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PRELIMINARY DESIGN AND CALCULATION OF BUTTON BPM FOR THE HALS STORAGE RING*

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Abstract

Button BPM is being designed for the Hefei Advanced Light Source(HALS) storage ring, which is a diffraction-limited storage ring (DLSR) located at the National Synchrotron Radiation Laboratory(NSRL) in Hefei city. Since beam size is very small, the required resolution of 50 nm for beam position measurement need to be obtained. The parameters of the HALS Button BPM are initially determined. According to theoretical formulas, electrode induced signal is calculated and the relationship between electrode induced signal and beam current is obtained. Signal to noise ratio(SNR)of the HALS Button BPM is calculated with different beam current when the required resolution is 50 nm. The results show that the SNR is 33.14 dB when beam current is 100 mA. In addition, the effects of BPM RF frequency and button electrode radius on SNR are analyzed.

INTRODUCTION

NSRL is ongoing the project of Research and Development for HALS. The parameters for the HALS are shown in Table 1. Since beam size is very small(sub-um level), beam orbit instability is very important. The required beam position resolution is 50 nm. This index is a challenge for BPM system. High resolution Button BPM sensor, High stability support and high-performance BPM electronics need to be developed or designed. This paper focuses on the introduction of design and calculation of the Button BPM for the HALS storage ring.

Table 1: Some Parameters for the HALS Storage Ring

Beam energy	2.0 GeV
Natural emittance	~ 50 pm·rad
Beam current	500 mA
RF frequency	100 MHz

BPM ELECTRODE INDUCED SIGNAL POWER

Preliminary design parameters of the HALS Button BPM is shown in Table 2. The vacuum chamber radius is 10 mm and electrode radius is 3mm. BPM RF Frequency is 400 MHz.

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Table 2: Preliminary Design Parameters for the HALS Storage Ring

vacuum chamber radius *b*	10 mm
BPM electrode radius *r*	3 mm
BPM electrode thickness *t*	2 mm
gap *g* between electrode and vacuum chamber	0.3 mm
BPM RF frequency *f*	400 MHz

According to the formulas from reference[1], BPM electrode capacitance and electrode induced signal power can be expressed as:

$$C_b = \frac{2\pi\varepsilon_0}{1n\left[\frac{r+g}{r}\right]}t \cdot \quad (1)$$

$$P = \frac{1}{2}I^2 R_0 \phi^2 \left(\frac{\omega_1}{\omega_2}\right)^2 \frac{(\omega/\omega_1)^2}{1+(\omega/\omega_1)^2}, \quad . \quad (2)$$

$$\phi = \frac{r}{4b}, \omega_1 = \frac{1}{R_0 C_b}, \omega_2 = \frac{c}{2r}, \omega = 2\pi f$$

Where I is beam current. R_0 is Characteristic impedance and equal to 50 Ω. c is light speed.

Based on the parameters from the Table 2 and formulas (1)-(2), the relationship between beam current and BPM electrode induced signal power is shown in Fig. 1. According to the relationship between electrode power and voltage, the relationship between beam current and BPM electrode induced voltage can also be obtained and is shown in Fig. 2. The results under three different beam currents(100 mA, 200mA and 400mA) are shown in Table 3.

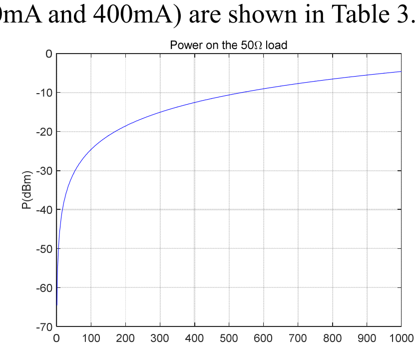

Figure 1: The relationship between beam current and BPM electrode induced signal power for the HALS BPM.

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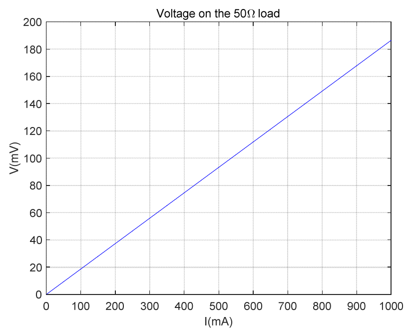

Figure 2: The relationship between beam current and BPM electrode induced voltage for the HALS BPM.

Table 3: The Results of Electrode Induced Signal for the HALS BPM

I /mA	P_{button} /dBm	V_{button} /mV
100	-24.59	18.65
200	-18.57	37.30
400	-12.55	74.60

SIGNAL-TO-NOISE RATIO AT 50 nm RESOLUTION

Based on boundary element method and matlab code [2], the HALS Button BPM model can be acquired, which is shown in Fig. 3. Horizontal sensitivity S_x is 0.1396 mm^{-1} and sensitivity curve for the HALS BPM is shown in Fig. 4. (The same for the vertical sensitivity curve). The range of linearity for the HALS BPM is [-2 mm, 2mm].

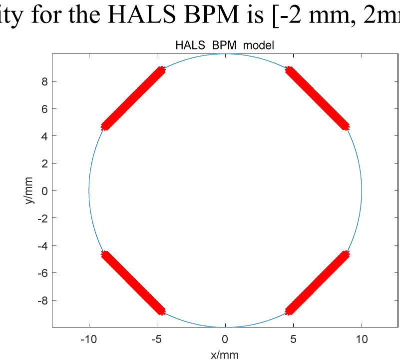

Figure 3: HALS Button BPM model.

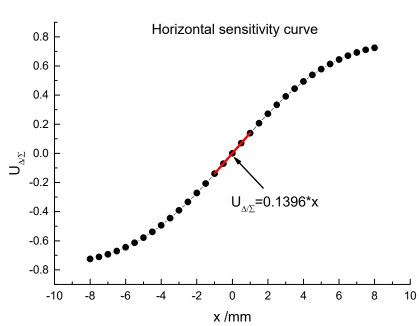

Figure 4: Horizontal sensitivity curve for the HALS BPM.

If beam deviates 50 nm from BPM center, corresponding normalized horizontal position change $\Delta U_{\Delta/\Sigma}$ according to difference/sum method can be equal to:

$$\Delta U_{\Delta/\Sigma} = S_x * 50nm = 6.98\times10^{-6} . \quad (3)$$

According to Fig. 2 and Table 3, BPM electrode induced signal Vbutton when beam current is I can be obtained. If beam deviates 50 nm from BPM center, corresponding electrode induced signal change V_{change} and P_{change} are equal to[3]

$$V_{change} = \Delta U_{\Delta/\Sigma} * V_{button} . \quad (4)$$

$$P_{change} = \frac{V_{change}^2}{R} . \quad (5)$$

In order to meet 50 nm resolution requirement for the HALS BPM system, BPM system noise signal power Pnoise must be small than P_{change}. P_{noise} can be expressed as:

$$P_{noise} = 4 * k * T * BW . \quad (6)$$

Where k is Boltzmann constant and T is temperature. BW is bandwidth of the BPM system and hypothetically set to 10 Hz(The slow acquisition mode data for the HALS BPM processor is used to measure closed orbit and required frequency is 10 Hz).

Signal to noise ratio SNR for the HALS BPM system can be expressed as:

$$SNR = \frac{P_{change}}{P_{noise}} . \quad (7)$$

According to Eq. (3-7), the relationship between SNR and beam current I for the HALS BPM system can be shown in Fig. 5. The results under three different beam currents(100 mA, 200mA and 400mA) are shown in Table 4.

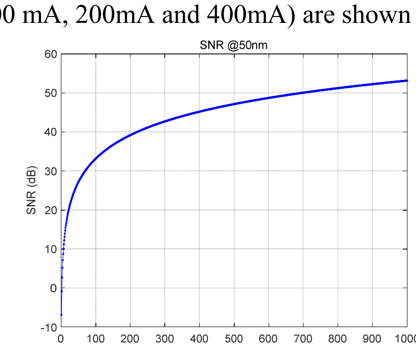

Figure 5: SNR varying with beam current @50nm.

Table 4: The Relationship between SNR and Beam Current

I /mA	resolution /nm	SNR /dB
100	50	33.14
200		39.16
500		47.12

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From Eq. (2), we know that BPM RF frequency *f* and electrode radius *r* have effect on the electrode induced signal and ultimately affect SNR. The relationship between SNR and BPM RF frequency *f* when *I* is 200 mA and electrode radius *r* is 3mm is shown in Fig. 6 and the relationship between SNR and electrode radius *r* when *I* is 200 mA and BPM RF frequency *f* is 400 MHz is shown in Fig. 7.

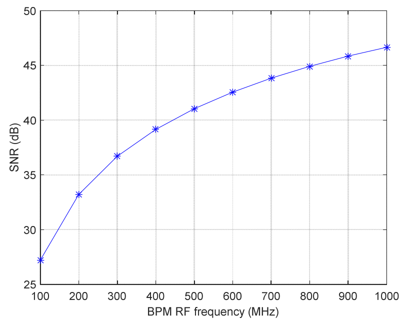

Figure 6: The relationship between SNR and BPM RF frequency @50nm.

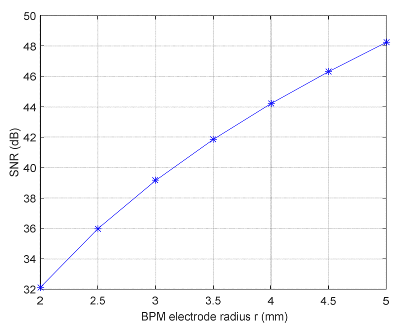

Figure 7: The relationship between SNR and electrode radius @50nm.

The SNR becomes better as BPM RF frequency or electrode radius becomes larger. But if BPM RF frequency is choosen to be too large, development difficulty and cost of BPM electronics will increase. If BPM electrode radius is large, HOM(TE11 mode) in the gap between electrode and vaccum chamber becomes serious and produced thermal effect has an impact on measurement resolution[4]. So choosing BPM RF frequency and electrode radius need to be considered comprehensively.

CONCLUSION

Button BPM for the HALS storage ring were preliminarily designed. According to theoretical formulas, the relationship between SNR and beam current under 50 nm resolution requirement has been obtained. In addition, the impact of BPM RF frequency and electrode radius on the SNR have also been analyzed. In the future, real physical effects such alignment errors, field errors and HOM need to be analyzed. Whether the final SNR meets our requirement need to be verified.

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