the measurements were carried out on the vertically focussing quadrupoles. These are expected to be the most critical ones. The measurement required 24 hours for the 148 quadrupoles/BPM's (the total number of BPM's is 277). These measurements [11] have revealed a systematic 0.25 mm vertical offset of the BPM's wrt the quadrupole axis (see Figure 1 [11]). As a consequence our attempts to correct the orbit (i.e. to center the beam with the monitors) resulted in a systematic offset of the vertical orbit at the sextupoles and in a twist of the beam ellipse.

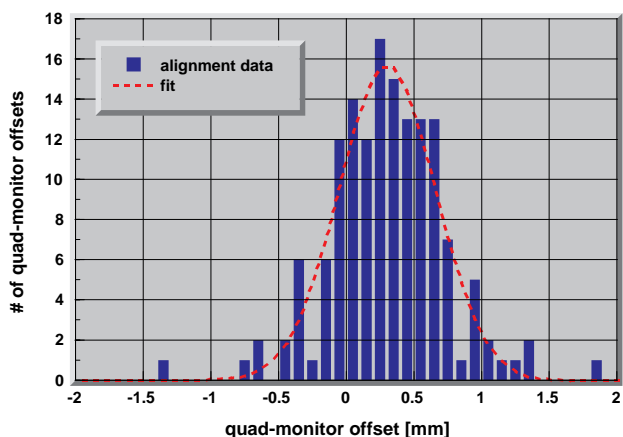


Figure 1: Alignment data.

For the 144 horizontally focussing quadrupoles, which are not equipped with BPM, the measurement technique, as well as the correction algorithm must be slightly modified [12].

#### 4 POLARIZATION OPTIMIZATION BY KICK MINIMIZATION – EXPERIMENTAL RESULTS

During the machine studies in December 1995 an attempt to apply the vertical orbit kick minimization for improving the polarization was finally made. The experiment was performed with electrons. The tunes of  $Q_x = 47.1$  and  $Q_z = 47.2$  were as usual chosen in order to push the first order resonances  $\nu \pm Q_{x,z}$  far from the operating half-integer spin tune.

The kick minimization was performed by using all available BPM's in order to have sufficient orbit sampling. For those BPM's which have not been measured the offset was assumed to be zero. Alternatively one could have assumed for them an offset equal to the systematic shift observed.

From the 1994 experience we expected, when we switched from electrons to positrons, that we could have to reoptimize the machine energy. The experimental magnets

and the HERA-p main dipole seem to have a small influence on the HERA-e energy too. In May 1994, when we were working with electrons (rotator on), maximal polarization was found at 27.49 GeV.

We had no time initially for a systematic energy scan but it was found that when the machine energy was lowered by 44 MeV to 27.51 GeV the observed polarization was around 60 %, the machine status having been optimized during the year for the Hermes experiment by the usual harmonic bump method.

The harmonic content of the coils involved in the harmonic bumps was computed with a best fit. The fit values reproduced the coil excitation well indicating that the harmonic components so computed were actually representative of the corrections applied to the machine for optimizing polarization.

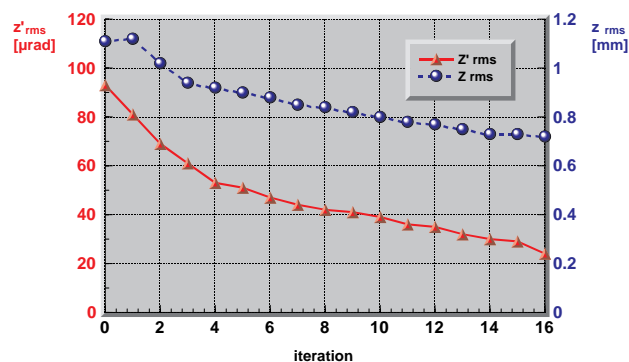


Figure 2: Rms-values of kick and orbit vs. iteration step.

After turning down these harmonics the polarization decreased to 11 %. Then the kick minimization algorithm was applied in 17 iterations by using 10 or 15 correctors per step until no further improvement was observed. This resulted in a reduction of the rms value of the vertical kick from 93  $\mu\text{rad}$  to 24  $\mu\text{rad}$ ; the rms value of the vertical orbit decreased too, from 1.11 mm to 0.70 mm. In Figure 2 the rms values of the vertical orbit and of the vertical orbit kick vs iteration step are shown. It was found that polarization increased reaching an asymptotic value of 28 %.

Harmonic bumps were then reoptimized and the polarization reached 65 %. However, the maximum bump amplitude needed was about a factor two smaller than usual. Furthermore the systematic beam offset in the sextupole magnets and the consequent twist of the beam ellipse were removed.

In the end there was some time left to perform an energy scan. To speed up the measurement, one harmonic was intentionally tuned to get a lower asymptotic polarization (around 30 %). In these conditions a peak of 47 % was found at 27.557 GeV, quite far from the energy at which we had been operating. The results of this energy scan are shown in Figure 3.

Unfortunately there was no time to stay at this energy after tuning back that harmonic, but by extrapolation one can estimate that the asymptotic value would have been around

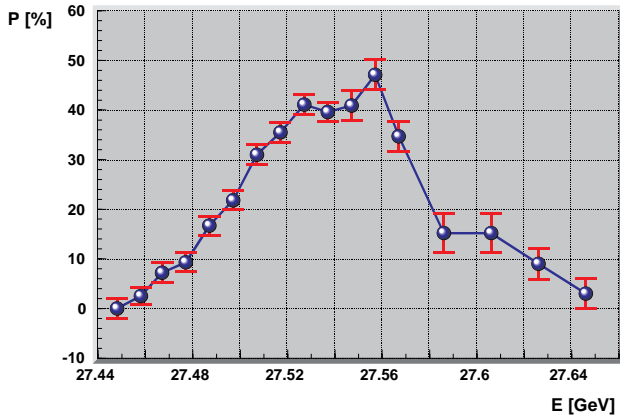


Figure 3: Measured polarization vs. energy .

76 %. This is somewhat higher than the typical values we have reached before, without kick minimization.

Simulations show that the minimum rms value of the orbit kick does not always lead to the highest polarization, in particular when the number of BPM's for which the offsets are unknown increases. It is therefore conceivable that with complete alignment of all quadrupoles an even higher polarization is possible.

## 5 CONCLUSIONS AND OUTLOOK

Vertical orbit kick minimization has been applied for the first time to improve polarization in an electron storage ring. The method is suitable for speedily setting up good machine conditions for polarization, in particular for very high energy machines. An empirical tuning of the harmonic bumps is still needed for reaching very high polarization.

The Beam Based Alignment will be in the future extended to the horizontally focussing quadrupoles too.

## 6 REFERENCES

- [1] *A. A. Sokolov and I. M. Ternov*, Sov. Phys. Dokl., vol. 8, pp. 1203-1205 June, 1964.
- [2] *V. Bargmann, L. Michel and V. L. Telegdi*, Phys. Rev. Lett., vol. 2, pp. 435-437 May, 1959.
- [3] *R. Rossmannith, R. Schmidt*, Nucl. Inst. Methods, vol. A236, pp. 231-248 May/June, 1985.
- [4] *H. Mais, G. Ripken*, DESY Report 83-062, July 1983.
- [5] *D. P. Barber et al.*, DESY Report 85-044, March 1985.
- [6] *D. P. Barber et al.*, Phys. Lett. B, 343, pp. 436-443 January, 1995.
- [7] *D. P. Barber et al.*, Nucl. Instr. and Methods, vol. A338, pp. 166-184 January, 1994.
- [8] *R. Brinkmann and M. Böge*, Proceedings of the 4th EPAC, London, June 1994, vol. 2, pp. 938-940, Edition World Scientific 1994.
- [9] *R. Assmann et al.*, CERN SL/94-08 (AP).
- [10] *K. Nakajima*, Proceedings of the 3th EPAC, Berlin, March 1992, vol. 1, pp. 717-719, Edition Frontiers 1993.
- [11] *M. Böge and R. Brinkmann*, Proceedings of the 4th International Workshop on Accelerator Alignment, Tsukuba, November 1995, pp. 412.
- [12] *R. Brinkmann*, Private communication.
- [13] *W. Bialowons and W. D. Gode*, Private communication.