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THE RF BPM PICKUP ELECTRODES DEVELOPMENT FOR THE APS-MBA UPGRADE*

X. Sun†, R.M. Lill, Argonne National Laboratory, Argonne, IL, USA

Abstract

Beam stability is critical for the Advanced Photon Source (APS) multi-bend achromat (MBA) lattice upgrade and will employ 560 radio frequency (RF) beam position monitors (BPMs). The RF BPMs will provide the primary measurement of the electron beam. Design goals for the BPM assembly include high sensitivity, low wakefield impedance, and ultra-mechanically stability. The design, electromagnetic simulation, manufacturing tolerance and prototype testing will be presented in this paper.

INTRODUCTION

The APS Upgrade project (APS-U) has recently completed the final design milestone and now moves into the production phase. The upgrade will require 560 BPM assemblies to achieve the beam stability requirements outlined in Table 1. For the final design, both the horizontal and vertical AC rms beam stability requirements are based on 10% the rms beam size at the ID source points from 0.01 to 1000 Hz. In addition, long-term drift over a 7 day period may be no more than 1 µm.

Table 1: APS-U MBA Beam Stability Requirements

Plane	AC Motion, rms (0.01 – 1000 Hz)	Long-term Drift, rms (7 days)
Horizontal	1.25 µm 0.25 µrad	1.0 µm 0.6 µrad
Vertical	0.4 µm 0.17 µrad	1.0 µm 0.5 µrad

THE RF BPM PICKUP ELECTRODES DESIGN

There are 560 RF BPMs in APS-U storage ring with 14 BPMs per sector and 40 sectors. There are 3 types of BPM assemblies per sector – 10 standard-, 2 P0- and 2 keyhole BPM assemblies. The P0 BPMs are located upstream and downstream of the insertion device. The keyhole BPMs have anti-chamber slots to prevent beam interception.

The four pickup electrodes used in each standard and P0 BPM assembly are evenly distributed circumferentially around the 22 mm diameter circular MBA beam pipe, shown in Fig. 1, and provide the primary measurement of the electron beam trajectory in the storage ring. In keyhole shaped BPM assemblies, 4 buttons position with 60° spacing. Each RF BPM includes 4 orthogonal button electrodes that are integrated into a vacuum chamber and are terminated with SMA connectors.

The APS-U MBA pickup electrode design was developed using the existing APS BPMs as the baseline design. This design operated at the APS for over 20 years with an extremely low failure rate for the BPM buttons. The design uses an alumina vacuum seal and feature a removable female SMA mating pin [1].

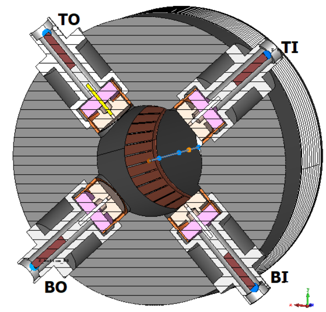

Figure 1: Standard APS-U MBA BPM assembly.

The design version 3 (v3) is shown in Fig. 2. The Alumina disk serves as dielectric, mechanical support, vacuum boundary and sets the mechanical concentric. The button material is Molybdenum which provides good thermal conductive. The Cu-Ni shell and Nickel center conductor rod are used to improve brazing procedure. The protruding fingers between the dielectric and the electrode can support/positioning the electrode as a hard stop [2] and improve the thermal conduction. The space between the dielectric and the electrode can supress the high frequency modes in the gap [3] and decrease the capacitance to increase the induced voltage on the button. The feedthrough with characteristic impedance of 50 Ω is designed to couple the beam signals out to the cable and electronics.

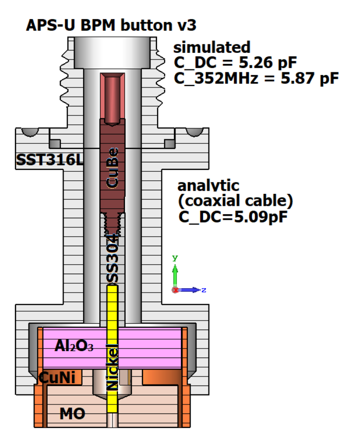

Figure 2: APS-U BPM button design v3.

The APS-U BPM button v3 was simulation studied using CST Microwave Studio (MWS) [4]. Its simulated capacitance is 5.26 pF at DC and 5.87 pF at 352 MHz. Its analytic capacitance according to the capacitance formula for coaxial cable is 5.09 pF.

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† xiang@aps.anl.gov

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THE APS-U MBA BPM BUTTONS MODELING

To understand the capacitive BPM button and optimized its design, an equivalent circuit model is built according to the electric potential distribution, shown in Fig. 3.

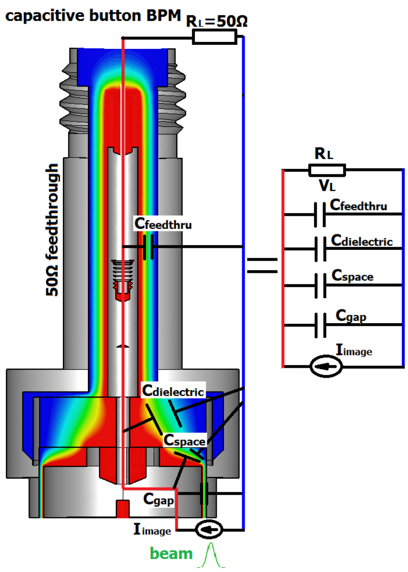

Figure 3: Simulated static electric potential on the APS-U MBA button v3 and its equivalent circuit.

The button capacitance between the center pin of the SMA and the body is the sum of the individual parts' capacitances.

$$C_{butt} = C_{ft} + C_{diel} + C_{spc} + C_{gap} \,,$$

$$V_L = Z_L \cdot I_{image} = \frac{R_L}{1+j\omega R_L C_{butt}} \frac{A}{2\pi a} \frac{d\lambda_{beam}}{dt} \,, \quad [5]$$

$$|V_L| \propto \frac{R_L}{\sqrt{1+(\omega R_L C_{butt})^2}} \,,$$

where ω is the working frequency; A is the electrode area; a is the distance between the electrode and beam; λ_{beam} is the beam linear charge density; R_L is the load resistance; V_L is the voltage on R_L.

The signal level on the 50 Ω loads varies mainly with the button capacitance.

THE MEASUREMENTS OF PROTOTYPE APS-U MBA BPM BUTTONS

Seventeen prototypes of APS-U MBA buttons v3 were manufactured and bench tested. Dimensions and vacuum leaks were checked. After the vision inspections, the capacitance at DC and 352 MHz were measured, shown in Fig. 4. Two buttons showed large deviations, but the relative deviations of the others are no more than 6%. The capacitances at DC and 352 MHz are little different because the wavelength at 352 MHz is 853 mm which is much longer than the button feedthrough.

The transmission (S_{21}) of buttons back-to-back and the reflected waveform of the button were measured using network analyzer and Time Domain Reflectometer (TDR) correspondingly [1]. Their performance were consistent with earlier simulation and measurements. The manufacture tolerance will be studied due to the deviation of capacitance measurements.

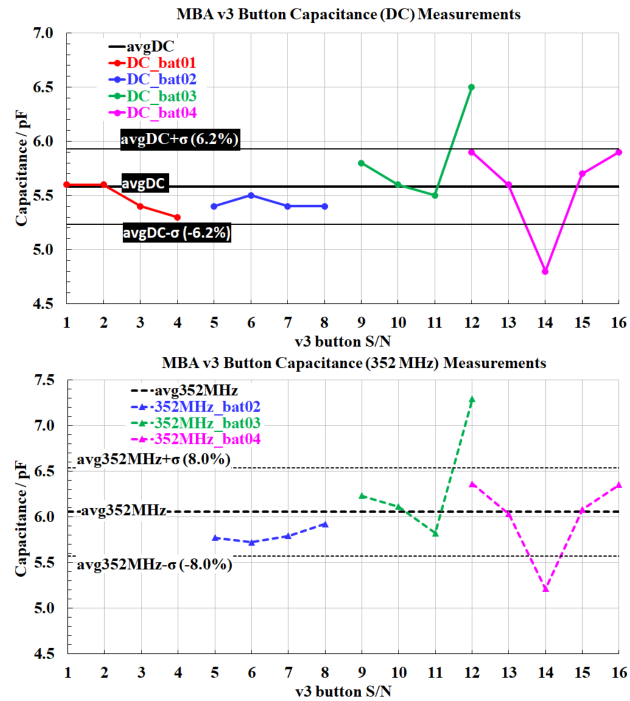

Figure 4: The measured APS-U MBA BPM prototype buttons (v3)' capacitance at DC (top) and 352 MHz (bottom).

THE MANUFACTURE TOLERANCE OF THE APS-U BPM BUTTONS

Analyzing the components of the BPM button capacitance, the electrode gap capacitance account for almost half of the whole button capacitance and the electrode off-center is the most possible problem in manufacture. The button capacitance vs the gap between the electrode and the shell is shown in Fig 5.

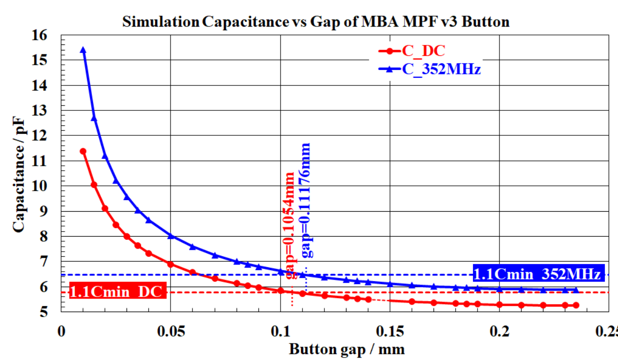

Figure 5: The capacitance of APS-U MBA BPM button v3 vs gap between the electrode and the shell.

0.53 pF or 10% DC capacitance deviation covered most prototype buttons, seen in Fig. 4. The minimum possible DC capacitance deviation is 0.1 pF or 2%. Those two situations are shown in Fig. 6.

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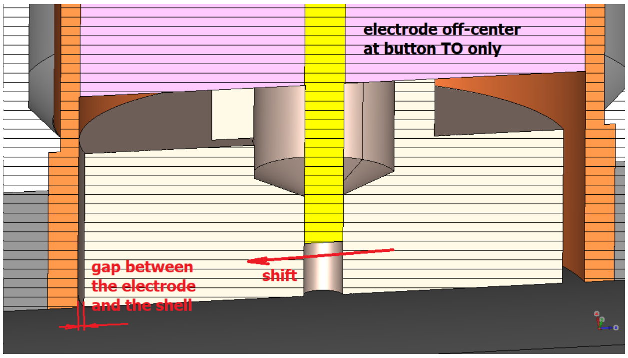

Figure 6: The APS-U MBA buttons with capacitance deviation due to the electrode off-center.

The study was performed in the APS-U MBA assembly, shown in Fig. 7 [6] and assumed only button TO has a DC capacitance deviation due to the electrode off-center and the other 3 button are normal. The simulation beam parameters are shown in Table 2.

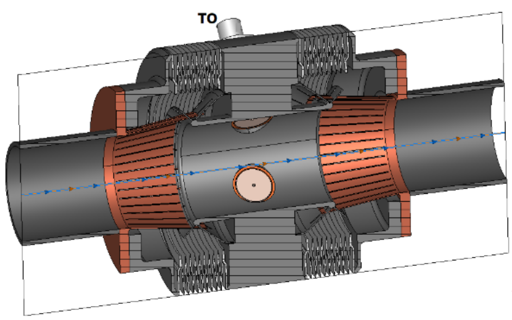

Figure 7: The standard APS-U MBA assembly with 3 normal buttons and button TO with DC capacitance deviation due to the electrode off-center.

Table 2: Beam Parameters

Fill Pattern	Mode	Current (mA)	Bunch Current (mA)	Bunch Charge (nC)	Bunch Length (ps/mm)
48	User	200	4.2	15.34	100.5/30.1

The simulated beam offsets after 20 MHz band-pass filter (BPF) and 30-ft long cable at 352 MHz in the standard APS-U MBA BPM assembly are shown in Fig. 8.

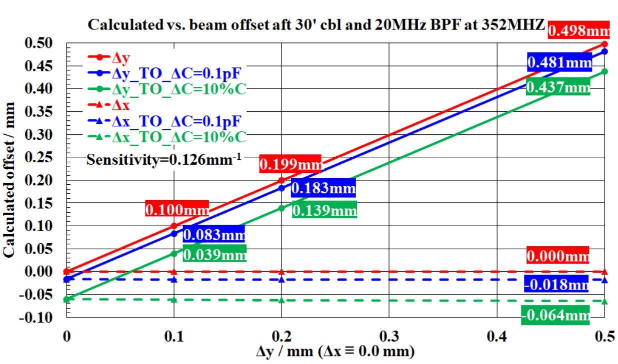

Figure 8: Simulated beam offsets in the standard APS-U BPM assembly with the button TO whose DC capacitance is normal, 0.1 pF/2% and 0.53 pF/10% deviation corresponding. The other 3 buttons are normal.

The beam power loss and power dissipation in the standard BPM assembly are summarized in Table 3.

Table 3: Simulated Beam Power Loss and Power Dissipation in Standard BPM Assembly Under MBA 48, 200 mA, σ_{t_rms} = 100.5 ps. (The Other 3 Buttons are Normal.) Unit: W

DC Capacitance Deviation of Button TO	Metals	Four Loads (50 Ω)	Beam Power Loss
ΔC = 0 pF	0.176	0.123	0.303
ΔC = 0.1pF (2%)	0.176	0.121	0.305
ΔC = 0.53pF (10%)	0.176	0.117	0.298

CONCLUSION

The APS-U MBA button v3 has been designed and optimized for the RF performance. The buttons and BPM assembly have been prototyped, measured and compared to simulated predicted performance. The manufacture tolerance have also been studied for the standard BPM assembly. A budget including electrical and mechanical offsets are presently being studied before the production phase of the BPM assemblies. Understanding the electrical and mechanical tolerances will greatly improve the production phase yield and provide a BPM that meets all requirements.

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