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GENERAL CONSIDERATION FOR BUTTON-BPM*

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Abstract

In order to design Button Beam Position Monitors (BPMs) for synchrotron facilities, one algorithm by C# have been developed which can calculate all required parameters to analyze optimal design based on vacuum chamber and button dimensions. Beam position monitors are required to get beam stabilities on submicron levels. For this purpose, different parameters such as capacitance, sensitivity versus bandwidth, intrinsic resolution, induced charge and voltage on buttons are calculated. Less intrinsic resolution and high sensitivity and capacitance are desired. To calculate induced charge and voltage on each button, Poisson's equation has been solved by Green method. For sensitivities calibration, two-dimensional map of BPM response is obtained theoretically and compared with the CST simulation map. Results show a good agreement where as their difference is less than 5%.

INTRODUCTION

The Beam Position Monitors (BPMs) have to be designed in order to provide reliable and accurate beam position readings.

Typical BPM consider four button-type electrodes mounted on the vacuum. By measuring the electrode signal at a number of different beam positions, the relative gains of the electrodes can be calculated. The idea is developing a software tool to simplify studying of BPM geometries and related parameters like as intrinsic resolution, sensitivities, Power loss at design phase.

At following all considered steps for developing this code are explained.

HOW TO MONITOR BEAM POSITION

A beam pickup can be thought of as a discontinuity in the vacuum chamber, which interrupts and diverts into a measuring device a portion of the wall image-charge induced by the beam. If the beam is displaced from the center of the vacuum chamber, the magnetic and electric fields are modified accordingly, so we can measure the beam position through the relative amplitudes of the induced charge on each button. Such charge depend in a non-linear way from the beam position, so it is important, in order to reconstruct accurately the beam position, to develop an algorithm to process the measured data [1].

We use a non-linear fit of two dimensionless quantities U, V derived from the charge Q induced on electrodes:

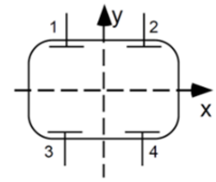

Figure 1: Schematic of a BPM.

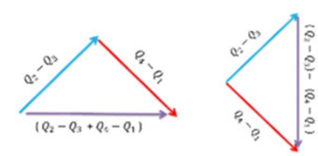

Figure 2: Beam displacements: a) in X Direction, b) in Y Direction.

$$U = \frac{1}{2}\left[\frac{(Q_2 - Q_3)}{(Q_2 + Q_3)} + \frac{(Q_4 - Q_1)}{(Q_4 + Q_1)}\right]. \quad (1)$$

$$V = \frac{1}{2}\left[\frac{(Q_2 - Q_3)}{(Q_2 + Q_3)} - \frac{(Q_4 - Q_1)}{(Q_4 + Q_1)}\right]. \quad (2)$$

The physical beam position (x, y) is derived from a polynomial function of (U, V) by the following equation:

$$x = K_x(x, y)U \quad , \; y = K_y(x, y)\; V . \quad (3)$$

Where:

$$K_x(x, y) = a_0 + a_1 y^2 + a_2 y^4 + a_3 x^2 + a_4 x^2 y^2 + a_5 x^4 \; .$$

$$K_y(x, y) = b_0 + b_1 x^2 + b_2 x^4 + b_3 y^2 + b_4 y^2 x^2 + b_5 y^4$$

Obtaining Such coefficients (a_i,b_i) allow, during normal machine operation, to reconstruct accurately the transverse beam position from the electrical position signals [2]. However having a constant coefficients without relation to x,y are required, then usually a0,b0 which obtained by considering beam at point (1,1) from centre of chamber considered to calculate beam position at other positions.

GEOMETRY PARAMETERS

To have less trapping HOM at annular gap and consequently less power dissipation, less Wakefield impedance and efficient transfer line to transfer image charge to electronic setup, most important points are button and vacuum chamber geometries.

Vacuum Chamber

Since button BPM usually can be used and installed on storage ring and Booster system, two different types of

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chambers were thought to be analyzed. A circular profile for the booster chambers and an octagonal profile for the storage ring [3].

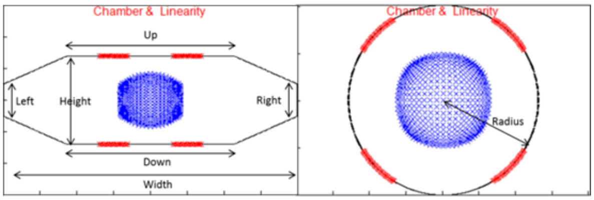

Figure 3: chamber profile and required dimensions.

Button

Code simulates the round electrodes buttons type and analyze either a single button design or make a comparison between three different buttons dimensions. Buttons are defined as [3]:

- Electrode diameter(d)
- Electrode thickness(t)
- Gap between the electrode edge and button shell(g)

CHARGE INDUCED CALCULATION (Q_I)

We derive induced charge Q_i by using Green's theorem and numerical solution of Laplace's equation in a two dimension region Ω closed by the boundary Γ, containing the charge density ρ(x, y) (see Fig. 4).

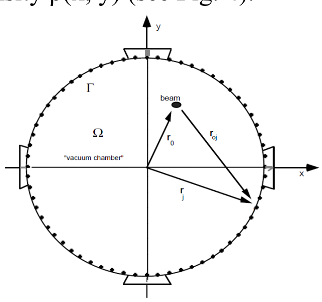

Figure 4: Boundary element method.

Hence numerical solution represents matrix equation:

$$[G]\sigma + B = 0 \,. \tag{5}$$

where G is m×m elements matrice and column vector B with elements B_j are introduced respectively at Eq.6 & Eq.7.

$$G_{ij} = \int_{\Gamma_i} \ln \frac{1}{|r_i - r_j|} dr_i \,. \tag{6}$$

$$Bj = \ln \frac{1}{|r_0 - r_j|} \,. \tag{7}$$

Here σ is the unknown column vector whose elements are the induced charge density on each boundary element (considering 720 small elements). LU decomposition method has been implemented in C# code to calculate the numerical solution for σ solving because of its best time-consuming (about 7 second).

At Eq.5 the charged particle considered to move vertically and horizontally inside a ±10mm range.

BPM-CODE

At first page of this code (Fig.6) , comparison between different button designs analyzed to determine which one better matches the accelerator requirements. For this purpose some calculation are supposed for different button design:

- Button capacitance
- BPM sensitivity
- Induced power on a 50Ω load
- BPM intrinsic resolution
- Non-linear BPM response (K_x, K_y)

OUTPUT

As illustrated in Fig.6 calculation done in two Single and comparison mode by defined geometry parameters.

Button Capacitance

Button BPM treat like a coaxial cable therefor we can obtain capacitance from:

$$C_b = \frac{2\pi\varepsilon_0 \, t}{\ln\left(\frac{d+g}{d}\right)} \,. \tag{8}$$

BPM Sensitivity

The sensitivity is one of the important characteristics of a BPM system. The beam position sensitivities (vertical and horizontal) are determined by difference over sum (Δ/Σ) method [4]. Sensitivity curves for displaced beam can show area that BPM has linear response. Also it can use to compare between different design (see Fig. 5).

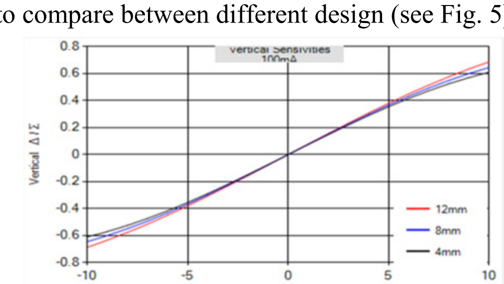

Figure 5: vertical sensitivity.

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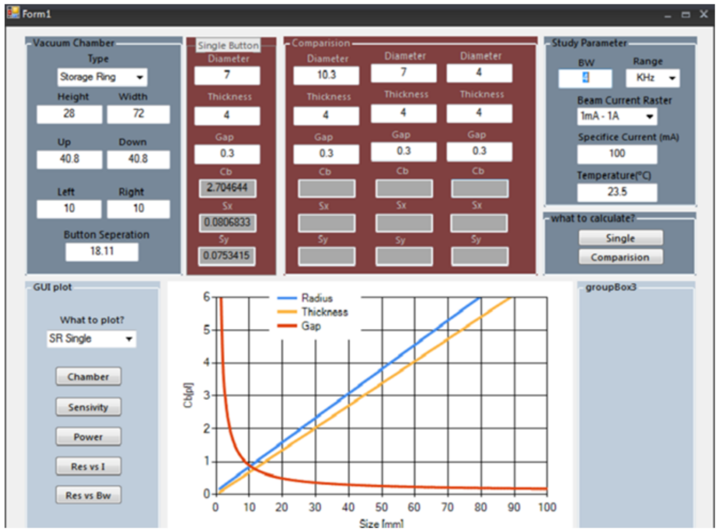

Figure 6: GUI of c# code, single calculation has been executed.

Induced Power

for a specific beam current I, the average induced power is approached as [5] where $\omega_1 = 1/R_0C_b$ and $\omega_2 = c/2r$:

$$\langle P_0(\omega)\rangle = \frac{1}{2}|I_0|^2 R_0 \phi^2 \left(\frac{\omega_1}{\omega_2}\right)^2 \frac{\left(\omega/\omega 1\right)^2}{1+\left(\omega/\omega 1\right)^2} . \qquad (6)$$

BPM Intrinsic Resolution

We estimate the intrinsic resolution from the ratio of signal to thermal noise. Measurement bandwidth (Bw) and temperature determine the thermal noise (N_{th}) [6].

$$\sigma_{int} = \frac{b}{2\sqrt{2}}\frac{1}{\sqrt{SNR}} , \ SNR = \frac{P_0}{N_{th}} , \ Nth = K_B T Bw . \qquad (7)$$

Intrinsic resolution curves can draw vs. beam current (at fixed frequency) and vs. bandwidth (at fixed Specific Current) by using Res Buttons in GUI plot.

To verify the code, obtained U,V from code (Induced charge calculation) compared with CST result (output voltage) with same situation. Fig.7 shows comparison of 2-dimensional calibration map which is done for ILSF Storage Ring and Fig.8 shows same situation for the booster of ILSF [7].

CONCLUSION

This developing code simplify design of button BPMs at synchrotrons. Required parameters which is essential at designing a BPM can be calculated very simply. Calculation of capacitance, induced charge based on different position of beam, BPM sensitivity, BPM intrinsic resolution and induced power at 50 ohm load can be done by the way. Less differences between 2-dimensional calibration map which calculated by this code and CST which are less than 5% verify this code very well. Verifying by practical results will be done at next step. Extending code to other beam instrumentation also is under consideration.

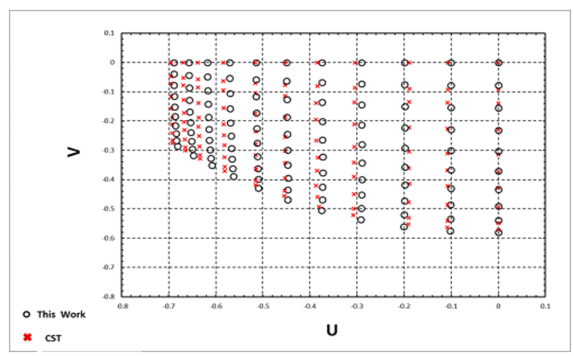

Figure 7: 2-dimensional calibration map for storage ring (octagonal profile).

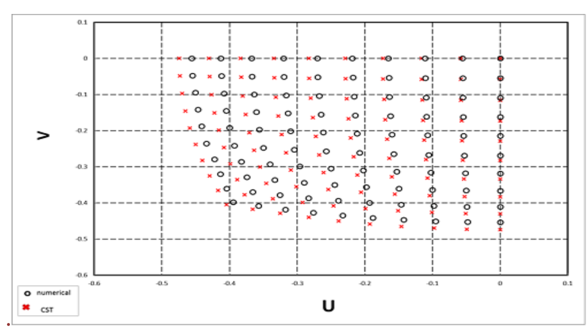

Figure 8: 2-dimensional calibration map for booster.

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