SIMULATION STUDIES OF BUTTON PICKUP ELECTRODE RESPONSE TO LONGITUDINALLY TILTED BEAMS*

X. Sun#, G. Decker, N. Sereno, ANL, Argonne, IL 60439, USA

Abstract

The APS storage ring beam position monitor (BPM) button-type pickup electrode was modeled and characterized. A pair of button electrodes above and below the accelerator midplane were simulated using CST Microwave Studio. A tilted beam of charge 1 nC was modeled using two very narrow Gaussian bunches displaced longitudinally by $\pm\sigma_z$, where σ_z is the rms bunch length. Transverse displacement of the two bunches above and below the midplane was used as a proxy for beam tilt, while parallel displacement of both bunches provided sensitivity to untilted beam position offset. The voltage on the BPM buttons by the beam was simulated and processed in time and frequency domain. The voltages show sensitivity linearly proportional to the pure tilt angles, or different pure vertical offsets. By using in-phase/quadrature-phase (I/Q) demodulation of the BPM button signal, the tilt and offset information in the hybrid situation can be separated and shows linear proportion sensitivity to tilt angles or vertical offsets, respectively.

INTRODUCTION

One important challenge of the Short-Pulse X-ray (SPX) in the APS upgrade project is the beam diagnostics. The SPX requires extremely accurate vertical / longitudinal bunch tilt measurements.

A Cavity BPM / Tilt Monitor was investigated for detecting vertical position and tilt of the beam in SPX because it has the highest sensitivity to beam position and tilt [1]. This design was found to be too complicated and expensive. Capacitive button-type pickup electrodes have already been used in the APS storage ring BPM system. In this paper, their response to longitudinally tilted beams will be modeled and characterized in the SPX insertion device (ID) chamber.

A pair of button-type pickup electrodes was mounted on the top and bottom of the ID chamber, as shown in Figure 1. The response of the buttons to the tilted or/and centroid vertical offset bunch passing through the ID chamber were simulated using CST Microwave Studio (MWS) [2].

BUNCH MODEL

It is impossible to model a tilted bunch directly in CST MWS Wakefield Solver. Instead, a beam of charge q, composed of two point charges q/2, located at distances $\pm\sigma_z$ along the beam direction, where σ_z is the rms bunch length, can be used to simulate a tilted Gaussian bunch [3-4]. This arrangement has the same total charge and second moment as a Gaussian distribution; however, CST MWS Wakefield Solver can model only Gaussian bunches. An alternative approach is an equivalent Double very Narrow Gaussian Bunches Model (DNGBM).

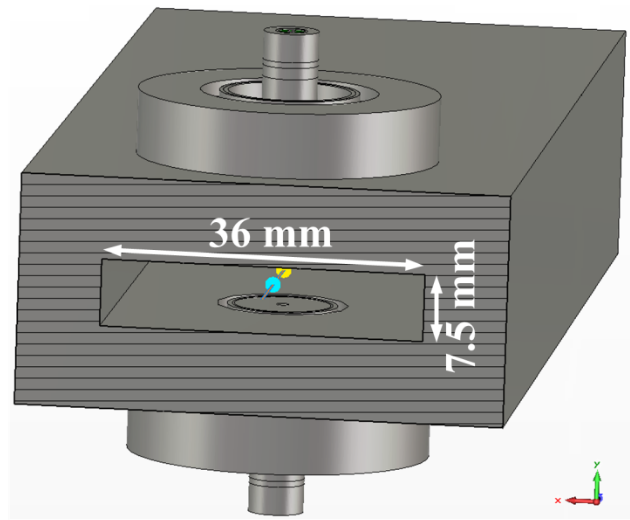

Figure 1: A pair of button electrodes mounted on the top and bottom of the SPX ID chamber.

The DNGBM is composed of two Gaussian bunches with charge q/2 and bunch length $\sigma_z/5$, displaced longitudinally by $\pm\sigma_z$. The model simulates a single Gaussian bunch of total charge q, bunch length σ_z, with tilt angle θ, and centroid vertical offset Δy (shown in Figure 2).

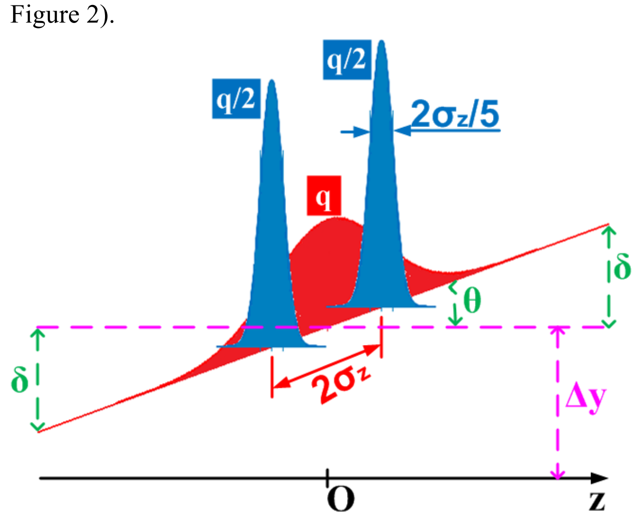

Figure 2: The DNGBM (blue) used to simulate a Gaussian bunch with tilt angle θ and centroid vertical offset Δy (red).

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#xiang@aps.anl.gov

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Even though the second moment of the distribution for the DNGBM is not as accurate as that for two point charges, the approximation is good enough at S-band if the bunch length is much smaller than the actual bunch length. Figure 3 shows the comparison of DNGBM and a single Gaussian bunch.

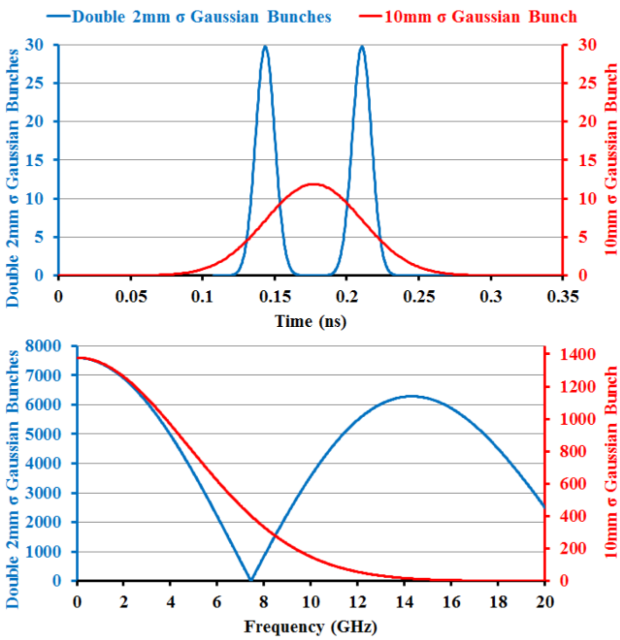

Figure 3: Comparison of Gaussian bunch with charge q and bunch length σ_z, and DNGBM.

SIMULATION

A tilted and/or vertically offset Gaussian bunch of charge 1 nC (σ_z = 10.05 mm) was modeled by DNGBM. In DNGBM, each narrow Gaussian bunch has charge 0.5 nC and bunch length $\sigma_z/5$ = 2.01 mm, and the distance between the two bunches is $2\sigma_z$ = 20.1 mm. Transverse displacement of the two bunches above and below the centroid was used as a proxy for beam tilt, while parallel displacement of both bunches simulated a pure bunch offset. The voltages on the buttons $\Delta V(t) = V_{top}(t) - V_{bottom}(t)$ were simulated for DNGBM using CST MWS. The frequency domain phase $\Delta\Phi(f)$ and amplitude $\Delta V(f)$ were derived from the digital Fourier transform of $\Delta V(t)$.

Pure Centroid Vertical Offset Bunch

Figure 4 shows that the voltages obtained from the simulation of an untilted vertically offset beam are linearly proportional to the bunch vertical offset.

Pure Tilted Bunch

Figure 5 shows that the voltages obtained from the simulation of a tilted, centered bunch are linearly proportional to the bunch tilt angle.

From Figure 6, the voltages between the pure tilted and pure offset bunches are seen to be out of phase by approximately 90^0, i.e., in quadrature with each other.

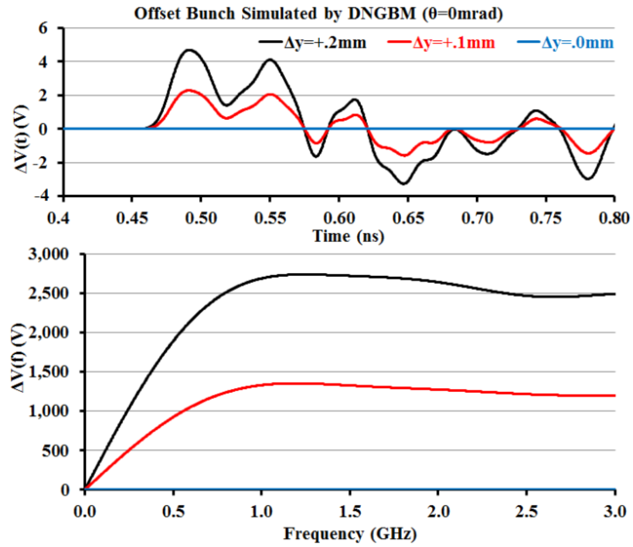

Figure 4: Simulation results of the untilted offset bunches.

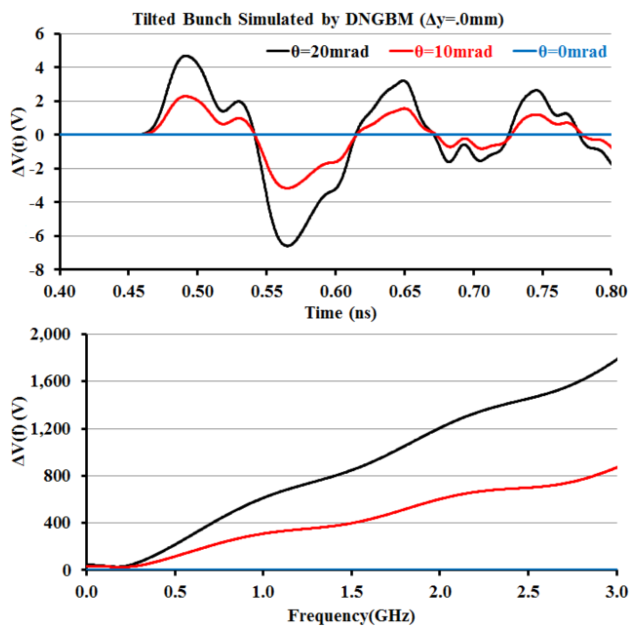

Figure 5: Simulation results of the pure tilted bunches.

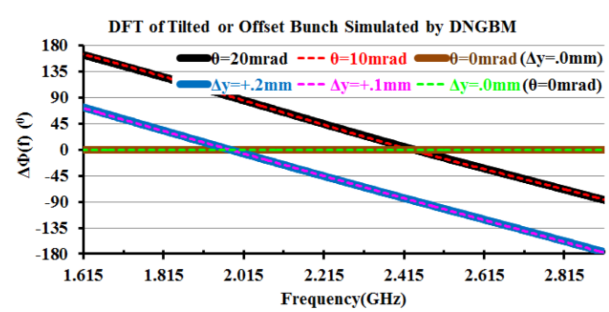

Figure 6: Phase simulation results of pure vertical offset and pure tilted bunches.

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Hybrid Bunch

A hybrid combining both tilted and vertical offset beam with charge 1 nC was modeled using DNGBM.

No obvious identification of signal due to tilt or offset is apparent from Figure 7 since for the hybrid case the signal contains both offset and tilt information.

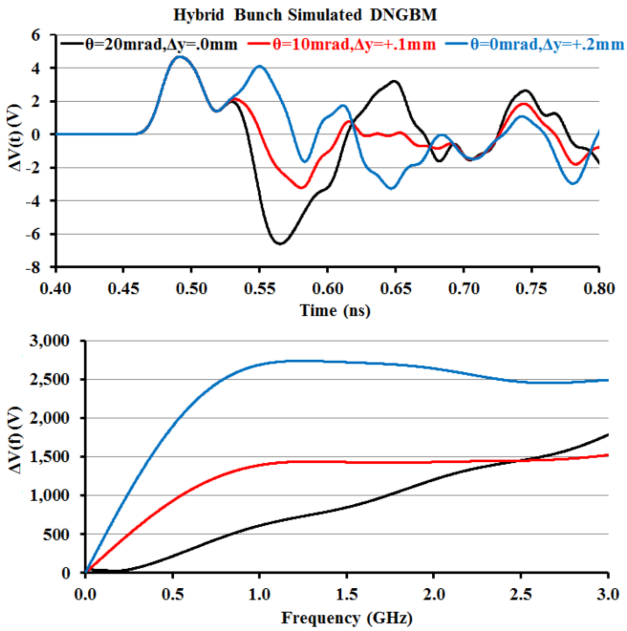

Figure 7: Simulation results of the hybrid tilted and centroid vertical offset bunches.

Using I/Q demodulation, the tilt and vertical offset information for the hybrid case can be separated. Figure 8 shows that by using I/Q detection the information due to beam tilt vs. offset are separated. The DC components illustrate linear proportionality to tilt angles or vertical offset respectively.

SUMMARY

A pair of button electrodes mounted on the top and bottom of a small-aperture insertion device vacuum chamber were simulated using CST MWS to investigate the sensitivity of capacitive button pickup electrode signals to longitudinally tilted beams.

The simulation was applied for σ_z = 10.05 mm (bunch length of 24-bunch fill pattern in APS) and q = 1 nC. The voltage on the BPM buttons by the beam was simulated and processed for the tilted or/and centroid vertical offset Double Very Narrow Gaussian Bunches Model in time and frequency domain.

The voltages demonstrate sensitivity linearly proportional to the pure tilt angles, or pure vertical offsets. The voltages between tilted bunches and the vertically offset bunches are seen to be in quadrature with each other. By I/Q demodulation of the BPM button signal, the tilt and offset information in the hybrid can be separated. The linear proportion sensitivity to tilt angles or vertical offset is shown respectively at DC frequency.

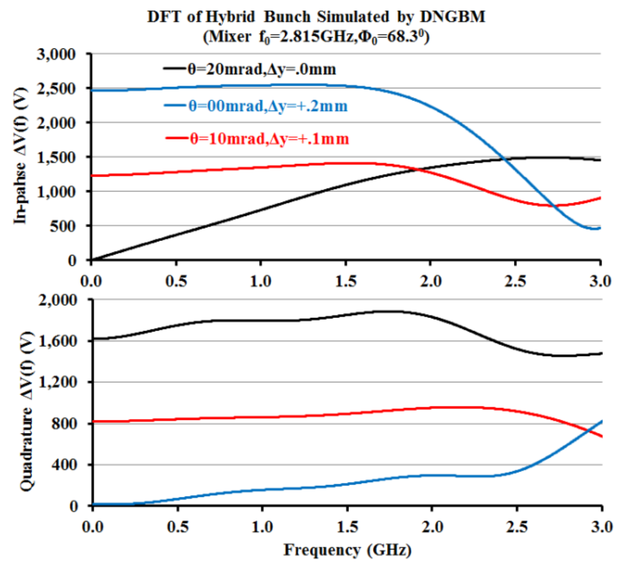

Figure 8: The I/Q demodulation results of the hybrid tilted and vertically offset bunch in frequency domain. DC components illustrated in-phase component linear proportionality to vertical offset (top) and quadrature component proportionality to tilt angle (bottom).

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