Accurate Measurement of the Beam Energy in the CLS Storage Ring

(J.M. Vogt, J.C. Bergstrom, S.Hu)

Canadian Light Source / Centre canadien de rayonnement synchrotron

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:

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

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:

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

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:

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

TRANSVERSE FEEDBACK SYSTEM

The CLS transverse feedback system is based on Libera Bunch-by-Bunch units. In transverse feedback operation, one Libera Bunch-by-Bunch front-end and two Bunch-by-Bunch processors are used (Fig. 1). The Bunch-by-Bunch processors were customized to CLS specification and a numerically controlled oscillator (NCO) was added. This oscillator controls the vertical Bunch-by-Bunch unit in bunch cleaning mode [8] and during storage ring energy measurements.

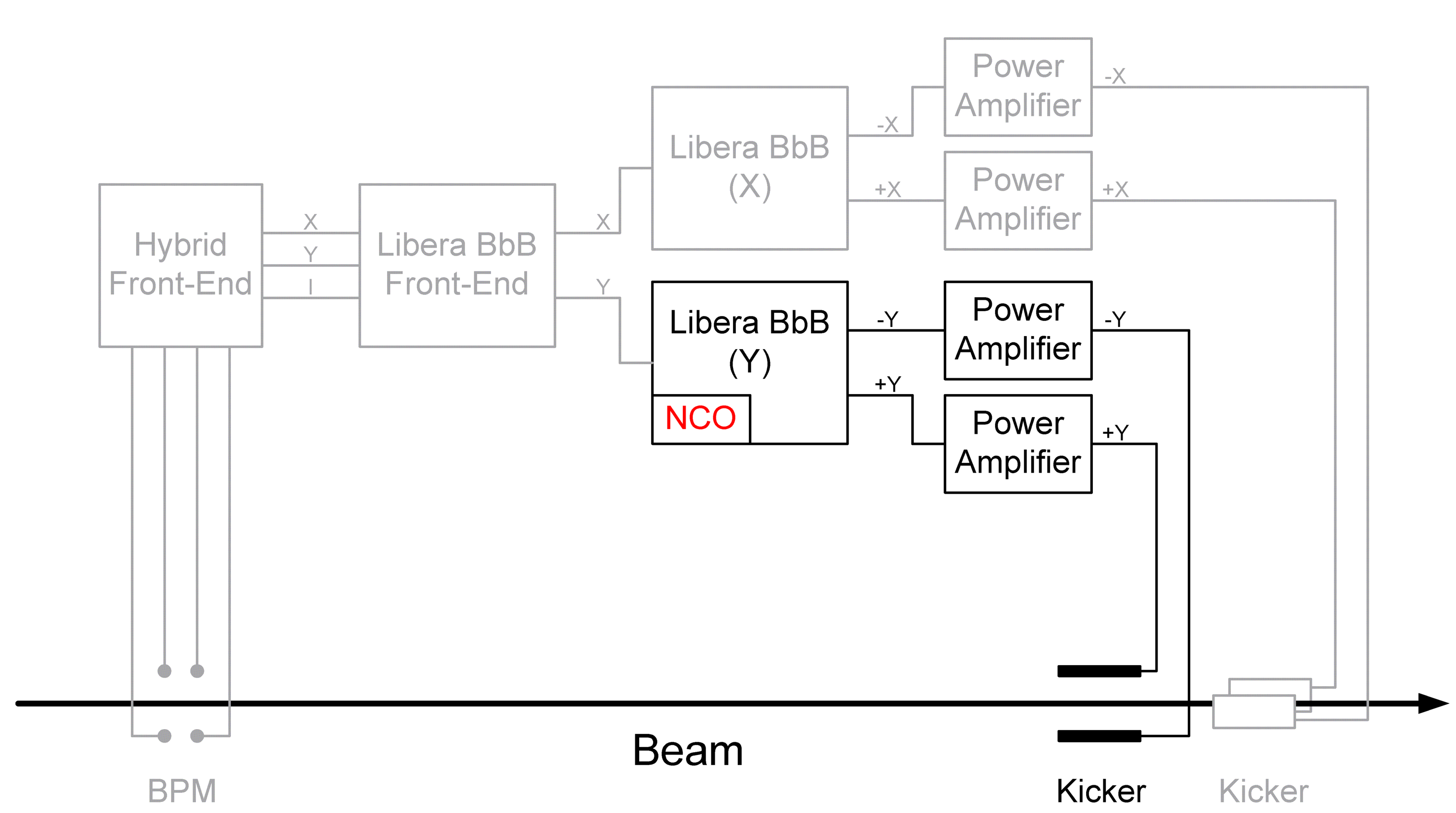

Fig. 1: The CLS transverse feedback system. Only the vertical system is used for storage ring energy measurements.

DETECTION OF DEPOLARIZATION

There are two methods of detecting depolarization:

1. Measuring the count rate of Touschek electrons. The cross section for Touschek scattering depends on the orientations of the electron spins. If the spins are anti-parallel, the cross section is higher than if the spins are parallel. Therefore there is less Touschek scattering in a polarized beam than in an unpolarized beam. In principle Touschek electrons can be detected on the outside of the storage ring. Since all other charged background occurs on the inside of the storage ring, the signal-to-noise ratio of such a measurement is very good. Unfortunately 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.
2. Measurement of the beam life time. Touschek scattering affects the life time of the beam in the storage ring. The beam current and the life time of the beam are continuously monitored and logged at the CLS. Therefore this detection method did not require any additional hardware to be set up.

ACKNOWLEDGEMENT

Work supported by Natural Sciences and Engineering Research Council (NSERC), National Research Council (NRC), Canadian Institutes of Health Research (CIHR), Western Economic Diversification Canada (WEDC).

MACHINE SETUP

- 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.

Compromise:

Three bunches in the storage ring were filled with a current of about 10 mA/bunch.

MEASUREMENT

- The frequency-modulated oscillator was swept and the product of life time and beam current was observed. The product dropped when the beam was depolarized (Fig. 2).
- After the beam was allowed to polarize again the process was repeated in narrower frequency ranges, until the depolarization frequency was determined with the desired accuracy.

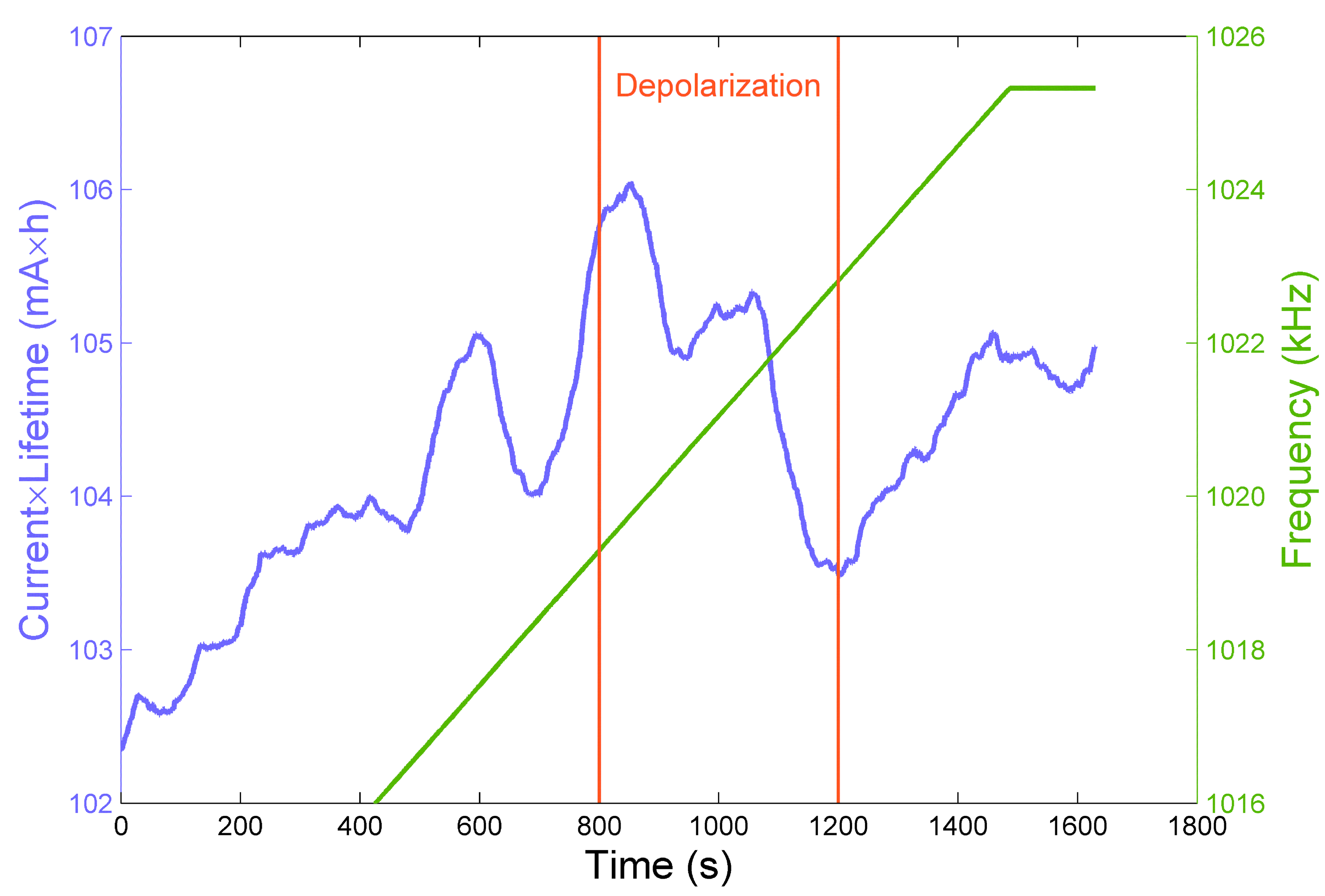

Fig. 2: The blue curve shows the product of beam current and life time. The green curve is the frequency of the oscillator. The blue curve drops between t=800s and t=1200s as the beam is depolarized.

RESULTS

Table 1 shows the results of the measurements. The error of the depolarizing frequency is dominated by the energy spread of the beam (± 3 MeV). The ambiguity between ν_{frac} and $1-\nu_{frac}$ leads to two solutions for the beam energy. The measurement was therefore repeated after the beam energy was increased slightly, and solution 2 was ruled out.

Table 1: Depolarizing frequencies and the resulting beam energies.

Machine Setting	Frequency	Energy (Solution 1)	Energy (Solution 2)
Lower energy	1.0190 ± 0.001 MHz	2899.8 MeV	2828.6 MeV
Higher energy	1.0205 ± 0.001 MHz	2900.2 MeV	2828.2 MeV

REFERENCES

[1] S.C. Leemann, “Precise Energy Calibration Measurement at the SLS Storage Ring by Means of Resonant Spin Depolarization,” Master Thesis, March 2002, ETHZ-IPP Internal Report 2002-02, http://simonleemann.ch/work.html.

[2] A.-S. Müller et al., “Energy Calibration of the ANKA Storage Ring,” Proceedings of EPAC 2004, Lucerne, Switzerland.

[3] S.C. Leemann et al., “Precise Beam Energy Measurement at the SLS Storage Ring,” Proceedings of EPAC 2002, Paris, France.

[4] P. Kuske et al., “High Precision Determination of the Energy at BESSY II,” Proceedings of EPAC 2000, Vienna, Austria.

[5] C. Steier, J. Byrd, P. Kuske, “Energy Calibration of the Electron Beam of the ALS Using Resonant Depolarization,” Proceedings of EPAC 2000, Vienna, Austria.

[6] L. Arnaudon et al., “Accurate Determination of the LEP Beam Energy by Resonant Depolarization,” August 1994, CERN SL/94/71 (BI).

[7] Ya.S. Derbenev et al., “Accurate Calibration of the Beam Energy in a Storage Ring Based on Measurement of Spin Precession Frequency of Polarized Particles,” Particles Accelerators 10 (1980) 177.

[8] J.M. Vogt et al., “Bunch Cleaning at the Canadian Light Source,” Proceedings of PAC09, 2009, Vancouver, Canada.