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BEAM ENERGY MEASUREMENTS USING RESONANT SPIN DEPOLARIZATION AT ALBA

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Abstract

Energy measurements with precision down to 1e-5 are inferred at ALBA from the lifetime evolution when the beam is depolarized using AC kicks produced by the Transverse Fast Feedback system. Lifetime measurements are carried out using the DCCT, the BPM sum signals, pin-diode BLMs, and a scintillator based Beam Loss Detector. We report our experience with this methodology and show our first results.

INTRODUCTION

During the ALBA Storage Ring (SR) commissioning, small differences were observed between the magnetic measurements and the results of the beam optics analysis. The differences in the dipole current settings and its focusing components revealed by the LOCO analysis pointed out that the beam energy was about 0.5% lower with respect to the nominal 3 GeV value [1]. In order to clarify these discrepancies, we decide to measure the energy using the method of the Resonant Spin Depolarization (RSD, as already used in many other facilities [2–5].

However, the technique still offers subtle difficulties to perform a valid measurement. In this report, we describe the experimental set-up developed for the measurements and show our first results.

THEORY

The technique is throughly described in [2], and is based on the assymetry in the spin-flip probability due to the emission of synchrotron radiation, which makes the electrons spins to gradually align anti-parallel to the magnetic field of the main dipole. This process is known as Solokov-Ternov effect, and the polarisation $P(t)$ and its build-up time are described by:

$$P(t) = P_0\left(1 - \exp^{\left(t/\tau_{\mathrm{ST}}\right)}\right) \tag{1}$$

$$\tau_{\mathrm{ST}}[s] \simeq 99\frac{C[m]\rho[m]^2}{2\pi E_0[GeV]^5}\,, \tag{2}$$

where P_0 is the initial beam polarisation, C is the SR circumference, ρ is the main dipole bending radius, and E_0 is the beam energy. Since the cross-section of the Touscheck scattering decreases for a higher polarization level, the observed (Touscheck) beam lifetime increases.

The spin vector of a relativistic beam precesses around the vertical axis with a frequency that depends on the electron beam energy. The number of spin oscillations per revolution is called spin tune and is defined as:

$$\nu_s = a \cdot \gamma\,, \tag{3}$$

where $\gamma = E/mc^2$ is the beam relativistic Lorentz factor and a=0.001159652193 is the anomalous magnetic momentum. Once the beam is polarized, if we apply a sinusoidal horizontal magnetic field with a frequency f_{exc} in resonance with ν_s, the beam polarization is destroyed:

$$f_{\mathrm{exc}} = (k \pm [\nu_s]) \cdot f_{\mathrm{rev}}\,, \tag{4}$$

where f_{rev} is the revolution frequency, k is an integer and $[\nu_s]$ represents the non-integer part of the spin tune. When the beam polarization is destroyed, a sudden increase in the beam loss rate and a sudden decrease of the beam lifetime occur, and the beam energy can be inferred using Eq. 3.

EXPERIMENTAL SET-UP

Initially, we looked at the beam lifetime obtained using the available instrumentation, i.e. the DCCT, the average Sum signal of all BPMs, and the Bergoz Beam Loss Monitors (BLM). In order to increase the sensitivity of the measurements, we installed a home-made scintillator based Beam Loss Detector (BLD). It consists on a 100x10mm diameter EJ-200 plastic scintillator rod attached to a PMT (Ham. H10722-110). For the time being, the PMT output is read by an avalible ADC card (Adlink cPCI 9116), but we plan to use a counter in the near future to increase the signal to noise ratio and avoid saturation for large beam losses.

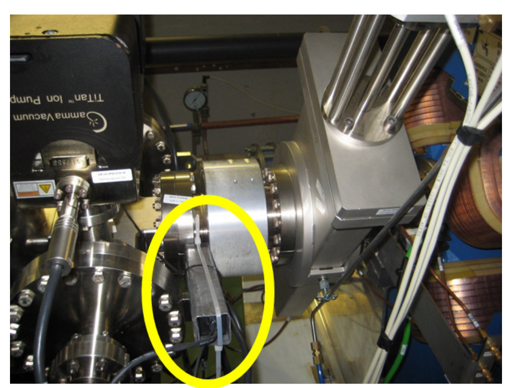

Figure 1: BLD picture and location in the ring.

The BLD should be placed in a place prone for Touscheck losses. In this case, we chose the injection straight, with a high dispersion function and where the presence of both horizontal and vertical scrapers help to locate the beam losses

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and increase the BLD sensitivity. The scintillator was installed in the inner side of the vacuum chamber, with its sensitive part in the orbit plane of the ring. Figure 1 shows the picture of the BLD and its location in the ring.

The excitation signal is produced using a Function Generator Tektr. AFG3102, that feeds our vertical feedback kickers (FFK) via two 100W amplifiers. The frequency generator has been calibrated using the Master Oscillator clock and a Spectrum Analyzer (SA), and its precision is in the 10 Hz range, limited by the SA. For the ALBA case, 10 Hz corresponds to an energy of 4 keV.

When the AFG voltage is 2.7V, the 100W amplifiers are used at full power and the FFK kick is of $\Delta\theta$=0.9μrad [6]. In order to depolarize the beam, the kick should add coherently from turn to turn. If we consider that the depolarization occurs when the spin flips by $\pi/2$, the depolarization time is estimated by $\tau_d = \frac{\pi/2}{\Delta\theta \cdot f_{\rm rev}} \sim 1.5$ sec . As it will be shown in the next Sections, the kick amplitude is a key parameter to properly detect the beam depolarization.

BEAM POLARIZATION

The beam lifetime in a 3rd generation synchrotron light source like ALBA is mainly composed of the gas-scattering lifetime and Tousheck effect. It is not easy to measure directly the lifetime due to Touscheck effect, but we can create some conditions to produce a beam whose lifetime is limited by Touscheck.

We usually do this by injecting a fresh beam of 320 bunches with about [0.3 - 0.4] mA/bunch. Moreover, we decrease the coupling from the nominal 0.5% to 0.1%, and limit the horizontal physical aperture from 16 to 8 mm using the horizontal scraper. Furthermore, the vertical scraper is closed by about 25% to locate the losses at the BLD location. In these conditions, the gas pressure lifetime is 60h, while the Touscheck lifetime is 8h.

For an electron beam, the Touscheck lifetime can be decomposed in two contributions, one τ_{T0} corresponding independent of the beam polarization, and another part depending on the polarization level. This is expressed by [3]:

$$1/\tau_T = (1 - A \cdot P_0^2)/\tau_{T0} \,, \qquad (5)$$

where P_0 is the degree of beam polarization, and A is a constant that depends on the machine parameters and for ALBA it amounts to A=0.15. This means that the relative increase of Touscheck lifetime is about 8% for a polarization level of P_0=84%. This is observed in Fig. 2, from where we obtain a degree of polarization of 86%, in agreement with the theoretical value. On top of it, we can also fit the polarization build-up time (13min). Given the noise in the measurement, this result agrees reasonably well with the 14.5 min predicted by Eq. 2.

Note that Fig. 2 does not show the lifetime evolution, but the product $R \equiv \tau \cdot I$, lifetime times beam intensity, which in terms of beam losses L detected in the BLMs or BLD is expressed by:

$$R = I^2/L \ . \qquad (6)$$

Unless the beam polarizes or depolarizes, the product R remains constant. In the following, we mainly use this R parameter because we found out its noise is smaller than the lifetime obtained using the DCCT or the BPMs.

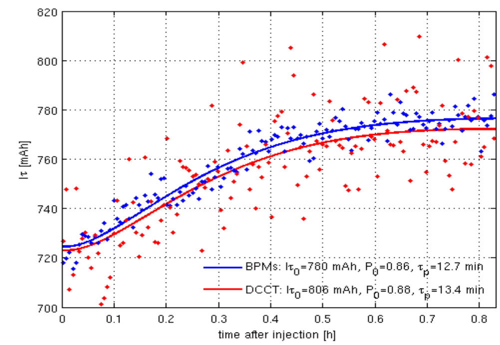

Figure 2: Example of the beam polarization.

BEAM DEPOLARIZATION

Once the beam is polarized, a sinusoidal vertical electric field (horizontal magnetic) is applied with a frequency that varies at around the expected corresponding spin tune. Since there was a significant uncertainty about the value of the beam energy, the first scans were done for wide tune space regions, with a step of 25Hz/s (equivalent to 10keV/sec).

Two of the main difficulties we saw durig these experiments are: 1) the excitation signal also produces resonances that blow up the beam vertically up to ranges where the beam is not limited by Touscheck effect, and 2) the lifetime decay did not show an abrupt decay, but rather a wide spread of about 0.5%, far from the expected 1e-5.

All the above was finally solved by decreasing the kick by a factor ~6. Figure 3 compares two scans at different AFG peak to peak voltages: at 1.0V and 0.5V. For the scan with 1.0V, the resonances hide the lifetime drop because it coincides with vertical beam size increase. Although similar effects are reported in [5], the nature of these resonances are unclear.

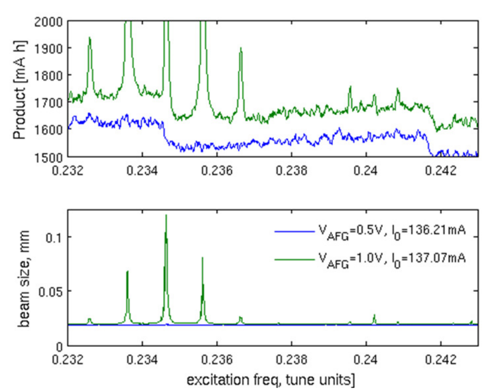

Figure 3: Two scans at different AFG kick voltages. For the scan at 1.0V, the beam size explodes vertically, and as a consequence, the lifetime increases as well.

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For our studies, we have focused on the lifetime product obtained using the BLD and the BLM. Figure 4 compares the evolution of the lifetime product R with different instrumentation. The data obtained using the DCCT and the BPM Sum signal is much noiser than the product obtained using the losses. For this reason, we often did our calculations averaging the counts from the BLD and BLMs.

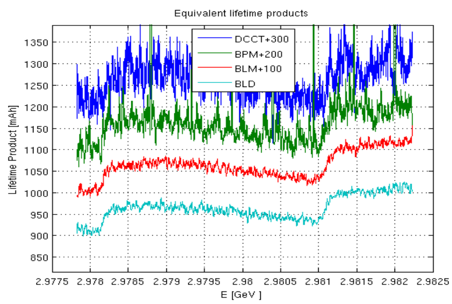

Figure 4: Comparison with the different instrumentation.

RESULTS

Using a similar model as in [4], we have described the evolution of the product R as:

$$R = R_0 + \frac{\Delta R}{1 + \exp^{(E - E0)/\sigma_E}} \tag{7}$$

where E in this case is the energy corresponding to the excitation scanning frequency, R_0 is the losses when the beam is depolarized, E_0 is the beam energy, and σ_E is the width of the decay product decay. An example of the fit following this equation is shown in Fig. 5, from where we obtain an energy of E_0=2.97813 GeV, with an uncertainty of σ_E=2e-5. Note that the depolarization is in the order of 8%, which is in agreement of the degree of polarization obtained in Fig. 2.

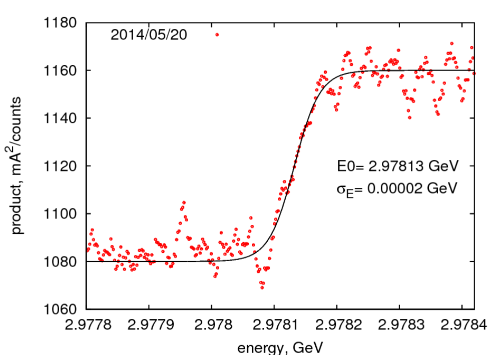

Figure 5: Evolution of the product obtained using the BLD during an energy scan. The black line is a fit to the experimental data, depolarization occurs at 2.9781(3)GeV.

Figure 6 shows the evolution of the beam energy in the scans performed during May 2014. Note that the reproducibility in the same day is in the order of the measurement uncertainty. However, for the scans performed during the last month, the beam energy has slightly changed and consequently, the rf frequency (automatically adjusted by the Orbit Feedback) changes. This points towards a real change in the beam circumference due to thermal expansion of the floor, which will be monitored in a long term.

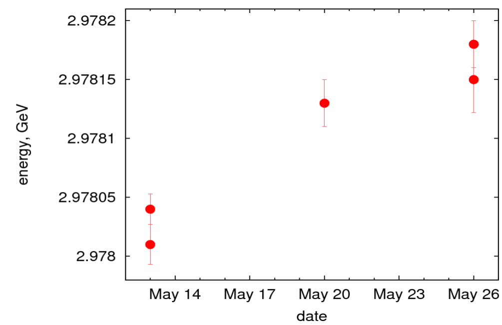

Figure 6: Beam energy evolution during May 2014.

CONCLUSION

The method of RSD to measure the beam energy at ALBA has been successfully carried out, and the energy has been measured with precision of 2e-5 GeV. The main difficulties faced in this process have been the appereance of resonances of unclear nature that blow up the beam vertically, and produced a beam that was not anymore Touscheck lifetime limited. This has been avoided by decreasing the excitation kick by a factor 5. The most useful instrumentation has been a scintillator based detector, and secondly the average of all our BLMs. The beam energy has been determined to 2.9781 GeV, although a small drift is detected with time, which will be monitored in a long term period.

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