A PRELIMINARY SIMULATION OF BPM SIGNAL DIODE DETECTOR FOR HLS II TUNE MEASUREMENT SYSTEM*

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Abstract

A high sensitivity BPM signal detection front-end electronics has been designed for HLS II tune measurement system according to the HLS II upgrade requirements. Classical tune measurement systems filter out just one or a few of these betatron sidebands frequency, as a consequence, most of the betatron energy is dropped and only a very small energy remains for further processing. A new method, referred to as Direct Diode Detection (3D) by LHC[1], improves this situation. In this paper, the HLS II BPM signals have been calculated out in time domain and frequency domain. Basing on the characteristics of HLS II BPM signals, a preliminary simulation is performed to test and verify the feasibility of diode detector for HLS II tune measurement system. The simulation results clearly show that the technique of diode-based circuit can be applied to HLS II tune measurement.

INTRODUCTION

HLS II consists an 800MeV linear accelerator and an 800MeV electron storage ring. The design value of the storage ring tune is near 3.2 in vertical and 4.4 in horizontal. The classical tune measurement systems [2-4] need an external excitation to reinforce the transverse beam oscillation motion. Then the enhanced signal obtained by the buttons on the BPM will be processed for spectrum analysis. However, the transverse dimension and emittance will be increased due to the outer excitation, which can seriously affect the brightness and lifetime of the beam and limit the performance of the source. Therefore, a more sensitive tune measuring system is necessary to be designed for HLS II.

3D method was first proposed by the Geller in CERN, and has been successfully applied on the tune measurement system of the LHC, PSP and BNL in which the sensitivity can reach about 10 nm betatron oscillation magnitude[5]. As the HLS II BPM signal also has a narrow pulse (150ps) and low duty cycle, a simple diode can time stretch the button signals so that more useful information relating to beam oscillation motion are reserved. At the same time, 3D method can filter off the convolution frequency and convert high-frequency signal into low-frequency signal, which greatly simplifies the circuit and reduce the cost of the circuit.

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BPM SIGNAL DETECTION FRONT-END ELECTRONICS

The schematic diagram of BPM signal front-end detector electronics designed for HLS II tune measurement system is depicted in Fig. 1, which consists of signal pick-up electrode, a diode detector circuit, a differential amplifier and filter circuit.

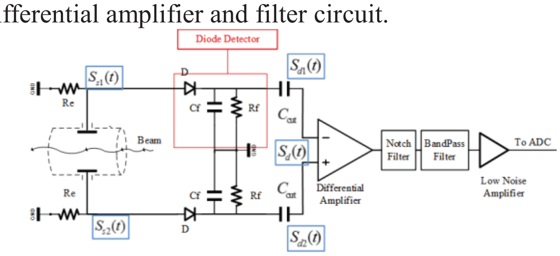

Figure 1: The diagram of front-end detector electronics.

The button-type BPM in HLS II with characteristic resistance R_e is 50 Ω, can be used as signal pick-up electrode directly in this system. Unipolar peak detector circuit can convert narrow pulse signals $S_{s1}(t)$, $S_{s2}(t)$ into low frequency signals $S_{d1}(t)$, $S_{d2}(t)$. C_{cut} is cut off capacitor of DC. The difference of the two signals $S_d(t)$ is amplified by high-impedance differential amplifier and then filtered by the filter circuit in order to improve the dynamic range. In this way the signal relating to beam oscillation can be better extracted.

The time stretching can be done by a simple diode detector (see Fig. 1). The diodes D are considered as ideal and followed by parallel R_f, C_f filters to form two peak detectors. The capacitor C_f has to discharge slightly before the next bunch arrives. Therefore, the value of τ has to be optimized comprehensively according to parasitic capacitance of BPM button, cable capacitance, modulation depth, modulation frequency and bunch interval.

HLS II BPM AND SIGNALS

The vacuum chamber of HLS II storage ring is octagonal and new button-type BPM includes four electrode, as is shown in Fig. 2, with some actual sizes. Note that there is a gap of 0.3 mm between button and mounting groove, which can be considered as a coaxial capacitor. This will has an impact on the high-frequency oscillation signal. The electrode capacitance depends on the electrode radius, the gap distance and the thickness of the electrode. The electrode capacitance is about 1.9 pF[6].

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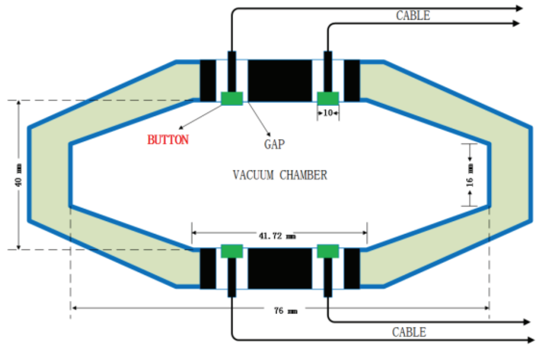

Figure 2: Schematic diagram of BPM in HLS II.

Assuming that the time-domain expression of inductive charges is $Q_{img}(t)$, which can be seen as a an charge integration in the direction of longitudinal beam movement

$$Q_{img}(t)=\int \rho(z)\frac{width(z)}{2\pi b}dz \qquad (1)$$

In which ρ is line density of charge and z represents the distance between the beam and button centre in the direction of beam movement. Assuming that button electrode radius is a, button electrode width seen at the cross-section in the longitudinal distance z is

$$width(z)=2\sqrt{a^2-z^2} \qquad (2)$$

If beam goes through the centre of the vacuum chamber at speed of light c, induced charge can be expressed as

$$Q_{img}(t)=\int \rho(z-ct)\frac{width(z)}{2\pi b}dz=FFT^{-1}(FFT(\frac{width(ct)}{2\pi b})\cdot FFT(\rho(ct))) \qquad (3)$$

Induced current is differential of induced charge

$$I_{img}=\frac{dQ_{img}(t)}{dt}=FFT^{-1}(i\omega\cdot FFT(Q_{img}(t))) \qquad (4)$$

Taking into account the impact of the electrode capacitance, the total conductance is

$$Z=(R^{-1}+i\omega C)^{-1} \qquad (5)$$

Since calculation of the frequency domain has to be involved, induced voltage in the electrode V_b can be expressed as

$$V_b=FFT^{-1}(Z\cdot FFT(I_{img})) \qquad (6)$$

which can significantly simplify the calculation. In addition, the effect of cable attenuation cannot be ignored. Frequency response formula of cable attenuation is

$$H_{coax}(f)=-0.0328L\left(0.12229\sqrt{f}+0.00026f\right)\text{dB} \qquad (7)$$

In which L is length of the coaxial cable and f is frequency. Defining voltage dB as

$$\text{dB}=\ 20\cdot\lg\left(V_{out}/V_{in}\right) \qquad (8)$$

Signal out of cable is

$$V_{cab}=FFT^{-1}(FFT(V_b)\cdot 10^{H(f)/20}) \qquad (9)$$

In accordance with the above formulas, the simulation results by Matlab are shown in Fig. 3 and Fig. 4, with simulation parameters shown in Tab. 1. The peak of induced charge is about 477 pC and the peak of induced current is about 1.93 A. The peak of button voltage is 79 V, while after 30 m cable attenuation the peak voltage becomes 47 V. The button voltage and signal out of cable are depicted in frequency domain in Fig. 4. It is obviously disadvantageous for the operating sensitivity of the tune measuring system. Therefore, the signal extraction circuit need be as close as possible to BPM so that cable attenuation effect can be as small as possible. The peak frequency is about 830MHz. The 3db spectral width is about 3 GHz, which makes it difficult to process.

Table 1: Main Parameters for Simulation

Parameters	Value
Current Intensity	200 mA
Bunch Length	150 ps
Pickup Capacitance	1.9 pF
Cable Length	30 m
Revolution Frequency	4.533 MHz
Bunch Numbers	45

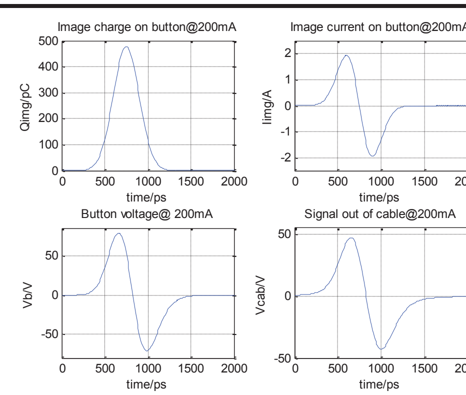

Figure 3: BPM signals for one bunch in time domain.

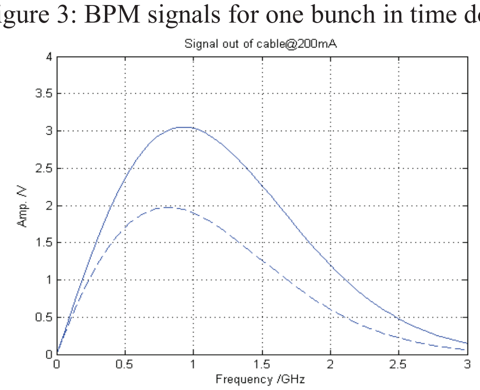

Figure 4: Simulated signal in frequency domain.

SIMULATION OF DIODE DETECTOR

The formula of simulated button signals is

$$S_{s1}(t)=S_s(t)(1+\alpha)(1+\beta\cos(2\pi f_b t))$$
$$S_{s2}(t)=S_s(t)(1-\alpha)(1-\beta\cos(2\pi f_b t)) \qquad (10)$$

For simplicity, the beam signal $S_S(t)$ was simulated as a voltage source giving pulses which are very short with respect to their repetition time T. T is considered as interval of HLS II BPM signals, about 220 ns, assuming that there is only a single bunch. The amplitude is set 80 V and the pulse time is set 150 ps . α is relative beam offset, while β describes the relative betatron oscillation amplitude. f_b is frequency of beam oscillation motion and the relationship between f_b and q is $q = f_b T$. R_e is characteristic impedance of BPM, which is about 50 Ω in HLS II. Since the parasitic capacitance of BPM electrode is approximately 2 pF , setting $C_f = C_b$ can avoid the effect of partial pressure of two capacitances. The value of R_f depends on time constant of RC circuit by $\tau = R_f C_f$. Figure 4 shows the simplified simulation schematic of signal extraction circuit by Pspice with $\alpha = 0.1, \beta = 0.05, q = 0.2$ and $T = 220ns$ (single bunch).

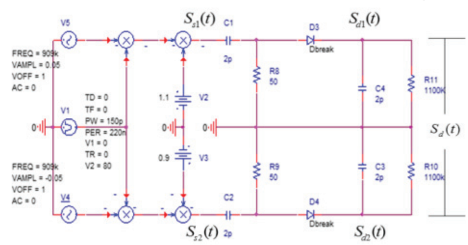

Figure 5: Simplified diode detector circuit by Pspice.

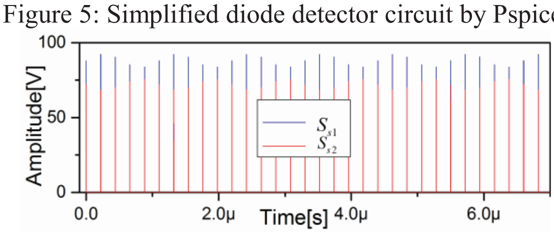

Figure 6: Simulation result of $S_{s1}(t)$ and $S_{s2}(t)$.

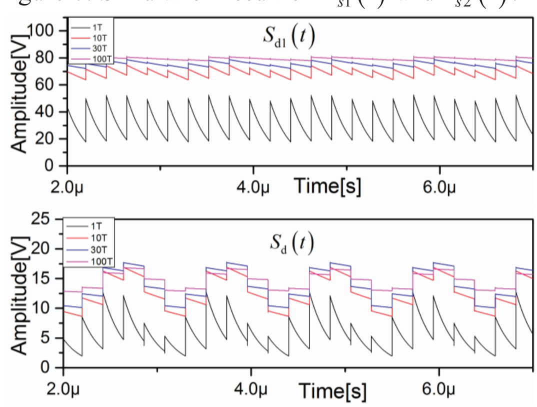

Figure 7: $S_{d1}(t)$ and $S_d(t)$ with different τ .

Plots in Fig. 6-7 show the results of the simulation with relevant parameters (see Fig. 5). $S_{s1}(t)$, $S_{s2}(t)$ are depicted in Fig. 6 while Fig. 7 shows C_f voltage $S_{d1}(t)$ and the difference of two electrode voltages $S_d(t)$ with different τ . The variation of $S_{s1}(t)$ is very high when the time constant τ is chosen to equal the revolution T, which also means that the time stretching of diode detector is done. And the simulated beam oscillation motion is clearly visible on the voltage $S_d(t)$. Increasing τ to 10 T reduces the variations of $S_{s1}(t)$ and it is seen that the increased DC offset of $S_{s1}(t)$ gives a much better representation of the peak bunch voltage. And the simulated beam oscillation motion is better described in the case of τ = 10 T. When τ is further increased to 30 T, the dragging effect appears and $S_d(t)$ is of distortion. In the case of τ = 100 T, it is seen that the time constant is too large for the assumed modulation depth (depends on β) and the modulation frequency (depends on q) so that the simulated beam oscillation motion completely cannot be reformed. Figure 8 shows results of simulation with many bunches. It is clear that for 45 bunches the waveform is much better than that for less bunches, which means less revolution frequency.

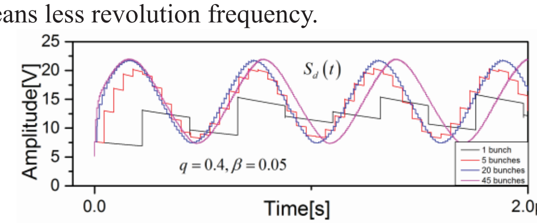

Figure 8: $S_d(t)$ with many bunches and q=0.4.

CONCLUSION

The BPM signals both in time domain and in frequency domain of HLS II were calculated out by Matlab. In order to avoid the attenuation of long cables, signal detection front-end electronics have to be close to BPM electrode. After some preliminary simulations by Pspice, it is clear that the effects of diode detector are different with changes of characteristic parameter τ and a suitable τ can extract more useful beam oscillation signals components and increase the sensitivity of HLS II tune measurement system. The value of τ will be given according to the final physical design β and q of Storage ring in HLS II. And in the future, the amplifier and optimized filter circuit will be actually designed.

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