THE CALIBRATION FACTOR DETERMINED AND ANALYSIS FOR HLS BUNCH CURRENT MEASUREMENT SYSTEM*

Y.L. Yang#, T.J. Ma, B.G. Sun, P. Lu, J.G. Wang, J.Y. Zou, C.C. Cheng
NSRL&SNST, USTC, Hefei 230029, P. R. China

Abstract

For bunch current measurement system, button electrode or strip-line electrode can be selected as its signal pickup, peak value or integral of signal from pickup can be used to indicate the related bunch current value. To obtain the absolute value of bunch current, the calibration factor should be determined with the help of DCCT. So, the calibration factor is a key parameter for bunch current measurement system. At HLS, the stretch effect of bunch length was observed when bunch current decay over time and this will affect the performance of bunch current detection for different pickups and calculate methods, which mean the calibration factor will be different. In this paper, theoretical analysis and experimental validation results are performed to find out an acceptable solution about pickup and signal processing method for bunch current measurement system at HLS. The results show that, the best performance can obtained by adopting strip-line pickup.

INTRODUCTION

Bunch current measurement is necessary elements for most accelerators, especially for synchrotron radiation light source. A lot of various types of measurement systems are developed by now [1-4]. Current transformers, pickup-electrodes and wall current monitors are most widespread among devices for bunch current measurement.

Hefei Light Source (HLS) is a synchrotron light source, many button pickups and strip-line pickups have been mounted on the vacuum pipe for the measurement of electron beam position called as BPM. Typically, a BPM have four electrodes to calculate both vertical and horizontal beam position. Additionally, the sum signal from the four electrodes carry the bunch charge information and its change rate is less than 0.005 when beam position alternated within 4mm [5]. So the sum signal can be used to calculate the bunch current.

HLS storage ring operates in 800MeV with 204.016MHz RF and 45 bunches, the bunch separated from each other only 5 ns, and the bunch length is about 300ps. So, two type of four-electrode pickup can be selected as the pickup of HLS bunch current measurement system [6]: button electrode and strip-line electrode. Peak value or integral of bunch signal from pickup can be used to calculate the related bunch current value. To obtain the absolute value of bunch current, the calibration factor should be determined with the help of DCCT. At HLS, the stretch effect of bunch length was observed [7] when bunch current decay over time and this will affect the performance of bunch current detection for different pickups and calculate methods, which mean the calibration factor will be much different. So, theoretical analysis and experimental validation results are performed to find out an ideal solution for bunch current measurement at HLS.

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#ylyang@ustc.edu.cn

BUNCH CURRENT CALCULATE

The electrons in a bunch from storage ring are usually expressed with a Gaussian distribution. When the total charge in bunch is Q_0 and bunch length is σ_τ, formula 1 show the expression of a bunch in time domain.

$$I_b(t) = \frac{Q_0}{\sqrt{2\pi}\sigma_\tau}\exp(-\frac{t^2}{2\sigma_\tau^2}) \tag{1}$$

For button pickup, the sum signal of four electrodes can be expressed as follow:

$$\begin{aligned} V_\Sigma(t) &= k\frac{dI_b(t)}{dt} \\ &= -k\frac{Q_0}{\sqrt{2\pi}\sigma_\tau^2}\exp(-\frac{t^2}{2\sigma_\tau^2}) \end{aligned} \tag{2}$$

k is the scale factor of electronics. The chart was shown in Figure 1(a) [8].

Peak value and integral value of each bunch sum signal carry bunch charge information, which can be obtained from formula 2:

$$V_{peak} = K_P\frac{Q_0}{\sigma_\tau{}^2} \propto \frac{Q_0}{\sigma_\tau{}^2} \tag{3}$$

$$V_{integral} = \int_{t_1}^{0} V_\Sigma(t)dt = K_I\frac{Q_0}{\sigma_\tau} \propto \frac{Q_0}{\sigma_\tau} \tag{4}$$

Where K_p is the calibration factor for using peak value of sum signal and K_I is the calibration factor for using integral of sum signal. The above equation shows the strong influence of the bunch length σ_τ, both on V_{peak} and $V_{integral}$.

Alike, for strip-line electrode, the chart was shown in Figure 1(b) and the sum signal expression is:

$$V_\Sigma(t) = \frac{\varphi Z}{4\pi}\left[I_b(t) - I_b\left(t - \frac{2l}{c}\right)\right] \tag{5}$$

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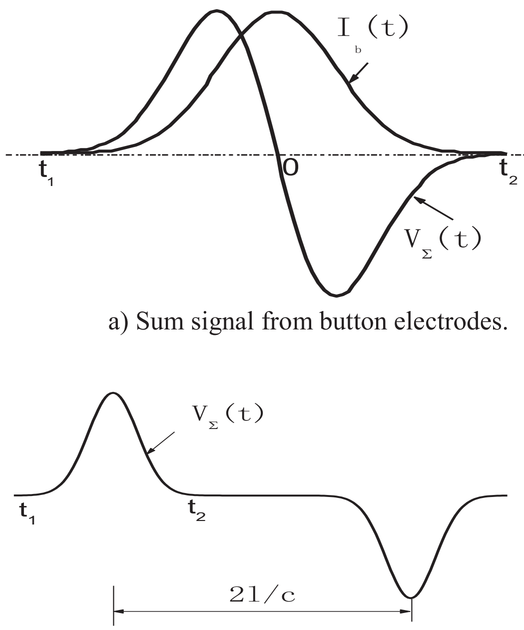
V_{peak} and $V_{integral}$ are approximated as formula 6 and formula 7:

$$V_{peak} = K_P \frac{Q_0}{\sigma_\tau} \propto \frac{Q_0}{\sigma_\tau} \tag{6}$$

$$V_{integral} = \int_{t_1}^{t_2} V_\Sigma(t)dt = K_I Q_0 \propto Q_0 \tag{7}$$

The equation 7 shows that the integral of sum signal of strip-line electrodes is proportional to bunch charge Q_0 and have no influence of the bunch length σ_τ



a) Sum signal from button electrodes.

b) Sum signal from Stripline electrodes

Figure 1: Sum signal of BPM.

EXPERIMENT DATA ANALYSIS

To evaluate how bunch length will influence the calibration factor of bunch current measurement, Beam current, bunch length and bunch current were monitored at the same time at HLS storage ring.

Beam Current Value Decay Over Time

Figure 2 shows the DCCT beam current value decay over time in HLS storage ring. Beam current decay from 200mA to 80mA within about 10 hours.

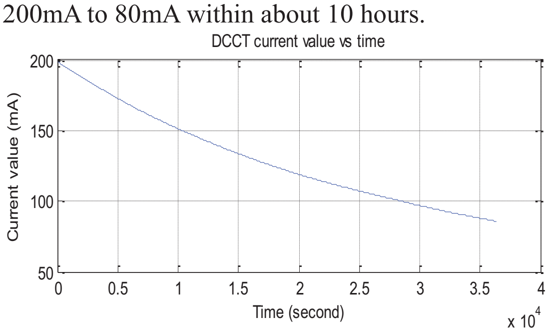


Figure 2: DCCT beam current value.

Bunch Length Stretch Effect at HLS

In this case, the stretch effect of bunch length was observed by Streak Camera [9]. Figure 3 shows that the bunch length changed from 303ps to 244ps, and the change rate is about 19%.

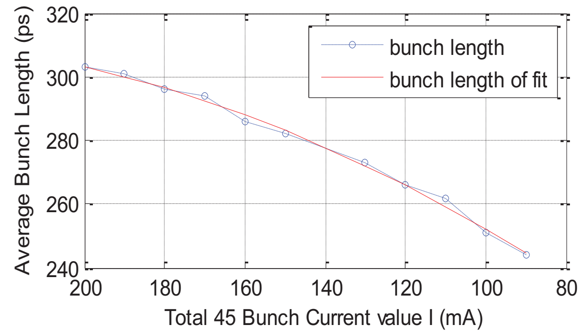


Figure 3: Bunch length changed with bunch current.

The bunch length stretch will affect the performance of bunch current detection for different pickup type and calculate method. With beam current decay from 200mA to 80mA, strip-line BPM and button BPM are used as pickup to detect the bunch current, integral value and peak value for each bunch of the sum signal from BPM are used to calculate the calibration factor.

Calibration Factor for Bunch Current

When beam current decayed from 198mA to 86mA, sum signal from button and strip-line pickup have been recorded by oscilloscope. Figure 4 show the sum signal of four-strip-line pickup, include all 45 bunches.

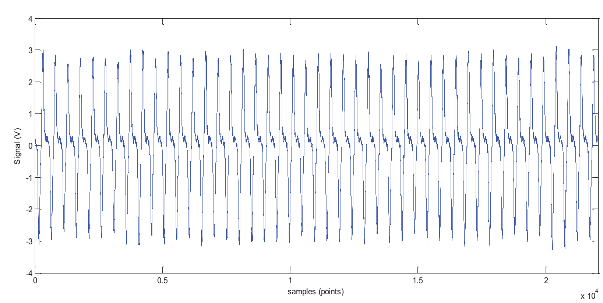


Figure 4: Sum signal of four-strip-line pickup.

From the sum signal waveform, peak value and integrate value of every bunch can be extracted and then the relative bunch by bunch current value can be obtained. Combined the DCCT beam current value, we can calculate the calibrate factor which changed following the beam current. The normalized calculating results were showed in Figure 5. With strip-line pickup and integral (Fig.5 a), the normalized calibration factor changed only 1.4% when bunch length have changed 19.3%, the measurement RMS is 0.003. The factor change rate is 16.1% with button pickup and integral (Fig.5 b), 15.5% with strip-line pickup and peak value, and 27.1% with button pickup and peak value.

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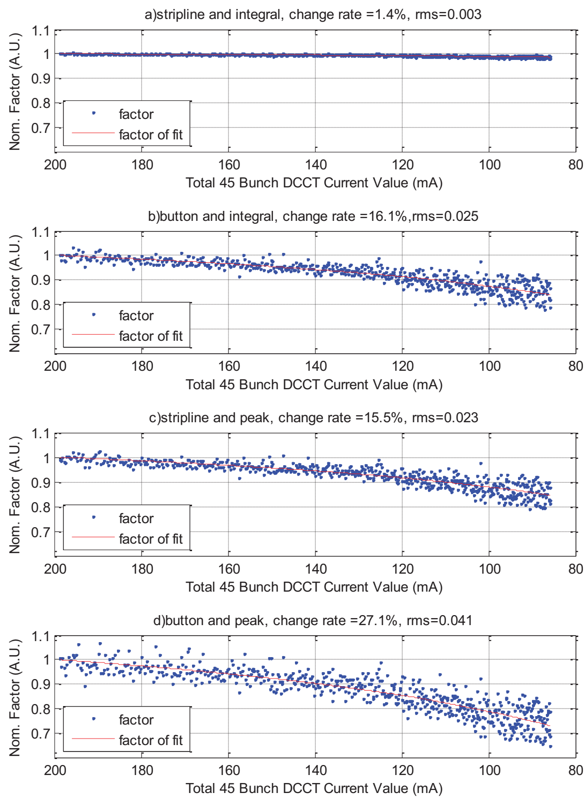

Figure 5: The calibration factor has changed with bunch current value.

So, strip-line pickup and integral method were finally selected to calculate the calibration factor and get the absolute bunch by bunch current value at HLS storage ring. Figure 6 show the bunch current measured by HLS bunch current measurement system.

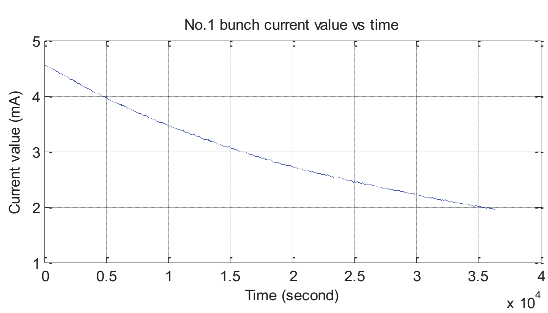

Figure 6: Bunch current decay over time.

SUMMARY

Theoretical and experiment data analysis show that, using strip-line as signal pickup and processing the sum signal waveform by integral, the bunch length stretch effective on calibration factor can be omitted, the best choice for bunch current detection for electron storage ring. The experiment data analysis show that the factor will change about 27% when bunch length changed about 19% if using button pickup and processing by peak value of bunch signal.

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