

HLS TURN-BY-TURN SYSTEM AND ITS APPLICATION*

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Abstract

Measurement principles and analysis of Turn-by-Turn beam position monitor system at Hefei Light Source (HLS) are presented in this paper. In emphases, several typical applications are presented here, which include the commissioning of upgraded injection system on HLS storage, monitoring of transient V and damping time of storage ring, beam instability in injection, as well as experiments of low frequency feedback system. Precise analyses of experimental results offer some conclusions, which are consistent with theoretical expectations. The system plays an important role in study of beam instability and improvement of machine performance.

INTRODUCTION

There are 31 BPM's (Beam Position Monitor) distributed along the electron storage ring of HLS. Each BPM has four-button type pick-ups mounted in a skew 45° direction. A 200MeV injection beam transported from linac and transport line is ramped to 800MeV and eventually stores 200-300mA in the storage ring. RF frequency is 204.035MHz, and harmonics number is 45. So the required sampling rate of clock system is 4.533MHz. The multi-cycle multi-turn injection system of HLS, with injection rate of 0.5Hz, is used for current accumulation.

In order to monitor the injection efficiency, damping rate, β oscillation and phase space after the upgrade of injection and RF system, a turn-by-turn (TBT) system based on log-ratio technique has been implemented [1]. In NSRL phase II project, which aimed at adopting the same lattice in different operation modes (GPLS and HBSL) for electron storage ring, we upgraded the injection system of HLS, in which we used four kicker magnets instead of three [2].

THEORY ANALYSIS OF LOG-RATIO BPM FOR TBT MEASUREMENT

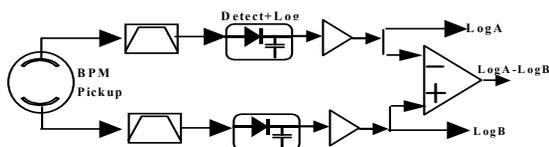


Figure 1: Schematic diagram of log-ratio detect.

TBT of the National Synchrotron Radiation Laboratory (NSRL) is composed of front-end pick-up electrodes, log-ratio electronics, clock & control system, data acquisition system and exciting system. The measurement principle

* Supported by National Key Project on Science- Phase II of NSRL & by National natural science Fund (10175063).
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for log-ratio electronics is show in Fig.1:

The signals from a pair of pickups are connected to log-ratio BPM and output the position information $Y[V]=Ky$ (LogA-LogB). Suppose the bunch charge distribution is Gaussian, for single bunch revolution operation mode, the signal spectrum can be represented as

$$U(\omega) = \frac{1}{2} U_b(\omega) \omega_0 \left[e^{j\varphi_0} \sum_n \delta(\omega - n\omega_0 - \nu_x \omega_0) + e^{-j\varphi_0} \sum_n \delta(\omega - n\omega_0 + \nu_x \omega_0) \right]$$

$$U_b(\omega) = jQ_0 \omega e^{-\frac{(\omega\sigma)^2}{2}}$$

Because of the periodic revolution of bunched beam, its spectrum is discrete, and the amplitude modulation is represented by spectrum lines which occur at both sides of the original one. Next the pickup signal is filtered by a band pass filter, which has parameters set as centre frequency 90^*f_0 , and pass band 2^*f_0 . In this case, the horizontal tune value is between 0.5 and 0.6. So the band pass filter output signal has only 4 spectrum elements, $(90 - \nu_x)$, $(89 + \nu_x)$, $(91 - \nu_x)$, $(90 + \nu_x)$. Analytic representatives of 4 terms can be denoted by:

$$\begin{aligned} & -\frac{\omega_0^2}{2\pi} (91 - \nu_x) e^{-\frac{((91-\nu_x)\omega_0\sigma)^2}{2}} \sin((91 - \nu_x)\omega_0 t - \varphi_0) \\ & -\frac{\omega_0^2}{2\pi} (90 \pm \nu_x) e^{-\frac{((90\pm\nu_x)\omega_0\sigma)^2}{2}} \sin((90 \pm \nu_x)\omega_0 t + \varphi_0) \\ & -\frac{\omega_0^2}{2\pi} (89 + \nu_x) e^{-\frac{((89+\nu_x)\omega_0\sigma)^2}{2}} \sin((89 + \nu_x)\omega_0 t - \varphi_0) \end{aligned}$$

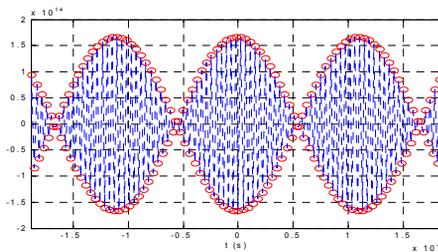


Figure 2: Turn by turn sampled record graph $\nu_x=0.51$.

As for the wide band "log amplifier", it actually incorporates a detector cascaded with an intermediate frequency log amplifier. Detection or demodulation of AM signal is equivalent to frequency mixing downward, that is, shifting spectrum elements to left or right by carrier frequency f_c . Result of detection is:

$$\begin{aligned} & \sin(v_x \omega_0 t + \varphi_0) + \sin((1-v_x)\omega_0 t - \varphi_0) \\ &= 2 \sin\left(\frac{v_x}{2} \omega_0 t\right) \cos\left(\frac{2v_x - 1}{2} \omega_0 t + \varphi_0\right) \end{aligned}$$

The turn by turn record points, which is shown at Fig.2.

APPLICATION OF TBT

HLS commissioning with upgraded injection system

The upgraded injection system consists of a pulse septum magnet and four kicker magnets [3]. Four kickers arouse a local bump orbit (Fig.3).

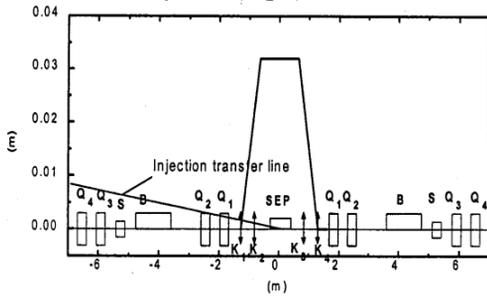


Figure 3: Local bump orbit of the HLS new injection system.

In order not to affect orbit outer bump in injection, we must have $\theta_1 = -\theta_2 = -\theta_3 = \theta_4$, that is, $\sum \theta_i = 0$.

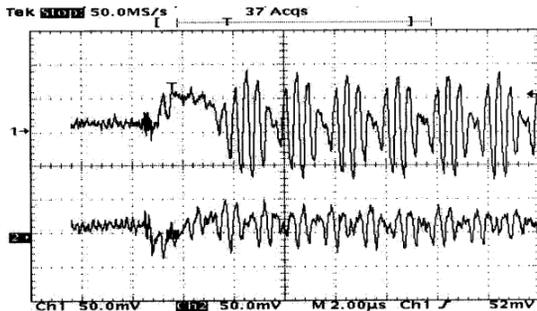


Figure 4: waveform while four kickers are supplied in the same time.

In the commissioning of new injection system, due to the unequal and asymmetrical distribution of the integral magnet fields of each group, the beam current only accumulated to 80mA. In injection processing, the bunch beam break-up (BBU), which has no evident relationship with the beam current, is detected from beam profile monitor, and at the same time, it is investigated with the turn-by-turn system and obtained results show there is a big remnant β oscillation (shown in Fig.4). It gives also the measurement results of the LR-BPM output for distorted orbit by oscilloscope. The CH1 and CH2 represent respectively horizontal (x) and vertical (y) beam positions.

On renewing fabricate ceramics vacuum, the subtle coat of coil and adjusting each coil inductance (these measures make the delay time inconsistency of delay time of each group from 200ns depress to 4ns), we performed a

number of experiments. The distorted orbit shown in Fig.5 is due to power supplied to four kickers simultaneously. The amplitude of the remnant β oscillation is only about 30mV. The injection beam current can accumulate over 200mA by improving injection system.

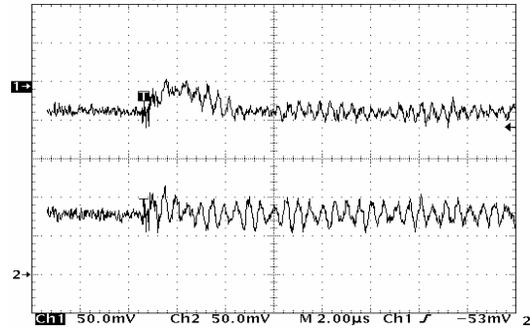


Figure 5: waveform while four kickers are supplied in the same time; Ch1: X Position, Ch2: Y Position.

HLS low frequency feedback system

In order to suppress HLS remnant β oscillation because of injected system error and to improve the accumulation of the injected beam, we implemented a low frequency feedback system (that is single mode feedback system) using output of LR-BPM of TBT. The centre frequency of low frequency feedback system is $f_L = 2.538MHz$, (because $v_x = 3.56$). The principle schematic is shown in Fig.6 and the experiment result in Fig7 and Fig8:

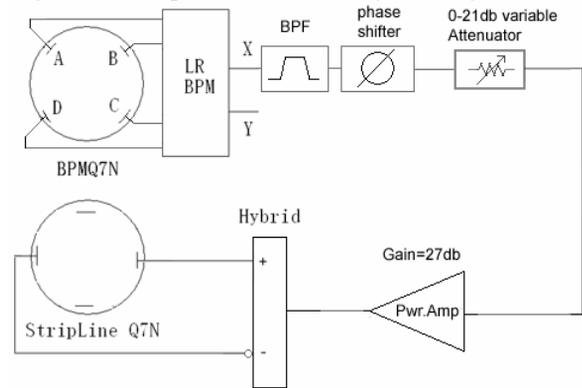


Figure 6: Schematic of low frequency feedback system.

From experiment result, we can see the damped effect obviously. The damping time is approximate 440 μ s with feedback off and it is only 2.86 μ s while we turn feedback on.

Instantaneous tune measurement experiment

The variation of storage ring instantaneous with time is of great importance. Monitoring of long time stability of Tune is valuable, helping us to evaluate environmental effects on beam stability.

By applying NAFF (Numerical Analysis of Fundamental Frequency) for instantaneous ν value estimation, one can obtain Tune value with desirable

accuracy, requiring smaller sampled data length. For instance, given data length of 256, by employing NAFF one can get extracted Tune with error less than 0.00005.

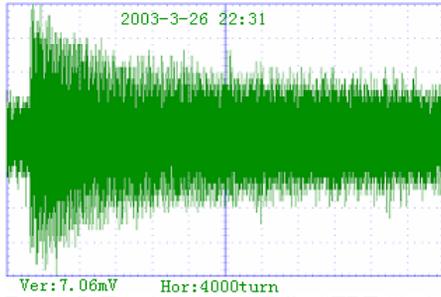


Figure 7: The data from ADC of TBT (feed-back off).

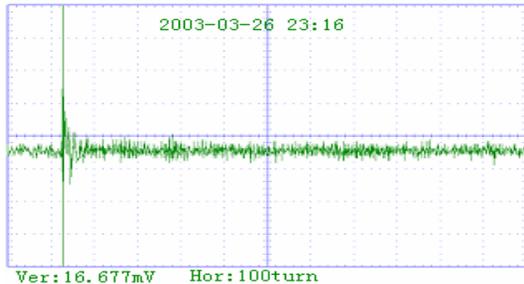


Figure 8: The data from ADC of TBT (feed-back on).

The principle of NAFF Tune extraction is to calculate the model of self-correlation, and search for the fundamental frequencies $v_{m,N}^{(k)}$ that maximize the absolute value of the correlator [3]:

$$I(v_{m,N}^{(k)}) = \sum_{n=m}^{m+N-1} f_n \exp(-i2\pi \cdot v_{m,N}^{(k)} n) \chi_{m-n}$$

$$\chi_n = \sin(\pi \cdot n / N)$$

It is graphically represented in Fig.9 the variety of Tune with time. The horizontal axis measures time by turns, and vertical axis measures the variation of fraction part of Tune value. From Fig.9 we can see beam accumulation is about 500 turns.

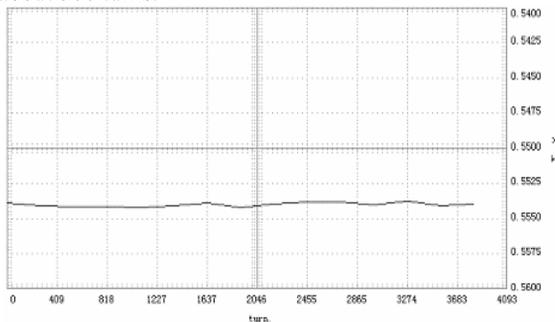


Figure 9: Variety of Tune with time.

Application in commissioning of HLS high brightness mode

In HLS high brilliance commission, the accumulation of the injected beam had been analysed using sum single

from four electrodes of TBT. From Fig.8 we can see that beam accumulation is about 500 turns.

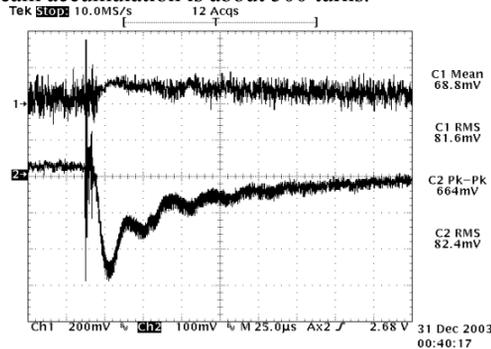


Figure 10: Beam accumulation in Commissioning of Highlight; Ch1: Position single, Ch2: Sum single.

From Fig.1 $\theta_1 = -\theta_2 = -\theta_3 = \theta_4 = 0$ we can conclude that beam accumulation is about 500 turns.

CONCLUSIONS

From above, the narrowband LR-BPM is a better scheme for transient position of beam: improved persistent, fast in response time, simple in circuitry, and wide in dynamic range. There is no doubt TBT application will be ever wider. It is an indispensable tool for research of machine instability and other beam dynamics. At HLS we have been developing and testing a TBT phase space measurement system, which implies another valuable application.

All of these are helpful in development of both bunch-by-bunch and lower frequency feedback systems in the future.

ACKNOWLEDGEMENTS

Authors would like to thank Dr. K.T. Hsu of SRRC of Tai Wan and Prof. Li Ma of BEPC for the beneficial discussion. We also would like to present our thanks to Prof. R. Hettel of SLAC, as well as T. Kasuga and T. Ieiri of KEK for their kindly help. Thanks to Li Wang and Hongliang Xu and Feng Zhao who takes in charge of the machine operation during the experiment.

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