ACCURATE MEASUREMENT OF THE BEAM ENERGY IN THE CLS STORAGE RING*

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Abstract

Resonant spin depolarization was used at the Canadian Light Source (CLS) to measure the energy of the beam in the storage ring with high accuracy. This method has been employed successfully at several other synchrotrons in the past. At the Canadian Light Source, however, resonant spin depolarization is an intrinsic capability of the transverse feedback system, which is based on a Libera Bunch-by-Bunch unit. The Bunch-by-Bunch system used at the CLS was customized to include a bunch cleaning feature based on a frequency-modulated oscillator. By setting the frequency of this oscillator to the spin tune, the beam can be depolarized and the effect can be observed by watching the life time of the beam. No changes have to be made to the permanent setup of the transverse feedback system, and no special instrumentation is required to make the energy measurement.

RESONANT SPIN DEPOLARIZATION

The theory of resonant spin depolarization as a means of measuring the beam energy in a storage ring has been described in detail in Ref. [1]. After injection, the beam polarization builds up with a machine-dependent time constant, usually in the range of a few tens of minutes. Depolarization is then accomplished by applying an RF-signal at the resonant frequency of the spin. The effect of the resonant depolarization is observed either as an increase in the amount of Touschek scattering, or as a decrease of the beam life time. Several facilities have used this method in the past [1-7].

The frequency at which resonant depolarization occurs is a direct measure of the beam energy. Equation (49) in Ref. [1] gives the spin tune ν as:

$$\nu = a\gamma = a\frac{E}{m_e c^2}\,, \tag{1}$$

where

$$a = \frac{g-2}{2} = 0.00115965$$

is the anomalous magnetic moment of the electron, E is the beam energy, and m_e is the electron mass. At the nominal beam energy of the CLS storage ring, which is 2900 MeV, the spin tune is $\nu = 6.5812$.

The expected resonant depolarizing frequency f_{dep} is:

$$f_{dep} = \nu_{frac} \cdot f_o = 1.0197\,\text{MHz}\,, \tag{2}$$

where ν_{frac} is the fractional part of the tune and f_o = 1.7544 MHz is the orbit frequency of the storage ring. Note that there is an ambiguity between $\nu_{frac} = 0.5812$ and $1-\nu_{frac} = 0.4188$, so that another solution for the depolarizing frequency is:

$$f_{dep} = (1-\nu_{frac})\cdot f_o = 0.7347\,\text{MHz}\,. \tag{3}$$

INSTRUMENTATION AT THE CLS

The Transverse Feedback System

The transverse feedback system is based on a Libera Bunch-by-Bunch unit, which was customized to include a frequency modulated oscillator for bunch cleaning [8]. The frequency of this oscillator was set to the spin tune and the amplifiers and the vertical kicker of the transverse feedback system were used to depolarize the beam.

Detection of Depolarization

Because of signal-to-noise considerations, the preferred method of detecting depolarization is by measuring Touschek electrons. However, the arrangement of the magnets in the storage ring and the shape of the vacuum chambers make it impossible to set up Touschek detectors at the CLS. Depolarization therefore had to be detected by observing its effect on the life time of the beam.

MEASUREMENTS

Machine Setup

The machine setup was determined by the following considerations:

- In order to maximize the Touschek effect on the life time, the bunch current had to be as high as possible,
- The bunch current was limited by the head-tail instability,
- In order to minimize the vacuum effect on the life time, the total current had to be as low as possible,
- The total current had to be high enough for a sufficiently accurate measurement of the storage ring current and the life time.

As a compromise, three bunches in the storage ring were filled with a current of about 10 mA/bunch.

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Frequency Sweep

The frequency-modulated oscillator was swept in a range of frequencies that included the expected resonant depolarization frequency. The product of life time and beam current was observed (see Fig. 1). If the life time of the beam is only determined by Touschek scattering, this product is expected to be a constant as long as the polarization of the beam does not change. When the beam is depolarized, Touschek scattering increases and the product of life time and beam current is expected to drop. In reality the product increases slowly, probably due to a contribution to the life time by the vacuum in the storage ring, which slowly improves as the beam current decays.

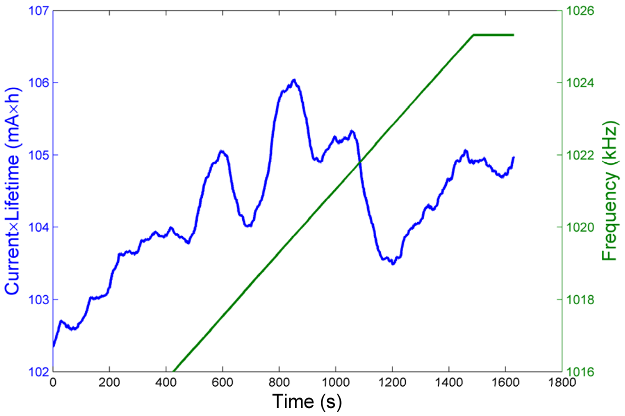

Figure 1: The blue curve shows the product of beam current and life time. The green curve is the frequency of the oscillator. The blue curve drops between t=800s and t=1200s as the beam is depolarized.

Because of the fluctuation of the current × life time measurement, the depolarization frequency could not be read with the desired accuracy. The measurement was therefore repeated several times after the beam was allowed to polarize again, and each time the range of the frequency sweep was narrowed. In the end the sweep was made narrower than the range necessitated by the energy spread of the beam in the storage ring, and the beam was partially depolarized.

RESULTS

The depolarization frequency determined in this manner was

$$f_{dep} = 1.019 \pm 0.001\,\mathrm{MHz}\,.$$

The error is dominated by the energy spread of the beam in the storage ring. Using Eq. (1) and Eq. (2), the beam energy can now be calculated as:

$$E_1 = \left(\nu_{int} + \frac{f_{dep}}{f_o} \right) \cdot \frac{m_e c^2}{a} = 2899.8\,\mathrm{MeV}\,, \tag{4}$$

where $\nu_{int} = 6$ is the integer part of the spin tune. This result is very close to the expected value of 2900 MeV. However, at this point the ambiguity between ν_{frac} and $1-\nu_{frac}$ could not be ruled out. Using Eq. (1) and Eq. (3), the second solution of the beam energy can be calculated as:

$$E_2 = \left(\nu_{int} + 1 - \frac{f_{dep}}{f_o} \right) \cdot \frac{m_e c^2}{a} = 2828.6\,\mathrm{MeV}\,. \tag{5}$$

In order to distinguish between these two solutions, the beam energy was slightly increased and the measurement was repeated. This time the depolarization frequency was measured as:

$$f_{dep} = 1.0205 \pm 0.001\,\mathrm{MHz}\,.$$

This leads to the solutions:

$$E_1 = 2900.2\,\mathrm{MeV}\,, \tag{6}$$

$$E_2 = 2828.2\,\mathrm{MeV}\,. \tag{7}$$

Since the beam energy had been increased, the results in (4) and (6) must be the correct solutions.

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