DEVELOPMENT OF MEASUREMENT AND TRANSVERSE FEEDBACK SYSTEM AT HLS *

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Abstract

In order to cure and damp coupled bunch (CB) instabilities caused by the high order modes (HOMs) of the RF cavity and the resistive wall impedance of the Ring vacuum chamber. HOMs are ineluctable during the operation of the accelerator. An observer system characterized by bunch by bunch measurement of transverse β oscillation and longitudinal synchrotron phase oscillation has been constructed and commissioned at Hefei Light Source (HLS) [1, 2]. A transverse bunch-by-bunch feedback system is under construction. The design and development of the observe systems, as well as diagnostics results of machine instabilities are presented in this paper.

INTRODUCTION

The high brightness and beam stability are the goals of the particle accelerator, but the coupled multi-bunch instability is the restriction against the high performance of the light source. After developing the bunch by bunch transverse, longitudinal and relative bunch charge measurement system, we conducted a series of experiments at HLS. We got some instability results and novel phenomenons by using gate circuits, for instance, single bunch detection, bunch array exciting, and single bunch exciting. (Some results show instability and novel phenomenons has been got by using a gate circuits.)

Table 1: Parameters of HLS storage ring

Parameter	Value	Unit
Beam Energy (E)	800	MeV
Total DC Current (I_0)	300	mA
Revolution frequency (f_0)	4.533	MHz
Harmonics (h)	45	
Tune (Qx/Qy/Qs)	3.58/2.58/0.037	
Radiation damping time ($\tau_x/\tau_y/\tau_s$)	21.2/21.7/10.95	ms
Beam Length (σ)	3.8	cm

At the HLS storage ring, a multi-cycle multi-turn injection system is used for current accumulation. The parameter of the HLS electron storage ring is listed below as Table 1.

HLS Bunch-by-Bunch System

The HLS BxB system consists of two projects: the BxB measurement system and the BxB transverse feedback system. Signal detection and feedback devices are BPM (Beam Position Monitor) and striplines. The BPM has four-button type pick-ups mounted in a skew 45°[3]

Design Idea and Parameter

The minimum interval between adjacent bunches is 5ns, requiring the bandwidth of the system not less than 100MHz.

Design parameter of Bunch-by-Bunch system of HLS:

- Working frequency:
  Transverse: 612MHz (3*fRF)
  Longitudinal: 1.224GHz (6*fRF)
- Bandwidth: 102MHz
- Adjustable delay precision: 10pS
- Adjustable shift phase precision and range:
  0.09 Deg , ≥360 Deg
- Measurable dynamic range: ≥40dB
- Reference Oscillation:
  ≥7dBm, PhaseNoise≤-80dBc
- Feedback Power: ≤100W
- Damping time of feedback: ≤44μS

Overview of the HLS BxB System

The BxB measurement system is designed for bunch oscillation detection, and also works as a part of the transverse BxB feedback system. Fig. 1 shows an overview of the BxB system of the HLS.
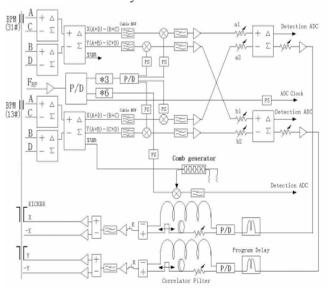

Figure 1: Overview of the BxB system of the HLS.

The BxB system includes four functions: to measuring transverse oscillation (horizontal and vertical direction); to measure longitudinal phase oscillation; to measure relative bunch charge; and to implement transverse wideband feedback using two BPMs. They are composed of pick-up electrodes and front-end circuitry for signal receiving, high-speed electronics for oscillation capturing, PXI PLL frequency multiplier modular, PXI RF controlling modular, PXI data acquisition modular and wideband exciting devices.

Transverse and longitudinal phase oscillation, as well as bunch charge can be recorded using the same digitizer modular. The transverse oscillation signal is detected at centre frequency 612MHz ($3*f_{RF}$) and longitudinal phase oscillation signal is detected at centre frequency 1.2GHz ($6*f_{RF}$) by summing BPM signals from Hybrids. The transverse width-band feedback system is composed of a front-end detection circuitry which base in transverse position detection system, a north filter which eliminate DC and revolution frequencies, a high frequency power amplifier as well as a wideband kicker (stripline).

DEVELOPMENT OF KEY CIRCUITRY

Cable Filter

Power divider/combiner delay cable make up of a simple cable FIR filter to acquire centre frequency 612MHz for measuring transverse position oscillation and frequency 1.2GHz for measuring longitudinal phase oscillation. We choose RG223 cable for the cable filter module.

PXI Modules: PLL Frequency Multiplier; RF Controller

From standard 204MHz RF signal we derive 6 f_{RF} and 3 f_{RF} by use of Phase Lock Loop, as well as several f_{RF} for clock delivering. These functions are implemented as two PXI modules. It incorporates input protect-limiter amplifier, log-power detecting and VGA to auto-adapting certain dynamic range, 3 and 6 PLL multipliers, frequency divider and signal deliver, SAW band limiter, LNA and output power driving, voltage controlled phase shifter and attenuator, multi-channel 12bit DAC for driving and controller external shifter and attenuator modules, as well as standard PXI/CPCI bus interfaces. The schematic diagram is shown as below.
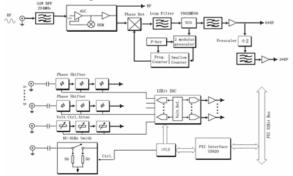

Figure 2: PLL freq-multiplier and RF controller.

Data Acquirement System

The HLS BxB transverse measurement system works at Radio Frequency. A PXI digitizer module (Acqiris DC440) is used for recording, characterized by 12-bit resolution, up to 400 MSPS (Million Samples Per Second) and simultaneous in two channels, 4MBs storing depth per channel. The PXI chassis is 6U MEN desktop system . An in-phase RF (204MHz) signal is used as the external clock of the ADC (Analog-to-Digital Converter), and an in-phase Revolution Frequency signal (4.533MHz) is connected with the External Trigger of the ADC.

Reliability Test of HLS BXB Measurement System

In order to approve the reliability of the BxB measurement system, a signal simulation experiment was designed [4]. The test result was shown in Figure 3
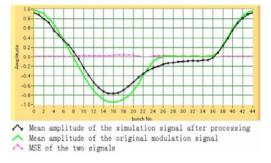

Figure 3: Simulation beam signal detected by ADC.

Figure 3 compares the original modulation signal and the modulated pulse signal processed by the BxB measurement system. The waveforms are detected by ADC, with 4.2M samples. The average of the Mean Square Error (MSE) of the 45 simulation bunches' normalization amplitude is 1.49%.

$$MSE = \frac{1}{n}\sum_{i=0}^{n-1}(x_i - y_i)^2 \qquad (1)$$

The test of the BxB measurement system by the simulation signal shows a good result of this high speed AD system.

EXPERIMENT RESULTS AND ANALYSES

Using the BxB measurement system, we obtain many significative measured results on the HLS storage ring. In particular, the gate circuits are useful in multi-bunch storage ring.

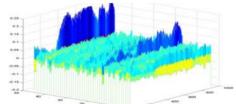### Transverses and Longitudinal Instabilities in Storage Operating

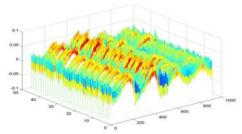Figure 4: Oscillation of 45 bunches in Y direction.

Figure 5: Synchrotron phase oscillation in the longitudinal direction: measured by phase detecting.

BxB Measurement of Using Burst Mode Resonant Frequency Exciting All Bunches
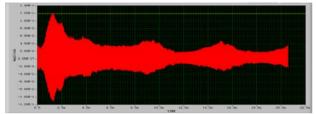

Figure 6: Coherent instability oscillation appeared in Y direction.

Fast Gate Application Using Fast Switch Gate Controlled Bunch Exciting

We use a ns-level fast switch to control stimulation strength and lasting time. This kicking-probing method can be used to investigate transverse coupled bunch instabilities detection and coupled-mode analysis.
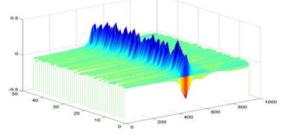

Figure 7: Oscillation damping of transiently stimulated bunches.

Single Bunch Detection under Multi-bunch Operation

By use of ultra fast switch, it is possible for us to pick up signals of one specific bunch from bunch trains. This implies that we can use a detecting bunch to evaluate effect of exciting and coupled instabilities.
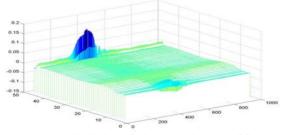

Figure 8: Single bunch detecting by use of fast switch.

Single Bunch Exciting in Case of Multi-bunch Operation

By using ultra fast switch and proper delay, we can concentrate exciting signal on one specific bunch, ignoring other bunches. Stimulating one bunch and recording oscillation of all bunches, we can study the bunch effect between adjacent bunches and evaluate coupling of movement between bunches. The results are especially distinctive when there is coherent coupling between bunches.
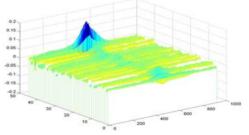

Figure 9: BxB Recording of single bunch exciting.

Other Applications at HLS

In addition, we can utilize the BxB system for transverse wideband feedback to cure bunch instabilities especially when storage ring operates in high current operation. Coupling of bunch movement between transverse directions can also be investigated when we capture simultaneously the vertical and horizontal oscillations. By studying Betatron phase at different locations we can evaluate the impedance distribution along the ring. The tune shift depend on the amplitude is also an interesting subject for beam dynamics study.

CONCLUSIONS

The commissioning of BxB measurement system is carried out on December 2004 and works in HLS and BEPC for performance study now. The experiments of single bunch stimulation and turn by turn detection system by gate circuits have got some ideal results [5].

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[1] M. Serio, "Multi bunch Instabilities and Cures", PAC'99, New York, NY, USA, 1999.
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[4] K. Zheng, J. H. Wang, J. H. Liu, Z. P. Liu, "Bunch Tracing by Bunch by Bunch Measurement System in HLS", PAC'05, Knoxville, TN, USA, 2005 May.
[5] J. H. Wang, W. M. Li, Z. P. Liu, etc, "Turn by Turn System of HLS and its Application", PAC'05, Knoxville,TN, USA, 2005 May.