BUNCH-BY-BUNCH BEAM POSITION AND CHARGE MONITOR BASED ON BROADBAND SCOPE IN SSRF*

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Abstract

A bunch-by-bunch beam position and charge monitor system, based on a broadband oscilloscope, has been developed at SSRF. The beam positions of each bunch could be located independently in this system by using the original signals from the button-type pickups on the storage ring. The relative charge of each bunch could be obtained by the sum signal from the pickups. Using sum weighted average method, turn-by-turn beam position could be got from the bunch-by-bunch beam position data. The difference of each bunch beam position have been observed during injection at SSRF.

INTRODUCTION

Brightness and stability are key specifications of synchrotron radiation light source [1]. Continual endeavor is derected to acquire high current, high brightness and favorable stability. Whereas the knowledge of coupling impedance (by which we mean the interaction between a beam and the surrounding vacuum chamber) indicates that the probability of improving performance of storage ring is limited by complicated beam surroundings. What caused the beam unstable, and how to cure the beam instabilities are the key questions, which all the accelerator researchers around the world need to face.

Observe and measure the beam in real time will help the researcher analyzing the storage ring. Realizing the measurements of the bunch by bunch position and charge will help study the beam impedance, coupling instability and nonlinear dynamics quantitatively, and can provide the accelerator physicists with an incredibly powerful machine study tool.

High sampling rate, multi-channel broadband scope with large memory capacity provides an ideal tool to obtain the raw data from BPM. Bunch-by-bunch beam position and relative charge could be got by off-line algorithm process. Turn-by-turn beam position could also be got from the bunch-by-bunch beam position data by using charge weighted average algorithm.

BEAM SIGNAL

The four chanel signals in time domain from BPM of storage ring can be expressed as follow by ignoring higher order:

$$\begin{cases} V_A(t)=\sum_{m=1}^{M}\sum_{n=-\infty}^{+\infty}V_m(t-nT_0-mT_{rf})\{1+\alpha x_m(nT_0+mT_{rf}) \\ \quad +\beta y_m(nT_0+mT_{rf})\} \\ V_B(t)=\sum_{m=1}^{M}\sum_{n=-\infty}^{+\infty}V_m(t-nT_0-mT_{rf})\{1-\alpha x_m(nT_0+mT_{rf}) \\ \quad +\beta y_m(nT_0+mT_{rf})\} \\ V_C(t)=\sum_{m=1}^{M}\sum_{n=-\infty}^{+\infty}V_m(t-nT_0-mT_{rf})\{1-\alpha x_m(nT_0+mT_{rf}) \\ \quad -\beta y_m(nT_0+mT_{rf})\} \\ V_D(t)=\sum_{m=1}^{M}\sum_{n=-\infty}^{+\infty}V_m(t-nT_0-mT_{rf})\{1+\alpha x_m(nT_0+mT_{rf}) \\ \quad -\beta y_m(nT_0+mT_{rf})\} \end{cases} \quad (1)$$

Wherein: $V_m(t)$ is the BPM signal when the beam is in the center of the BPM detector; x_m and y_m are the positions which the Number m bunch passes through the BPM; M is the number of bunch in the storage ring; α and β are constant with the relevant of BPM detector. T_0 is the period which the electrons run around the storage ring a circle. T_{rf} is the interval of bunch.

For SSRF, T_0 is 1.44μs. T_{rf} is 2ns. M is 500 in the supplying light mode [2].

MEASURE METHOD

Using broadband scope which has high sampling rate, four channels and large memory capacity, we could obtain the raw data in formula (1).

From formula (1), if we could obtain the data at the sampling interval T_{rf}. The position could be got as follow:

$$\begin{cases} x=k_x\cdot(V_A-V_B-V_C+V_D)/(V_A+V_B+V_C+V_D) \\ y=k_y\cdot(V_A+V_B-V_C-V_D)/(V_A+V_B+V_C+V_D) \end{cases} \quad (2)$$

Wherein: k_x and k_y are constant.

To achieve higher precision, the sampling point must be at the peak of $V_m(t)$.

The first step is to obtain T_{rf}. T_{rf} is the reciprocal of the RF frequency. The most straightforward way to get it is to record the frequency reading of signal generator using for synchronizing the whole accelerator. However, the frequency reading of signal generator is consequentially different from the true frequency. So FFT algorithm is

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used to obtain RF frequency. To improve the precision, we use zero-padding method which makes the data length 128 times than the raw data [3]. And if the original data length is not the integer powers of two, zero-paddling its length to the integer powers of two and then makes the data length 128 times than it.

In the actual experiment, the whole data length is 33th powers of two. If we use the double type to store the whole data at computer, we need 64GB RAM. However, the target we want is just to find the peak position near the 500MHz. In addition, FFT algorithm in Matlab is optimized which is faster than other codes. To use the FFT algorithm in Matlab and to solve the large RAM need problem, we just calculate the FFT result near the 500MHz.

Refer to the derivation process of time-decimal FFT algorithm, we derive the new algorithm whose output is only a small section based on the existing FFT calculation results. The new algorithm can be expressed as follow:

$$X[k+p\cdot\tfrac{N}{M}]=\sum_{q=0}^{m}FFT[x(M\cdot r+q)]\cdot W_N^{q\cdot(k+p\cdot\frac{N}{M})} \tag{3}$$

Wherein: N is the data length and must be the integer powers of two;

M is the number of segment we calculate the whole data;

k=0, 1, 2, ..., N/M-1; p=0, 1, 2, ..., M-1;

x(M·r+q) means the N/M length data whose interval is M and start at x(q);

FFT[·] is the FFT calculation. And the value in the formula is the Num. k result of the whole transform.

From formula (3), if we just calculate a continuous region of FFT result, the existing FFT calculate results can be used. And the data length can be short at every FFT calculation.

The next is to determine the starting point. In consideration of channel time delay mismatch in oscilloscope and the measurement accuracy, we choose the first peak point as the starting point for each channel.

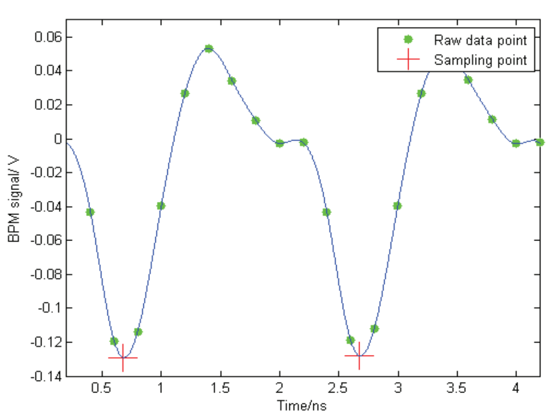

Figure 1: Relationship between sampling point and the original data point.

The bunch-by-bunch BPM signal could be obtain from the raw waveform data with the sampling interval T_{rf}. Since the sampling point may not be on the original sampling point from oscilloscope, cubic spline interpolation algorithm is used to get the sampling point data. Figure 1 gives the relationship between sampling point and the original data point.

The bunch-by-bunch position could be get by using difference over sum method(Δ/Σ). And the sum of four signal is the relative change of each bunch.

To get turn-by-turn beam position we use charge weighted average algorithm which is expressed as follow:

$$\begin{cases} x_{turn-by-turn}=\sum x_m\cdot S_m/\sum S_m \\ y_{turn-by-turn}=\sum y_m\cdot S_m/\sum S_m \end{cases} \tag{4}$$

Wherein: x_m and y_m are the positions which the Number m bunch passes through the BPM and S_m is the sum signal of each bunch.

BEAM EXPERIMENT

A oscilloscope with 100M point sampling depth and 5Gsps sampling rate was used to sample the four channel signal simultaneously from BPM during the injection process of SSRF which is running on top-up mode. And the data process method is described previously.

Figure 2 is the sum signal of each bunch. The first 500 position is filled with change. And the relative amplitude shows the quantity of electric charge of each bunch.

Figure 2 also gives the difference of sum signal between the beginning and the end of the injection process. From Fig. 2, we could confirm the change was injected at the Bunch 1 and Bunch 4.

Figure 3 is the horizontal position of Bunch 1 during injection which shows the vibrating is quite different on the injected bunch and others.

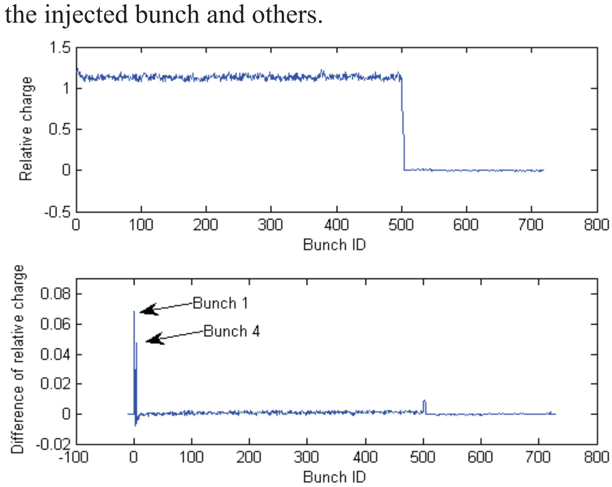

Figure 2: Sum signal of each bunch(up) and increments of sum signal between the beginning and the end of the injection process(down).

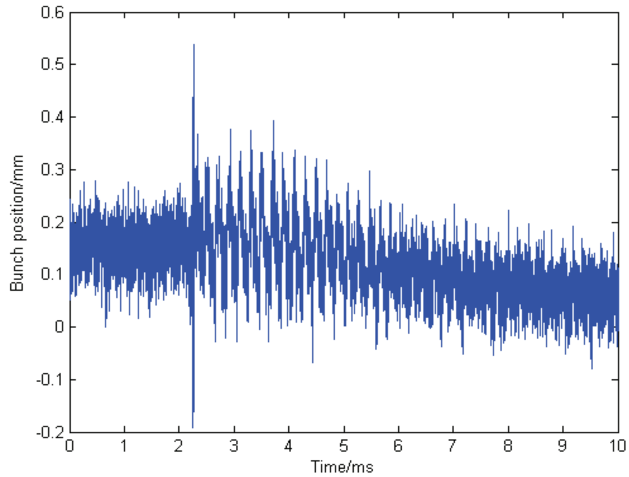

Figure 3: Horizontal position of Bunch 1 during injection.

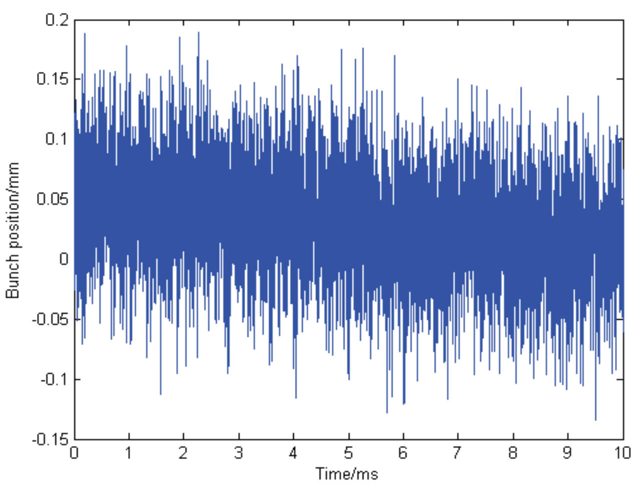

Figure 4: Horizontal position of Bunch 3 during injection.

Figure 4 is the horizontal position of Bunch 3. In Fig. 4 we can find the vibrating of bunch which near the injected bunch is slight.

Figure 5 shows the horizontal position of Bunch 300 which is quite the same as the turn-by-turn position during the injection process.

Figure 6 is the turn-by-turn position and its spectrum which is obtained by using sum weighted average method from bunch-by-bunch position and sum data during the injection process.

CONCLUSION

With broadband scope which has high sampling rate, four channels and large memory capacity, we have the raw data of BPM signal. High-precision FFT algorithm was used to get RF frequency which is the simultaneous sampling frequency. By cubic spline interpolation algorithm, the bunch-by-bunch BPM signal was gained. The bunch-by-bunch beam position and relative charge was achieved from bunch-by-bunch BPM signal. Using sum weighted average method, the turn-by-turn position was obtained.

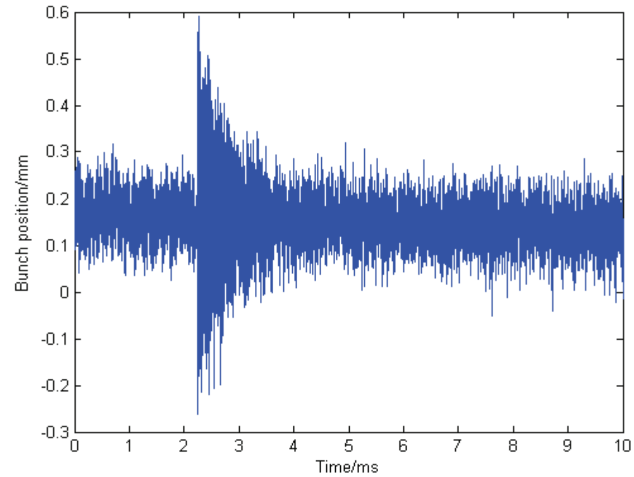

Figure 5: Horizontal position of Bunch 300 during injection.

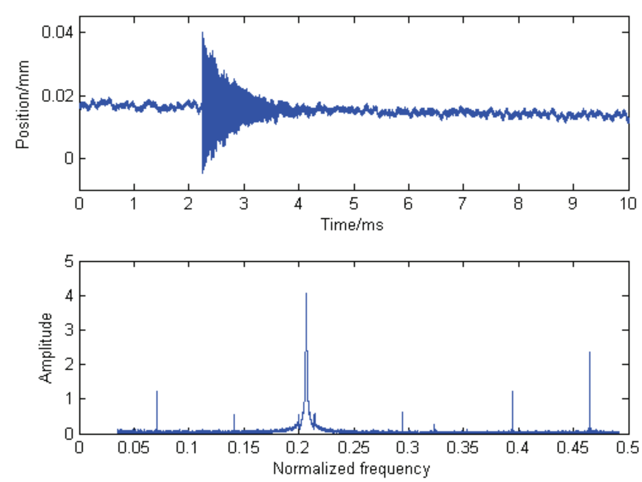

Figure 6: Turn-by-turn position and its spectrum.

REFERENCES

[1] Yang Guisen, Leng Yongbin, Yuan Renxian, Yan Yingbing, "Beam Instabilities Based on Spectrum of Turn-by-turn Position," High Power Laser and Particle Beams, 08(2011)23.

[2] Leng Yongbin, Yan Yingbing, Yuan Renxian, Zhou Weimin, "Betatron tune measurement system for Shanghai Synchrotron Radiation Facility storage ring," High Power Laser and Particle Beams, 10(2010)22.

[3] John G. Proakis, Dimitris G. Manolakis, *Digital Signal Processing (4th Edition)*, (Prentice Hall, 2006), 252.

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