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DESIGN AND OPTIMISATION OF BUTTON BEAM POSITION MONITOR FOR SPS-II STORAGE RING*

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Abstract

The Beam Position Monitors (BPMs) for the new Thailand synchrotron light source, Siam Photon Source II (SPS-II), has been designed utilizing as the essential tool for diagnosing the position of the beam in the storage ring. Its design with four-button type BPM has been optimized to obtain the high precision of position data in normal closed orbit and feedback mode as well as turn by turn information. We calculate feedthroughs capacitance, sensitivities, induced power on a 50 Ω load, and intrinsic resolution by using Matlab GUI developed by ALBA, to find the appropriate position, thickness, and gap of the BPM button. Extensive simulation with the electromagnetic simulation packages in CST Studio Suite was also performed to investigate the dependence of the induced BPM signal, wakefield, Time Domain Reflectometry (TDR), and power loss on different BPM geometry.

INTRODUCTION

Four-button pick up electrodes have designed for a stable and precise beam position monitor in the SPS-II storage ring. They are an essential part to provide information about the position of the beam in the vacuum chamber during machine commissioning, beam tuning and routine operation. The preliminary design of the button electrode is performed by using ALBA/DIAMOND Matlab tool [1]. The button diameter, thickness and the gap between button and chamber wall are necessary to optimize for archiving low power losses, high signal transmission, Time Domain Reflectometry (TDR), Thermal transferring and proper impedance matching. These simulations are performed by using simulation packages in CST Studio Suite. [2]. The model was used in the simulation shown in Fig. 1.

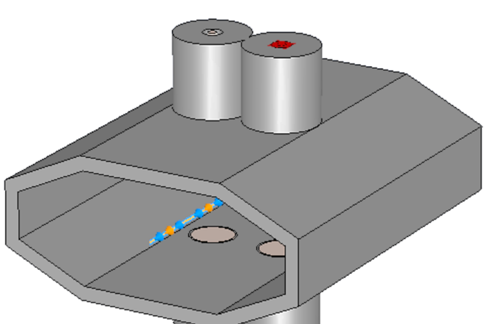

Figure 1: A simulation model of SPS-II storage ring BPM.

SPS-II BPM REQUIREMENT

The SPS-II storage ring consists of 14 Double Triple Bend Achromat (DTBA) cells and each cell is equipped with 10 BPMs. In total, there are 140 BPMS utilized for the machine operation. Since the beam size at the center of an IDs is approximately 2.6 μm, the beam position stability of 0.2 μm level needs to be obtained. The BPM button geometry, especially for button diameter has been considered to provide about 100 nm position resolution at 100 mA and 2 kHz bandwidth.

GENERAL CONSIDERATION OF BPM BUTTON

The BPM chamber has been modeled based on a standard storage ring vacuum chamber which is designed as an octagonal shape with a vertical inner aperture of 16 mm, a horizontal inner aperture of 40 mm and sides of 6.6 mm. To achieve the required resolution, the calculation of sensitivity, signal power and intrinsic resolution are performed by using Matlab tool. This software can study the basic geometries and related parameters of BPM at a preliminary design phase. The goal of this calculation is to optimize the button diameter, button gap and thickness, as well as the button separation on the storage ring vacuum chamber.

Mechanical Design

In order to achieve sufficient induced power, sensitivity, and mechanical limitation of the storage ring vacuum chamber the BPM button diameter is considered to be 6 mm. The gap size between button electrode and housing should be smallest as possible as a mechanical limitation, to increase the button capacitance and shifts the high order modes (HOM) resonances to higher frequencies [3]. The trapped HOMs can be caused by beam instabilities and will leak inside the button when the button thickness is too thin. To avoid this issue, we considered increasing the button thickness to be 4 mm. Design parameters of the SPS-II button pick up electrodes are shown in Table 1.

The simulation results of sensitivity, signal power and intrinsic resolution are shown in Fig. 2. To obtain the horizontal and vertical sensitivities (Sx and Sy), a Delta over Sum method is used [4], the slope at no beam displacement gives us the Sx and Sy is 0.1359 and 0.1343, respectively. Considering a bandwidth of 2 kHz, which is the expectation value for a fast orbit measurement system, the calculated intrinsic resolution of the BPM button at 100 mA beam current is 14.63 nm, which meets the specific requirements for the measurement resolution.

Table 1: Preliminary Design Parameters for the SPS-II BPM Button

Button calculation parameters (mm)	
Button diameter	6
Button thickness	4
Button gap	0.3
Button separation	10.5

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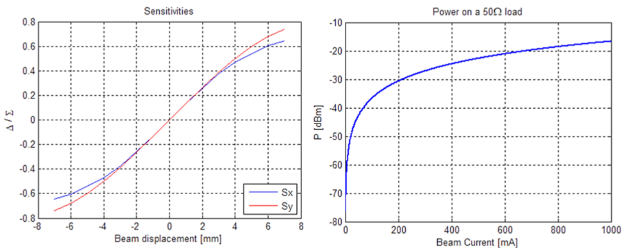

Figure 2: Calculated sensitivity and signal power of SPS-II storage ring BPM.

Optimisation of BPM Buttons Separations

Sensitivity is one of the important characteristics of a BPM system, which depends on the button diameter, the horizontal and the vertical separations of the buttons, and the distance from the button to the electron beam. In our case, the vertical button separation is fixed due to the chamber inner aperture of 16 mm. The length of horizontal button separation can be optimized with no more than 20 mm by combining button diameter and button gap between button and housing. Hence, the maximum button separation is 13.4 mm with considering the button diameter and button gap of 6 and 0.3 mm, respectively. We have calculated the sensitivity with different horizontal button separations from 10 mm to 12 mm to determine the proper horizontal button separation. The result is shown in Fig. 3. The horizontal button separation of 10.5 mm is chosen that both sensitivity Sx and Sy are approximately the same at 0.134.

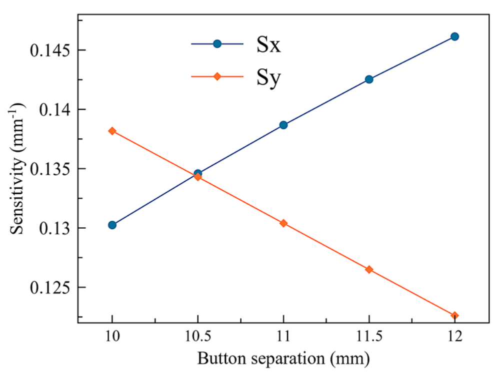

Figure 3: BPM sensitivities in the horizontal and vertical direction as a function of horizontal button separation.

Impedance Matching

The BPM button pick up electrode is defined as similar to a coaxial cable which has a characteristic impedance of 50 Ω. If it is matched well to 50 Ω, there will be no TEM-modes reflected in the chamber [5]. Thus, the diameter of ceramic, pin and feedthrough are optimized by using Eq.1.

$$Z_0 = \frac{1}{2\pi\varepsilon_0 c} \cdot \sqrt{\frac{1}{\varepsilon_r}} \cdot \ln\left(\frac{D}{d}\right), \tag{1}$$

where Z_0 is characteristic impedance in Ω, ε_0 is vacuum permittivity, ε_r is the relative permittivity of the dielectric, c is the speed of light, D is the inner diameter of the outer conductor and d is the diameter of the inner conductor. The matching gives us the diameter of feedthrough, pin and ceramic diameter is 2.764 mm, 1.2 and 6.6 mm, respectively.

SIMULATION OF BPM BUTTON SIGNAL

The SPS-II button geometry as shown in Fig. 4 is based on button geometry implemented at ALBA [6]. The BPM housing and chamber are made of stainless steel 316L. The BPM button and central conductor are made of Molybdenum and form the central pin of a reverse-polarity female SMA connector. An insulator is located between the central conductor and the outer conductor for electric insulation and vacuum shielding and is made of aluminium oxide (Al_2O_3). There is an insert step button and an upper ceramic gap in the button structure which use to improve the time signal and shift HOM inside the button.

To check the BPM performance, we have simulated RF characteristics on the BPM button pick up electrodes such as induced voltage signal, wake impedance, Time Domain Reflectometry and power loss by using CST CST Studio Suite with three simulation packages consists of Wakefield solver, Time domain solver, and Thermal and Mechanics. The BPM model as shown in Fig. 1 and Fig. 4 are used in the CST simulation.

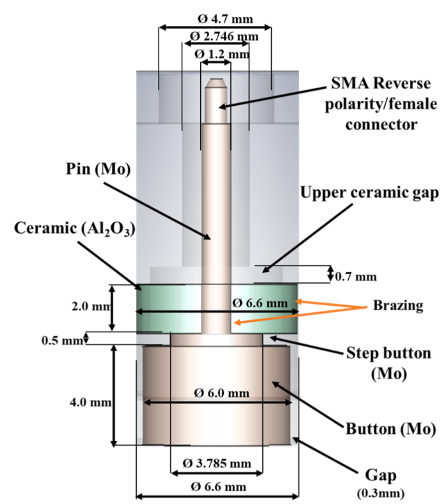

Figure 4: The designed BPM button electrode for the SPS-II storage ring.

Time Signal

An induced voltage signal for a single bunch electron beam obtained from the Wakefield simulation package in the CST Particle Studio is shown in Fig. 5.

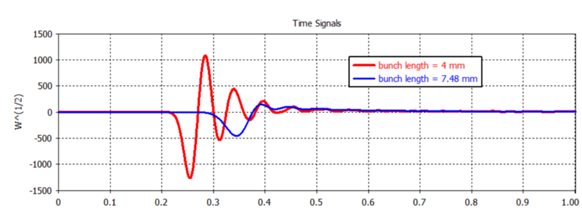

Figure 5: Simulation result of an induced voltage signal of BPM button as a function of time with different bunch lengths.

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A signal waveform with bunch length (σ) 4 mm and 7.48 mm are also plotted for comparison. At the natural bunch length of 7.48 mm (24.9 ps), a bipolar oscillating impulse can be observed.

Wake Impedance

In the preliminary design, it is preferable to have the ceramic insulator of 1 mm thickness but the manufacturing might be an issue due to the brazing process with low thickness ceramic size. Thus, the effect of different ceramic thicknesses on the longitudinal wake impedance are also studied together with the effect of the step button and upper ceramic gap. For the 2 mm thickness ceramics, the first trapped mode arises at frequency 13.49 Hz, compared to the 1 and 1.5 mm thickness ceramics with arising at frequency 14.30 Hz and 13.87 Hz, respectively as shown in Fig. 6. This suggests that the low ceramic thickness should be chosen for shifting the first trapped mode to a higher frequency.

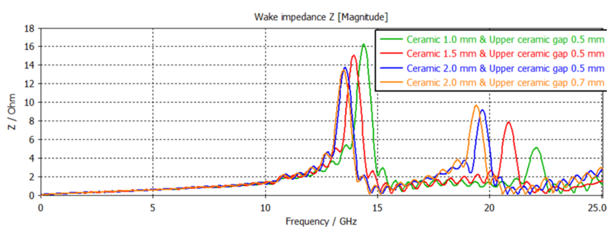

Figure 6: Simulation result of longitudinal wake impedance as a function of frequency with different ceramic thickness and upper ceramic gap thickness.

In the simulation results caused by an adjusting thickness of the upper ceramic gap, it was found that there is no strong effect on longitudinal wake impedance. With 0.5 mm thickness, the first trapped mode is slightly better than 0.7 mm thickness.

Time Domain Reflectometry (TDR)

TDR curve obtained by CST Time domain simulation is shown in Fig. 7. It can be seen a slightly mismatching in ceramic position at a time of 0.16 ns when the ceramic thickness is increased. While adjusting the thickness of the upper ceramic gap does not affect the TDR curve.

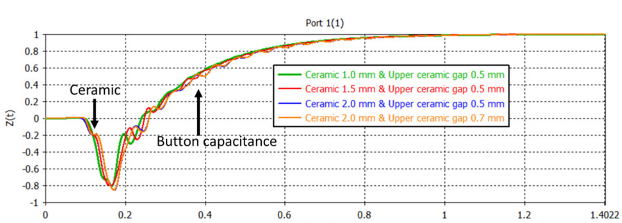

Figure 7: TDR simulation result.

In TDR simulation results, the button capacitance of 3.10 pF can also be obtained by fitting the curve with the equation of reflectivity as:

$$\rho = 1 - e^{-\frac{t-t_0}{\tau}} \qquad (2)$$

$$\tau = R \cdot C_b,$$

where R is feedthrough characteristic impedance and C_b is button capacitance [7].

Power Loss

The loss factor due to a single bunch was calculated for all three different ceramic thicknesses by using the Wakefield solver. The wake loss factor (κ_{loss}) for the longitudinal wake component is calculated by:

$$\kappa_{loss} = -\int_{-\infty}^{\infty} \lambda(s) W_{||}(s) ds \qquad (3)$$

where $\lambda(s)$ describes the normed charge distribution function over electron direction (s) and $W_{||}(s)$ is the longitudinal wake impedance. It is given in [V / pC] [8]. The power loss (P_{loss}) depends on the wake loss factor and bunch parameters, which can be defined as

$$P_{loss} = T_0 \frac{I_{av}^2}{M} \kappa_{loss}, \qquad (4)$$

where I_{av} is the total average current, T_0 is the revolution period, and M is the number of bunches.

Summary results of the wake loss factor are shown in Table 2. The calculation results for bunch length (σ) of 4 mm and 7.48 mm are also shown for comparison. The power loss is found at 1 to 7 Watt, for σ = 7.48 mm and 4 mm respectively, at I_{av} = 300 mA in M =140 bunches and 1.2 µs revolution period. As shown in Table 2, the wake loss factor increases slightly when the thickness of the ceramic is increased.

Table 2: Summary Results of the Loss Factor for Different Ceramics Thickness

Ceramic (mm)	**κ_{loss} (mV/pC) (σ = 4 mm)**	**κ_{loss} (mV/pC) (σ = 7.48 mm**
1.0	9.301	1.441
1.5	9.358	1.485
2.0	9.369	1.519

THERMAL ANALYSIS OF BPM BUTTON

Thermal simulation of heat transfer for three different ceramic thicknesses was calculated by CST Thermal and Mechanics module. In the simulation, an ambient temperature of 30 ºC and one watt heat source are applied to each button as a worst-case. The simulation results are shown in Fig. 8. It can be seen that increasing the ceramic thickness reduces the temperature difference between Button and Pin (ΔT = T_{button}-T_{pin}). The greatest temperature difference ΔT= 2.24 ºC) is found on the BPM structure with 2.0 mm ceramic thickness. This is mainly due to the larger contact area between the button and ceramics.

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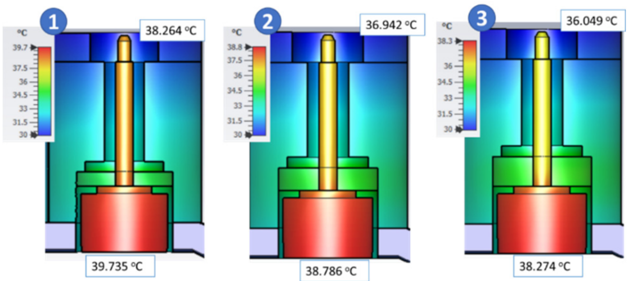

Figure 8: Thermostatic results for 1) Ceramic thickness 1 mm, 2) Ceramic thickness 1.5 mm, 3) Ceramic thickness 2 mm.

CONCLUSION

The SPS-II BPM is composed of the four-button pick up electrodes and the 50-Ω-matched SMA-type feedthrough mouthed on the octagon chamber. The button diameter, the button gap, and the horizontal separations of the buttons are designed as 6 mm, 0.3 mm, and 10.5 mm, respectively. This BPM design is sufficient to obtain 100 nm position resolution at 100 mA and 2 kHz bandwidth. In order to verify the BPM performance, the RF characteristics together with the thermal analysis on the BPM button are also performed by using the simulation packages in CST Studio Suite. The BPM capacitance, sensitivities obtained from CST simulation is in good agreement with the value calculated by the Matlab tool. The effect of different bunch lengths and different BPM button geometry on the induced voltage signal, wake impedance, wake loss, TDR and heat transfer have been analysed. It was found that these parameters need to be optimized together in order to determine the proper BPM geometry. Manufacturing of the SPS-II BPM button prototypes will be performed by choosing the BPM structure with the ceramic thickness of 1.5 mm and the upper gap thickness of 0.5 mm.

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