BUNCH BY BUNCH BEAM DIAGNOSTICS IN SSRF *

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Abstract

A set of broadband beam instruments including filling pattern monitor, scope based BPM processor and streak camera has been implemented in the storage ring of SSRF. Several parameters such as charge, lifetime, transverse position, betatron tune and beam length, can be measured for individual bunch by these devices. The operation experience and measurement results will be introduced. The preliminary effort to retrieve wake field information from these measurements will be presented as well.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF), as a 3.5 GeV third generation light source, started user operation with seven beamlines since 2009 [1]. Couple thousands of experiment proposals have been performed during past three years. Meanwhile almost the same number of proposals were rejected or delayed due to limited beamlines and beam time. In order to take full advantage of SSRF an upgrade project of adding more than twenty beamlines has been planed. Lots of in vacuum insertion devices with small gap will involve in this upgrading. Beam instability introduced by multi-bunch interaction will be a very series issue in this case. Study of machine impedance and wake field became a high priority job. Several broad band instruments with bunch by bunch capability was developed and implemented for this purpose and showed very good potential in recent machine studies.

Table 1 shows the primary specification of broad band diagnostics devices equipped in SSRF ring.

Table 1: Specification of Bunch by Bunch Instruments

Measurement	Devices	Resolution
Charge	Button pickup + digitizer	0.1%
Position	Button pickup + Scope	50 um
Length	Streak Camera	2 ps

During a typical SSRF user shift, beam in storage ring will be filled up to 210 mA with equivalent 500 bunches then decays to 140 mA. A lots of history data produced by above instruments have been accumulated. Detailed analyze of these data will give us some knowledge of multi-bunch interaction.

BUNCH POSITION

An digital oscilloscope embedded EPICS IOC was developed to do bunch transverse position measurement [2]. Broad band beam signals from four button electrodes are link to four channels of scope independently. Voltage waveforms from four electrodes introduced by passing electron bunches can be recorded at the same time. Applying proper algorithm the absolute bunch position can be derived. The sample size for each bunch is up to 3650 turns due to the large buffer of scope, which makes precise individual bunch tune and dumping time measurement possible.

Fig. 1 shows a snapshot of 1650 turns of the transverse bunch position after injection. As two examples a bunch at the head (#11) and a bunch at the tail (#490) are plotted. colour circles indicate the turn number. The darkest blue circle stands for the first turn and the darkest red circle stands for the latest turn. It is easy to find that betatron oscillation is excited for each bunch due to injection kicking. The oscillation amplitude in horizontal direction is ten times larger than vertical. The behaviour of bunches train head is obviously different with the tail, which could be the effect of wake field.

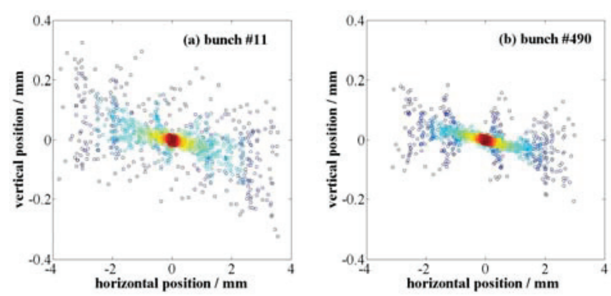

Figure 1: Snapshot of 1650 turns of transverse bunch position after injection.

FFT analyze is very powerful tools to retrieve information of betatron oscillation from position data. Applying DFT calculation on the above data we can get position spectrum of individual bunch shown in Fig. 2. The bunches at head, middle and tail are plotted. 3650 turns of data and optimized algorithm give us frequency resolution better than 0.0001 which is good enough to distinguish the tune difference between bunches.

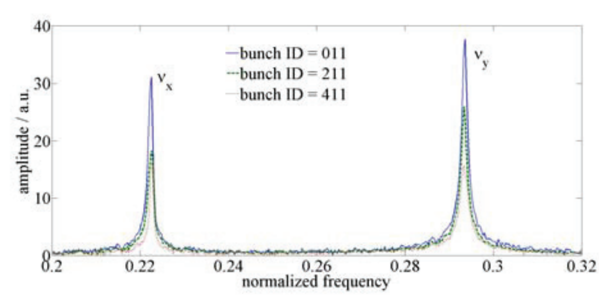

Figure 2: Position spectrum of individual bunch.

In horizontal plane the frequency and amplitude of betatron oscillation show strong correlation with bunch location in the bunch train. In vertical plane there is a

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little difference that the frequency of betatron oscillation is not clearly link to bunch location.

Put all bunches data together we can get the tune value and oscillation amplitude distribution shown in Fig. 3. The bunch train head gets the strongest betatron oscillation. The amplitude of oscillation decreases bunch by bunch. Horizontal tune shifts 0.0002 from head to tail. A reasonable guess for this distribution is wake filed effect. The environment what posterior bunches see is modified by wake field of previous bunches.

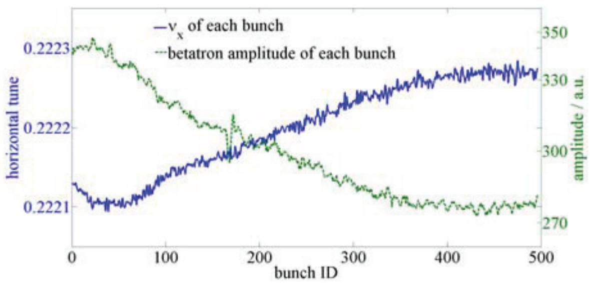

Figure 3: Horizontal betatron tune and amplitude distribution.

Another parameter can be retrieved from position data in time domain is damping time. Fitting the envelope of damping oscillation with exponential function, we can get damping time. Fig. 4 shows a typical bunch position waveform after injection, fitted exponential curve and acquired damping time.

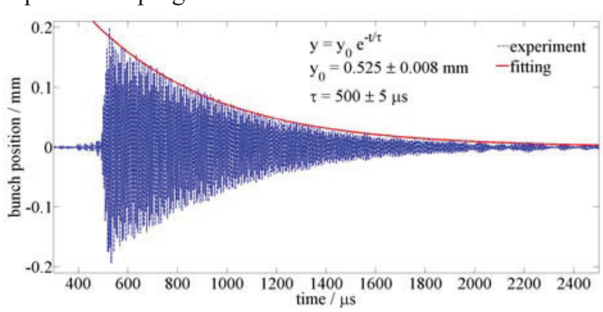

Figure 4: Damping time retrieved from betatron oscillation and fitted envelope.

Applying above process for all bunches we can get the damping time distribution like Fig. 5.

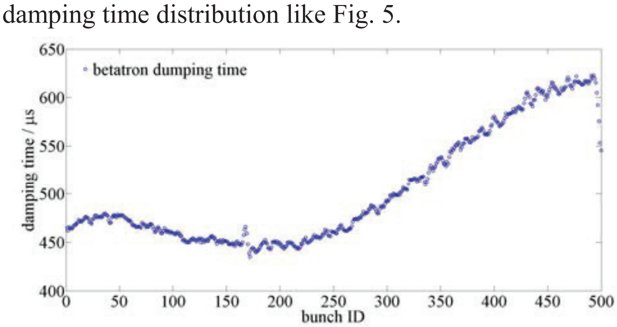

Figure 5: Horizontal damping time distribution.

Damping time distribution shows very good agreement with frequency domain analyze result. The glitch around bunch # 170 is introduced by fresh injected beam.

Bunch by bunch capability of transverse position measurement makes retrieve individual bunch information such as transverse traces, tune and damping time possible. Preliminary analyze of collected data during user run confirmed the strong correlation between these parameters and bunch location. Further dedicated experiments can help us understand wake field situation better.

BUNCH CHARGE AND LIFE

In order to satisfied the requirements of top-up operation, a filling pattern monitor which is capable of acquiring individual bunch charge, has been implemented in the SSRF ring [3]. This instrument consists of four-buttons type beam pickups, RF front end, 8 GHz sampling rate 10 bits waveform digitizer, and a PXI IOC.

Calibrated with DCCT, this device shows linearity and charge resolution as good as 0.1% of the full range shown as Fig. 8.

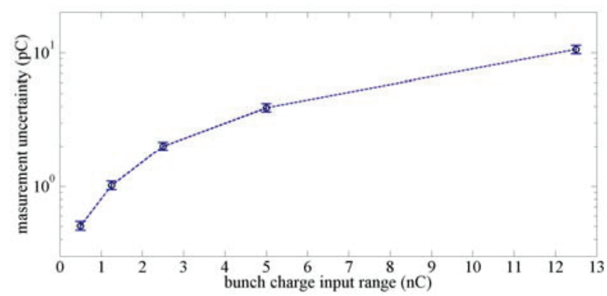

Figure 6: Resolution of bunch charge monitor.

For daily operation the filling pattern monitor is configured with 1.25 nC input range. It give us 1 pC charge resolution at 2 Hz data rate, which is good enough for bunch lifetime measurement.

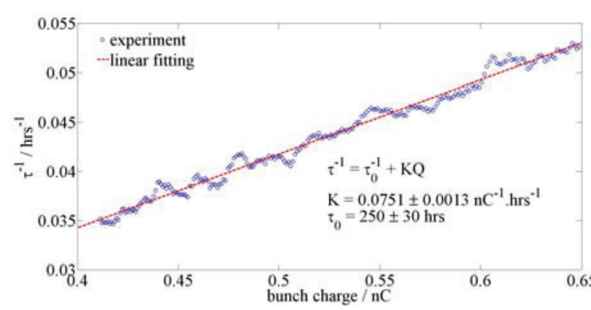

Figure 7: Linear correlation between bunch life and bunch charge.

Analyzing accumulated history data during user runs, we found the relationship between bunch lifetime and bunch charge can be described as following equation:

$$\frac{1}{\tau} = \frac{1}{\tau_0} + kQ \,. \qquad (1)$$

τ refers to bunch lifetime. Q refers to bunch charge. k and τ_0 are fitting parameters determined by machine configuration and bunch location in the bunch train. Fig. 7 shows a typical measurement and fitted parameters.

Applying above process for each bunch to obtain k and τ_0 then we can rebuild bunch location, bunch charge and bunch lifetime mapping like Fig. 8.

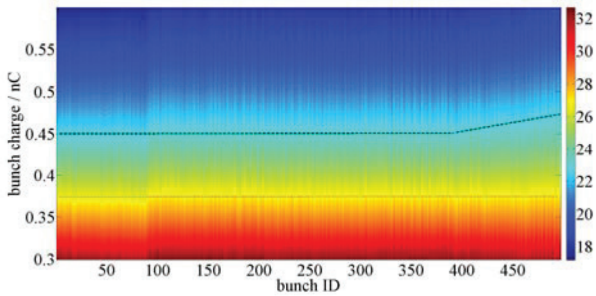

Figure 8: Bunch life dependency of bunch charge and ID.

In the above graph different colour indicates different bunch lifetime. Dark blue stands for smallest lifetime and dark red stands for longest lifetime. To emphasis the difference, a dot line is added at the edge between 'orange' and 'yellow' to show that bunch lifetime is almost irrelevant to bunch location (ID) with low charge. Another dash line is added at the edge between 'blue' and 'light blue' to show that bunch lifetime is correlated with bunch location (ID) with high charge. The lifetimes of bunches at the tail part are clearly larger than previous bunches. This could be another flag of wake field effect.

BUNCH LENGTH

Bunch length measurement is realized in traditional way with a commercial 2D streak camera (HAMAMAZU C5680), which is installed in the dedicated diagnostics beamline [4]. Fig. 9 shows a raw streak camera image captured during user run.

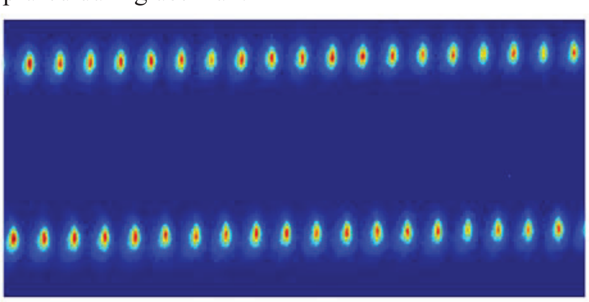

Figure 9: Raw streak camera image .

Set proper delays and repeat above measurements longitudinal length of all bunches could be obtained. Fig. 10 shows the mean value and deviation of 100 measurements. There is no any sign showing bunch length link to bunch location in this experiment.

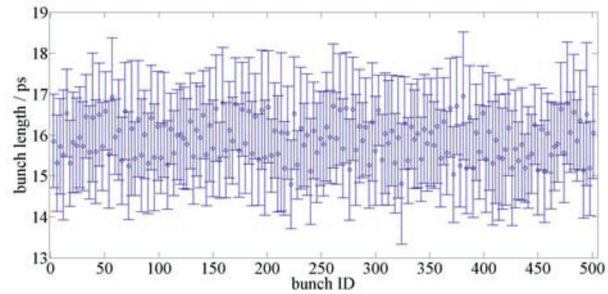

Figure 10: Bunch length distribution.

CONCLUSION

Scope based beam position processor, filling pattern monitor and streak camera have been implemented in SSRF to do bunch by bunch diagnostics. Information deduced from bunch position and charge shows strong correlation with longitudinal bunch location. It makes these two instruments very useful tools for multi-bunch interaction study. More dedicated experiments and further data analyze method will be performed in the near future. Current setup is only working for offline data analyze mode due to poor real-time processing capability of scope. FPGA based bunch by bunch BPM processor development is in plan.

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