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THE RF BPM PICKUP AND FEEDTHROUGH TESTING RESULTS IN THE LAB AND SR FOR APS-U*

X. Sun†, W. Cheng, Argonne National Laboratory, Argonne, IL, USA

Abstract

560 RF Beam Position Monitors (BPMs) have been manufactured and installed at the Storage Ring (SR) of the Advanced Photon Source Upgrade (APS-U). The BPM feedthroughs were manufactured and tested at the vendor and the APS lab. All feedthroughs were sorted in groups of four according to their capacitance. Four feedthroughs with close capacitance were welded to the housing in an assembly. The assemblies were measured in the APS lab to confirm their electrical performance and their electric offsets were calculated according to the Vector Network Analyzer (VNA) data. After the BPM assemblies were installed in the SR, they were measured again to verify their connections. The x/y offsets including the jump cables were compared with the previous data and will be used as the reference in beam commissioning. The testing results at the vendor, APS lab and APS-U SR were analyzed.

INTRODUCTION

The SR of the APS-U accommodated 560 RF BPMs, organized with 14 BPMs per sector across 40 sectors. These BPMs have undergone manufacturing and subsequent installation in APS-U SR.

Each sector features four types of BPM assemblies: 10 standard- (STD), 2 P0-, 1 AP2-keyhole- and 1 BP5-keyhole assemblies. Prior to integration, BPM feedthroughs [1, 2] were tested at the vendor. Afterwards they were welded into a stainless-steel vacuum chamber, which is then integrated within a pair of rf-lined bellows [3]. Post-welding the BPM assemblies were tested at the APS lab and APS-U SR. This paper outlines the testing procedures and results conducted in both lab and SR environments.

FEEDTHROUGHS TESTING AT THE LABS

The BPM feedthroughs underwent manufacturing and testing at the vendor. High potential tests (HiPot) were conducted using Fluke 1507, while their S-parameters, time-domain reflectometer (TDR), and button capacitance C_b at 352 MHz were tested using Teledyne Lecroy WavePulser 40iX (WP) with port extensions set at 0 ps and 140 ps. The 140-ps port extension corresponds to the button capacitance measurement.

The initial batches of feedthroughs were also re-tested at the APS lab using identical instruments, and their data was confirmed to be consistent with the vendor's results. The remaining feedthroughs were tested by the vendor, who provided data to the APS for further analysis.

Figure 1 illustrates a typical test result of four feedthroughs before welding. The top-left plot shows their S-parameters within the 0 - 40 GHz range. The dip observed at 11.3 GHz indicates a button concentricity issue, a finding which has been validated by simulations. Notably, the magnitude of the dip at 11.3 GHz correlates with the severity of the button concentricity. The bottom-left plot shows their TDR results. The plot on the right shows a zoomed-in view of the TDR, highlighting the reflection coefficients (and consequently, the Voltage Standing Wave Ratio, VSWR) at the feedthrough neck portion. The bottom row shows the button capacitance (C_b) at 352 MHz with a port extension of 140 ps.

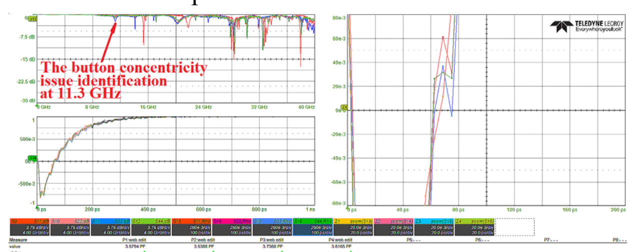

Figure 1: Four feedthroughs were tested with WP when the port extension was set to 140 ps at labs.

The electrical performance of feedthroughs was evaluated and analyzed at the APS lab. Approved feedthroughs were sorted into groups based on their capacitance consistency and four feedthroughs with closely matched capacitance were welded onto the housing as part of a BPM assembly.

The capacitance analysis of the feedthroughs which were welded in the SR BPMs, along with their consistency assessment, is summarized in Fig. 2 to 4 and Table 1 to 2.

Most BPMs exhibited a capacitance difference ($\Delta C = C_{max} - C_{min}$) of less than 0.1 pF, or relative capacitance difference ($\Delta C/C_{mean} \times 100\%$) of less than 1% in each BPM before welding.

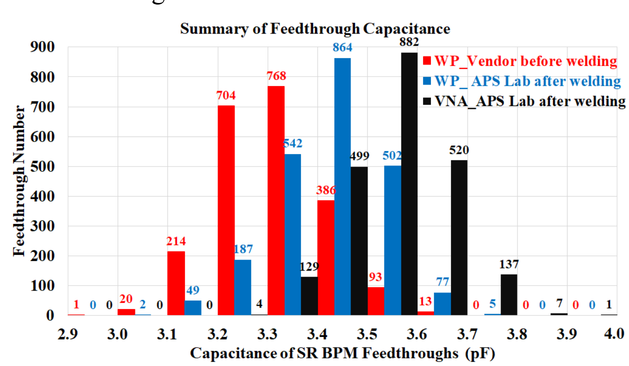

Figure 2: The distribution of the capacitance of the feedthroughs tested at both the vendor and APS lab.

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† Xiang@anl.gov

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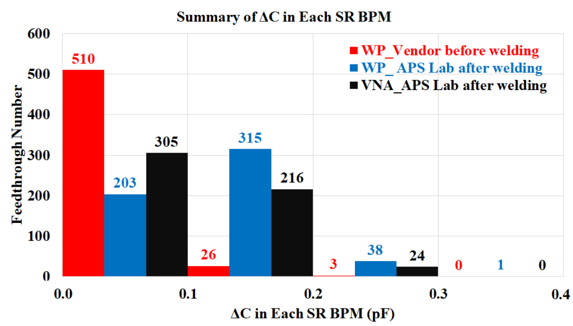

Figure 3: The distribution of the capacitance difference ($\Delta C = C_{max} - C_{min}$) for each BPM.

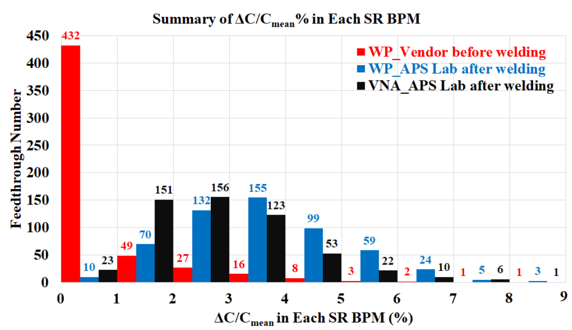

Figure 4: The distribution of the relative capacitance difference ($\Delta C/C_{mean} \times 100\%$) for each BPM.

Table 1: Comparison of Capacitance for 2,240 Feedthroughs Tested with Both WP and VNA Before and After Welding

Parameters	With WP at the vendor, before welding	With WP at the APS, after welding	With VNA at the APS, after welding
Max (pF)	3.6700	3.7775	3.9143
Min (pF)	2.9826	3.0798	3.2679
Mean (pF)	3.3229	3.4325	3.5512
Pk-Pk (pF)	0.6874	0.6977	0.6464
Pk-Pk/Mean	20.69%	20.33%	18.20%
STD (pF)	0.1002	0.1042	0.0974
STD/Mean	3.01%	3.03%	2.74%

RF BPMS TESTING AT THE APS LAB

The RF BPM assemblies were tested at the APS lab using both the WP and Keysight E5080B VNA. The electrical performance of the BPMs was evaluated and summarized in Fig. 2 to 4 and Table 1 to 2, comparing them with the results obtained before welding. Results from both WP and VNA measurements showed consistency.

After welding, changes were observed in the capacitance C_b of the feedthroughs, as well as in the capacitance difference ΔC and the relative capacitance $\Delta C/C_{mean}$ in each BPM, as compared to the results before welding. Most of the capacitance differences in each BPM are less than 0.2 pF, or 4% of relative capacitance difference.

The offsets on both the X and Y planes were calculated [4] based on the VNA data obtained at the APS lab, owing to its higher resolution in frequency domain. We will then compare these offsets with the results obtained from the BPMs installed in SR.

Table 2: Comparing Capacitance Consistency in Each BPM (2,240 feedthroughs in 560 BPMs)

Parameters	With WP at the Vendor, before welding	With WP at the APS, after welding	With VNA at the APS, after welding
ΔC Max (pF)	0.2720	0.3021	0.2945
ΔC Min (pF)	0.0000	0.0183	0.0128
ΔC Mean (pF)	0.0229	0.1214	0.0998
ΔC Pk-Pk (pF)	0.2720	0.2838	0.2817
ΔC STD (pF)	0.0379	0.0499	0.0486
$\Delta C/C_{mean}$ Max	8.33%	8.79%	8.12%
$\Delta C/C_{mean}$ Min	0.00%	0.53%	0.36%
$\Delta C/C_{mean}$ Mean	0.68%	3.54%	2.81%
$\Delta C/C_{mean}$ Pk-Pk	8.33%	8.25%	7.76%
$\Delta C/C_{mean}$ STD	1.13%	1.46%	1.35%

RF BPMS TESTING AT THE APSU SR

Once the BPMs were installed in APS-U SR, we measured their S-parameter from the patch panel using VNA. The patch panels are connected to the BPMs at AP0/BP0 via SiO2 hardlines and to the remaining BPMs through PEEK cables.

These measurements allowed us to verify the connection from the patch panel to the feedthroughs of BPMs. During the process, connection issues were identified in 11 feedthroughs or cables across 8 BPMs. A typical example of such an issue is shown in Fig. 5 at S14:BP0.

In this case, the center pin of the Top-Inner (TI) feedthrough at S14:BP0 BPM was off-center, and the pin of the TI cable was damaged. After the pin of the feedthrough was fixed and the cable was replaced, the problem was resolved, as shown in Fig. 6.

The X/Y offsets of the BPMs with cables at the APS-U SR were calculated based on the VNA S-parameter data and are presented in Table 3 and Figs. 7 and 8.

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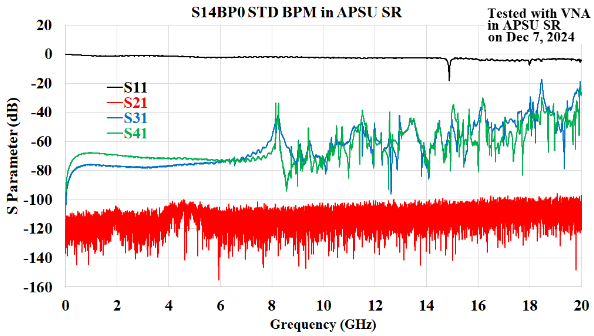

Figure 5: VPN S-parameters measurements. There are connection issues observed with Port2-TI feedthrough and cable.

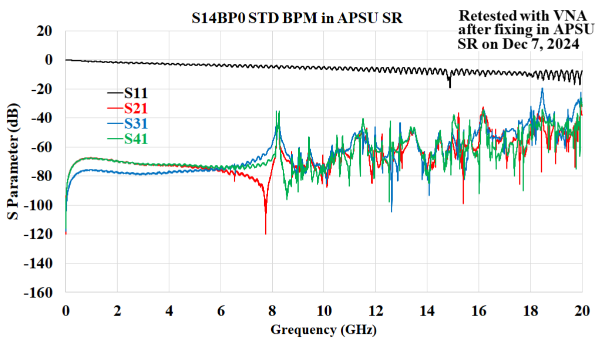

Figure 6: VPN S-parameters measurements. All connections appear to be normal.

Table 3: Offsets of BPMs at the SR

Parameters	X_offset	Y_offset	|X_offset|	|Y_offset|
Max (mm)	0.754	0.608	0.754	0.729
Min (mm)	-0.547	-0.729	0.000	0.000
Mean (mm)	0.012	-0.016	0.139	0.137
Pk-Pk (mm)	1.301	1.337	0.754	0.729
STD (mm)	0.178	0.178	0.112	0.115

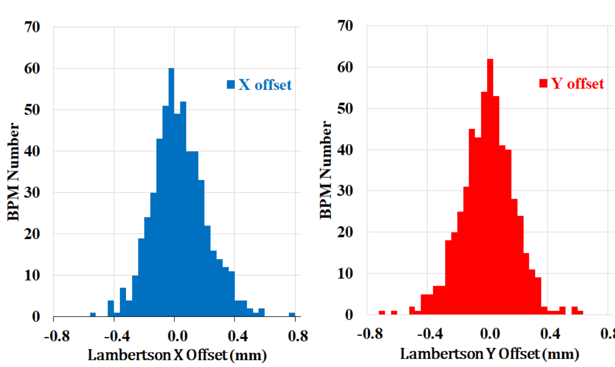

Figure 7: Offsets of BPMs at the SR.

In Fig. 8, the average offsets are consistent across each BPM type. Specifically, for keyhole BPMs located at AP2/BP5, with a button position at 60° and the coefficients are K_x = 11.18 mm and K_y = 6.64 mm, the Mean_absX_offset is maximized while the Mean_absY_offset is minimized. This relationship arises due to the proportional relationship between X_offset (or Y_offset) and the respective coefficient K_x (or K_y) in the formula. For STD and P0s BPMs with a button position at 45°, their offsets tend to fall somewhere between the maximum and minimum because their K_x and K_y values are equal to 8.07 mm.

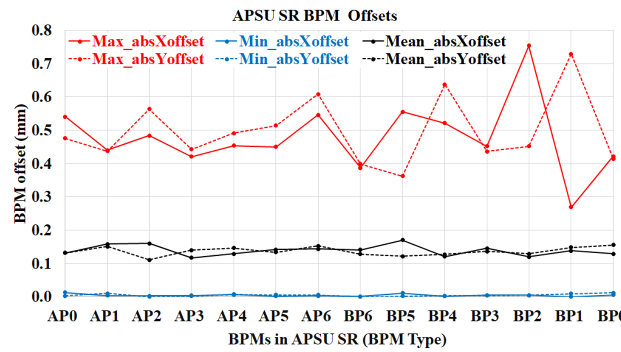

Figure 8: Offsets of BPMs at the SR by BPM types.

The offsets calculated based on the measurements in the SR with cables remain consistent with the results obtained at the APS lab without cables. These X/Y offsets, inclusive of the cables, provide a reliable reference for beam commissioning.

CONCLUSION

The thorough testing and sorting of feedthroughs capacitance before welding guaranteed consistent capacitance in each BPM after welding. The testing of BPMs with cables verified the integrity of connections of the BPMs as installed at the SR. Most offsets were found to be minimal, providing a reliable reference for the beam commissioning.

REFERENCES

[1] X. Sun, R. Lill and B. Stillwell, “The RF BPM pickup electrodes design for the APS-MBA Upgrade”, in *Proc. IBIC’17*, Grand Rapids, MI, USA, Aug. 2017, pp. 199-202. doi:10.18429/JACoW-IBIC2017-TUPCF03

[2] X. Sun and R. Lill, “The RF BPM pickup Electrodes development for the APS-MBA Upgrade”, in *Proc. NAPAC’19*, Lansing, MI, USA, Sept 2019, pp. 256-258. doi:10.18429/JACoW-NAPAC2019-MOPL012

[3] B. Stillwell *et al.*, “Progress on the Design of the Storage Ring Vacuum System for the Advanced Photon Source Upgrade Project”, in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 3590- 3592. doi:10.18429/JACoW-IPAC2017-WEPVA137

[4] G. Lamberson, “Calibration of Position Electrodes Using External Measurements”, Larence Berkeley Laboratory, Geneva, USA, LSAP Note-5, May 6. 1987.