EXPERIMENTS TO MEASURE ELECTRON BEAM ENERGY USING SPIN DEPOLARIZATION METHOD ON SOLEIL STORAGE RING

J. Zhang*, L. Cassinari, M. Labat, A. Nadji, L. S. Nadolski, D. Pédeau
Synchrotron SOLEIL, Gif-sur-Yvette, France

Abstract
The electron beam energy on SOLEIL storage ring wassuccessfully measured using spin depolarization method after several attempts over the pastfew years. The experimental results demonstrate that the effective polarization was91.3% ± 3% and polarization time was17±2.3 minutes as expected from the simulation using SLIM code. The beam was depolarized using an AC shaker and the depolarization was monitored using DCCT and beam loss monitors. The beam energy was measured with accuracy up to a few 10^{-5}.

INTRODUCTION

SOLEIL storage ringis a 3rd generation synchrotron light source with low emittance and high brilliance commissioned in 2006. During commissioning period, the electron beam extracted from the booster was injected on axis in the storage ring with quadrupole and sextupole magnets turned off. The beam was lost afterthe first 3 dipoles and the orbit was measured using the 8 BPMs in-between. A least square minimization fitting was applied to the orbit measured by the BPMs, and the beam energy was deduced as 2.739 GeVbased on dipole magnetic measurements [1], which is 0.4 % lower than the design beam energy 2.75 GeV. The measured beam energy was double checked using a NMR probe to measure the magnetic field in adedicated dipolewhich is powered in series with the other dipolesin the storage ring.

Requirement to measure the storage ring energy with a better precision is coming both from the machine and experimental sides. For example, the momentum compaction factor is a critical parameter depending on the beam energy. The Metrology beamline expressed the need of knowing the absolute energy with a 10^{-5}precision.

Resonant spin depolarization method has been used successfully to measure the electron beam energy in the storage rings of BESSY II [2], ALS [3], SLS[4], ANKA [5] with an accuracy ranging from 10^{-4} to 10^{-5}. Even if in principle the method is easy to implement, it takes time and effortsto get expected results. New light sources of intermediate energy like SOLEIL, DIAMOND, and Australian synchrotron light source faced lots of difficulties to make a valid measurement.

In this paper we report the preliminary results obtained at SOLEIL after several attempts.

EXPERIMENTAL PRINCIPLE

The synchrotron radiation of the electron in the storage ring can slip the electron spin, and makes the electron beam get spontaneously polarized. For an electron beam with zero initial polarization, the polarization build up follows asemi-exponential processcharacterized by the effective polarization level P_{eff} and the polarization timeτ_{eff} [6]:

$$P(t) = P_{\text{eff}}\left[1 - e^{-t/\tau_{\text{eff}}}\right] \text{and } \frac{1}{\tau_{\text{eff}}} = \frac{1}{\tau_{\text{ST}}} + \frac{1}{\tau_{\text{dep}}} \quad (1)$$

The parameter τ_{dep} is mainly determined by the horizontal field errors(misalignment, multipole field errors, etc),$\tau_{ST}$is the polarization time for the electron beam in an ideal storage ring without field error:

$$\frac{1}{\tau_{\text{ST}}[\text{s}]} \approx \frac{2\pi}{99} \frac{E[\text{GeV}]^5}{C[\text{m}]\rho[\text{m}]^2} \quad (2)$$

Where E is the beam energy, C is the ring circumference, ρ is the bending radius of the dipoles. For a storage ring of intermediate energy, the ideal beam polarization time τ_{ST}can be several tens of minutes. For SOLEIL storage ring, its value is 17.3 minutes.

If the vertical closed orbit distortion is small and horizontal magnetic field errors are weak in the storage ring, which are the cases for most of the 3rd generation synchrotron light sources, then the equilibrium beam polarization can reach the ideal level 92.38 % [6].

The electron spin tune ν_{spin} and the beam energy E in the electron storage ring follow[7]:

$$\nu_{\text{spin}} = \frac{E[\text{MeV}]}{440.648626[\text{MeV}]} \quad (3)$$

For SOLEIL storage ring, the spin tune is 6.2158, which corresponds to the beam energy 2.739 GeV.If an external sinusoidal horizontal magnetic field is applied on the polarized electron beam in the storage ring, and the beam is in resonance with the spin frequency, the beam polarization can be destroyed. Then using eq.(3), beam energy E can be determined by

$$E[\text{MeV}] = 440.648626\left(\left[\nu_{\text{spin}}\right] + \frac{f_{\text{dep}}}{f_0}\right) \quad (4)$$

Where $[\nu_{spin}]$ is the integral part of the spin tune ν_{spin}, f_{dep} is the frequency of the external field when the beam is depolarized, $f_0$is the revolution frequency.

SIMULATION OF THE POLARIZATION

The spontaneous polarization of the storage ring beam can be simulated using the simulation code SLIM[7]. In this code, various sources impacting the polarization level are included, such as horizontal magnetic field from

*jianfeng.zhang@synchrotron-soleil.fr

correctors, quadrupoles and sextupoles, misalignment errors of the magnets and girders.

Using SLIM, beam polarization on SOLEIL storage ring is studied withdifferent closed orbit distortions. Fig. 1 demonstrates the equilibrium beam polarization on SOLEIL ring for a RMS horizontal and vertical closed orbit distortion of 200 µm and 50 µm respectively (pessimistic scenario). Around the expected beam energy 2.739 GeV, the depolarization effects on SOLEIL ring is very weak, the beam polarization is close to the ideal value 92.38% and the characteristic polarization time is 13 minutes which are good conditions for the energy measurement experiment using resonant spin depolarization method.

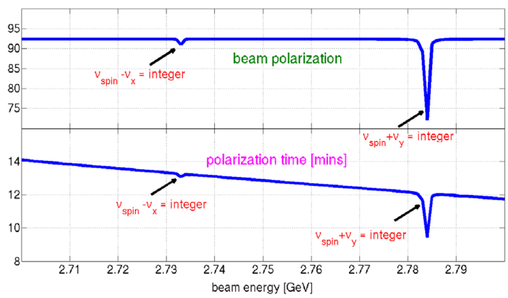

Figure 1: Beam polarization and polarization time simulated using SLIM for different beam energies on SOLEIL ring. The resonances between spin tunes (ν_{spin}) and betatron tunes (horizontal tune ν_x ,vertical tune ν_y)partially depolarize the beam.

EXPERIMENTAL SETUP

Tools to Measure Beam Polarization

On the electron storage ring, Touschek lifetime depends on beam polarization, it increases with the increase of beam polarization. On SOLEIL storage ring, the Touschek lifetime of a fully polarized beam is about 12% higher than the one of an un-polarized beam.

It is difficult to measure the Touschek lifetime on storage ring, but for a Touschek lifetime dominant electron beam, the beam lifetimecan be used as a tool to measure beam polarization [8].

Another tool to measure beam polarization is using beam loss monitor (BLM) which is located at an area sensitive to the Touschek beam loss. Normally there are two types of BLM on the storage ring: pin diode and scintillation detectors. Due to the high count rate and fast response time, scintillation detectors are used as a tool to measure beam polarization in the experiment to measure beam energy using spin depolarization method.

Depolarization Device

Any device on the storage ring that can generate an alternative horizontal magnetic field can be used to depolarize the beam if its power is large enough.

There are two types of devices on SOLEIL ring to generate horizontal field. The first one is the AC shaker that is used to measure the horizontal betatron tune; the other one is the vertical stripline of Transverse FeedBack (TFB) that damps horizontal excitation of each electron bunch with high single bunch current.

For convenience, the AC shaker is used to depolarize the beam during the experiment to measure beam energy using resonant spin depolarization. With an integrated field 4.6 µT·m, depolarization time is about one second.

EXPERIMENTS

Machine Settings

In order to get the beam dominated by Touschek lifetime, two operation modes can be used: (1) storing a beam with current 60 mA into 8 bunches and 1% natural coupling; (2) storing a beam with 400 mA into 416 bunches but with minimum coupling 0.1 %.

In order to maximize the beam polarization, various sources are switched off such as orbit feedback systems, TFB, tune excitations.

As seen from the simulation in Figure 1, the resonance between the horizontal betatron tune ν_x and the spin tune ν_{spin} is close to the beam energy 2.739 GeV on the SOLEIL ring. During the experiment, horizontal betatron tune is reduced to push it far away from this resonance.

Measurement of the Beam Polarization

A Touschek lifetime dominated electron beam was injected in the ring, and the beam lifetime normalized by current and the beam loss rate normalized by current square were recorded. After waiting 2 to 3 times of the ideal polarization time, the normalized beam lifetime and normalized beam loss rate got saturated and the beam polarization reached its equilibrium value (Figure 2).

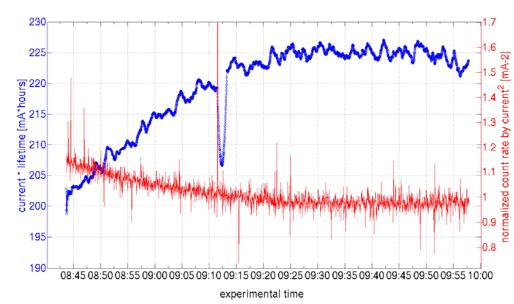

Figure 2: Beam lifetime normalized by currentand beam loss rate normalized by current square. The suddendecrease of the lifetime and the sudden increase of the beam loss around 09:12 are due to the beam micro loss.

The effective beam polarization and polarization time fitted using Eq.(1) are shown in Figure 3. The fitted effective polarization P_{eff} is 91.3% ± 3%, the fitted effective polarization time τ_{eff} is 17.0 ± 2.3 minutes, the fitted depolarization time τ_{dep} is 1462 ± 30 minutes which denotes the depolarization effect in SOLEIL ring is very weak. The fitted polarization time is slightly higher than the 13 minutes simulated using SLIM, this is due tothat the measured polarization is based on total but not Touschek lifetime and the measurement errors of total beam lifetime. In Figure 3, the measured and fitted polarizations are compared with the oneonan ideal storage ring. it shows the beam polarization on SOLEIL storage ring is very close to the one on a perfect storage ring with field errors.

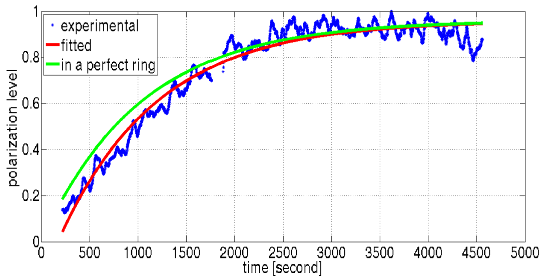

Figure 3: Polarization build up process on SOLEIL storage ring. The measured polarization is fitted using Eq.(1), then compared with the polarization on an ideal storage ring.

Measurement of the Beam Energy

With the fully polarized beam, a sinusoidal horizontal magnetic field is applied on the electron beam through the shaker; the frequency of this signal is swept around the depolarization frequency 182.736 kHz which corresponds to the beam energy 2.739 GeV, and the frequency sweep is 50 Hz/swhich allows for the energy accuracy 10^{-4}. The beam lifetime is measured by fitting the current decay measured by DCCT in 90 seconds; the beam loss is measured by a scintillation detector located in a straight section sensitive to the Touschek beam loss, and the count is integrated over one second.

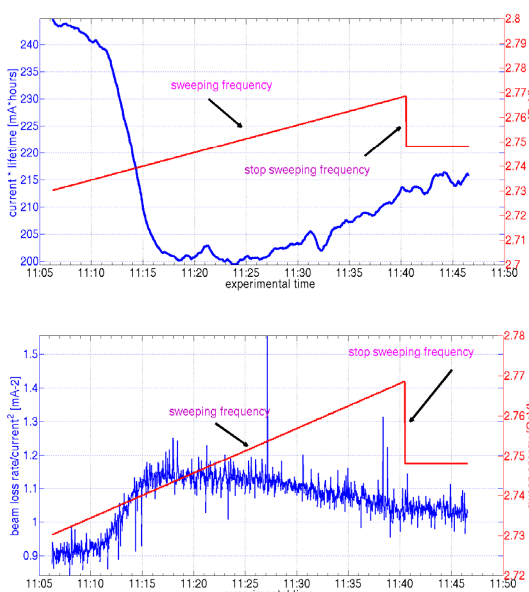

Figure 4: Upper). Normalized lifetime and down) normalized loss rate show one spin depolarization over 35 minutes. The beam energy corresponding to the sweep frequency is shown by the right y-axis.

Fig. 4 illustrates the first measurement of the beam energy. The decrease of normalized beam lifetime and meanwhile the increase of normalized beam loss rate demonstrate the spin depolarization by the horizontal field generated by the shaker. The slower response of the change of lifetime is from the slow current decay and the longer fitted time range. The beam energy is determined by the depolarization frequency according to Eq.(4). Unfortunately the measured beam energy is 2.7376±0.0023 GeV with an accuracy of 8 x 10^{-4}.

The measured beam energy is checked in later experiments. In these experiments, the same energy accuracy 10^{-3} are measured. Then the machine setting, such as Fast Orbit FeedBack, Slow Orbit FeedBack systems, are carefully studied and changed during the following experiment. During our latest experiment, the beam is depolarized in a small frequency region 200 Hz and the beam energy is measured as 2.73729 ± 0.00016 GeV with an accuracy of 6 x 10^{-5}.

CONCLUSION

The electron beam energy was measured using spin depolarization method on SOLEIL ring. The experiments show the polarization can be built up to a high level as expected from the simulation. The first experimental results show the measured energy accuracy was 10^{-3}. After changing the machine settings, the energy was measured with an accuracy of 6 x 10^{-5}. The reasons why we measured beam with higher accuracy will be studied in the future experiments.

ACKNOWLEDGEMENTS

We would like to thank all the staff that contributed to the spin depolarization experiments at SOLEIL over the years. Special thanks to L. Chevalley for the preparatory work done during her master thesis.

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