Simulation of several hybrid modes for APS and APS-U

AOP-TN-2015-024
Michael Borland
May 28, 2015
Accelerator Systems Division, Advanced Photon Source

1 Introduction

Presently the APS operates in a 1+8x7 hybrid mode about 10% of the time. Some users are interested in additional time in hybrid mode. For example, P. Anfinrud has suggested a 1+21 hybrid mode might be a workable substitute for 24 bunch mode. In this mode, two bunches are left out of the 24-bunch train, resulting in an isolated bunch with a spacing of 108 buckets on either side. In this case, one might imagine putting the "extra" charge into the isolated bunch, giving it a current of 12 mA. There is also interested in a 1+45 hybrid mode for APS-U as an alternative to the 48-bunch uniform fill mode. Here, because we are more limited in the charge we can put in a single bunch, the "extra" charge would be distributed among all the bunches, raising their charge by only 4%.

One issue with hybrid modes is that the nonuniform fill pattern results in transient beam-loading in the rf system. This produces variation in the phases of the bunches. In APS today, this is perhaps tolerable because we do not have a higher-harmonic rf cavity (HCC). Users must, however, accept a perhaps significant variation in the arrival time of the bunches relative to the rf source. In APS-U, this is much more of a concern because it may prevent getting the desired bunch-lengthening effect from the HHC [1].

In this note, we show results of simulations of these modes for both APS and APS-U. For APS-U, the 3PW-V6 lattice [2] is used. In both cases, we use `Pelegant` and include a feedback model for the main rf system[3]. For the APS-U, more details of the simulation methods are found in [1].

2 APS Simulations

We performed simulations for three bunch patterns:

1. 1+8x7 hybrid mode, with 16 mA in the isolated bunch. This provides a test of the simulation, since we have measurements of this case [4].
2. 1+21 hybrid mode, with 4.55 mA in all bunches. We'll call this the "low charge" case, referring to the charge in the isolated bunch.
3. 1+21 hybrid mode, with 12.75 mA in the isolated bunch and 4.25 mA in the others. We'll call this the "high charge" case.

For these runs, we did not include the short-range longitudinal impedance, since this won't affect the relative position of the bunches. This provides a significant savings in computer time.

Figure 1 shows the arrival time offsets for 1+8x7 hybrid mode. For the 56 bunches, the variation in arrival relative to the rf source time is 63 ps. This agrees reasonably well with streak camera data [4], which gives a value of 56-64 ps, depending on how one reads the data.

Figure 2 shows the arrival time offsets for 1+21 hybrid mode, i.e., for cases 2 and 3 above. Not surprisingly, the variation is small even in the worst case, amounting to about $\pm 10\%$ of the 33-ps rms bunch duration. The high-charge case shows a very uniform arrival time, which in retrospect is to be expected because the current distribution is still nearly uniform and balanced. For the low-charge case, the current distribution is unbalanced and hence induces transients in the rf system. This understanding is supported by the voltage data for the individual bunches, shown in Fig. 3.

With such small timing variations, we can be confident that there will be very little variation in the bunch duration amoung the 22 bunches in these patterns.

3 APS-U Simulations

Simulations for APS-U followed the procedure described in [1]. The main differences from the simulations for APS are the inclusion of the HHC and the longitudinal impedance. Three hybrid modes have been simulated:

H1 48-bunch, 200 mA mode with $\pm 1.1\mu$s gaps on either side of the isolated bunches. All bunches have equal charge.

H2 48-bunch, 200 mA mode with $\pm 0.66\mu$s gaps on either side of the isolated bunches. All bunches have equal charge.

45+1 45+1[1], 200 mA mode, created by removing two bunches from either side of the isolated bunches starting from a uniform 48-bunch pattern. The charge from the "missing" bunches is added to the remaining bunches.

The HHC detuning was 13.5 kHz in all cases.

Figure 4 shows the bunch durations for the three modes. A clear issue with H1 and H2 is the lack of effective bunch lengthening. In many cases, the bunches are not much longer than the 35-ps value expected from the longitudinal impedance alone. For comparison, the rms bunch duration for a 48-bunch uniform fill would be 77 ps, so we would expect the lifetime to be reduced by a factor of nearly two. Given that 48 bunch fills suffer from short lifetime even when lengthening by the HHC is effective[5], this reduction in HHC effectiveness is not workable. Not surprisingly, the third pattern fares much better, with an average rms bunch duration of 71 ps, only 10% less than for a uniform fill.

Figure 5 shows the arrival time offsets for the three modes. H1 and H2 show large variations, about five times worse than for the present hybrid mode. The effects are more modest for 45+1 mode, but still almost twice as large as for the present hybrid mode. More simulation is needed to understand whether these variations in the equilibrium positions of the bunches will complicate the injection process.

Figure 6 shows the longitudinal density for each bunch averaged over 2000 turns for H2, while Fig. 7 shows similar data for the 45+1 pattern. Somewhat surprisingly, the former appears more regular. This is explained by the fact that in the H1 and H2 modes, the voltage induced in the HHC is reduced by the large timing offsets. With the smaller timing offsets in 45+1 mode, the voltage induced in the HHC is larger and has a greater impact on the bunch shape.

4 Conclusion

We looked at several hybrid bunch pattern options for the APS and APS-U. For APS, we used the present 1+8x7 mode to verify the simulations, obtaining good agreement. We then modeled a 1+21 mode and found a negligible timing shift due to the gap. For APS-U, we revisited the hybrid mode studies published elsewhere, adding a 45+1 (or 1+45) mode. This mode would have lifetime within 10% of the 48-bunch mode lifetime, and is probably acceptable. Timing shifts are as large as the rms bunch duration and significant bunch shape variation is expected.

5 Acknowledgments

Simulations used the APS weed cluster (for present APS) and LCRC blues cluster (for APS-U).

6 Revision Notes

- None

[1] We used 45+1 instead of 1+45 in the simulations. In reality, the results are identical.

References

[1] M. Borland et al. Tracking Studies of a Higher-Harmonic Bunch-Lengthening Cavity for the APS Upgrade. In *MOPMA007, IPAC15*.

[2] M. Borland et al. Hybrid Seven-Bend-Achromat Lattice for the Advanced Photon Source Upgrade. In *IPAC15, TUPJE063*.

[3] T. Berenc and M. Borland. Modeling RF Feedback in Elegant for Bunch-Lengthening Studies for the APS. In *IPAC15, MOPMA006*.

[4] A. Lumpkin, 2004. Private communication.

[5] A. Xiao and M. Borland. Intra-Beam and Touschek Scattering Computations for Non-Gaussian Longitudinal Distributions. In *IPAC15, MOPMA012*.

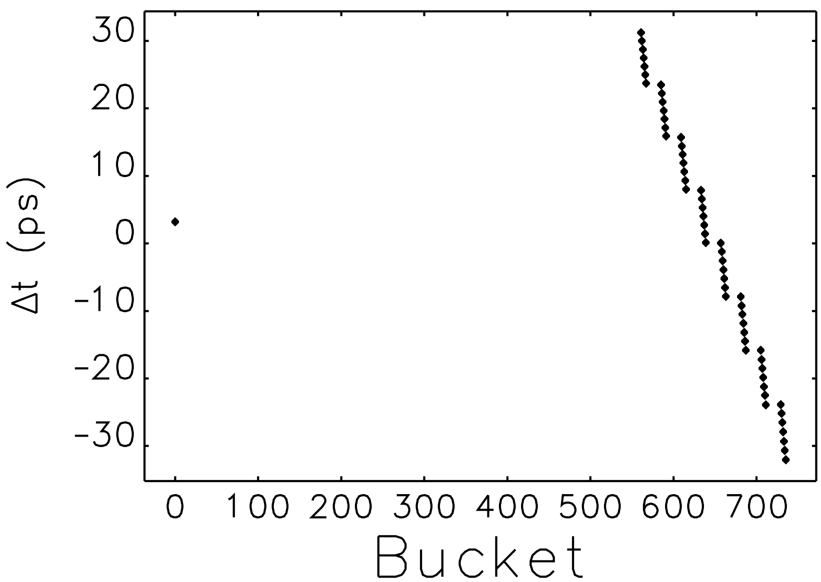

Figure 1: Arrival time offsets for standard APS hybrid mode.

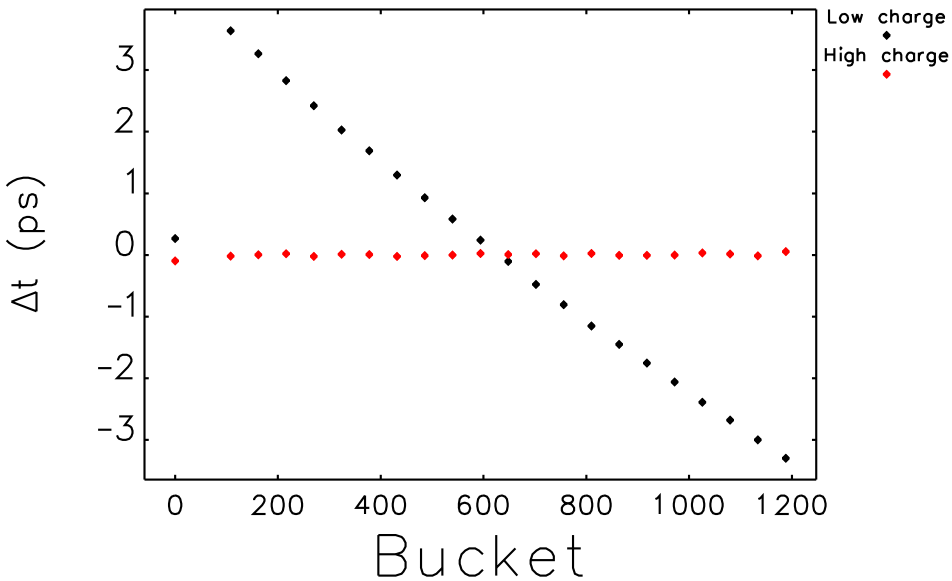

Figure 2: Arrival time offsets for APS 1+21 hybrid modes, showing low and high charge options for the isolated bunch.

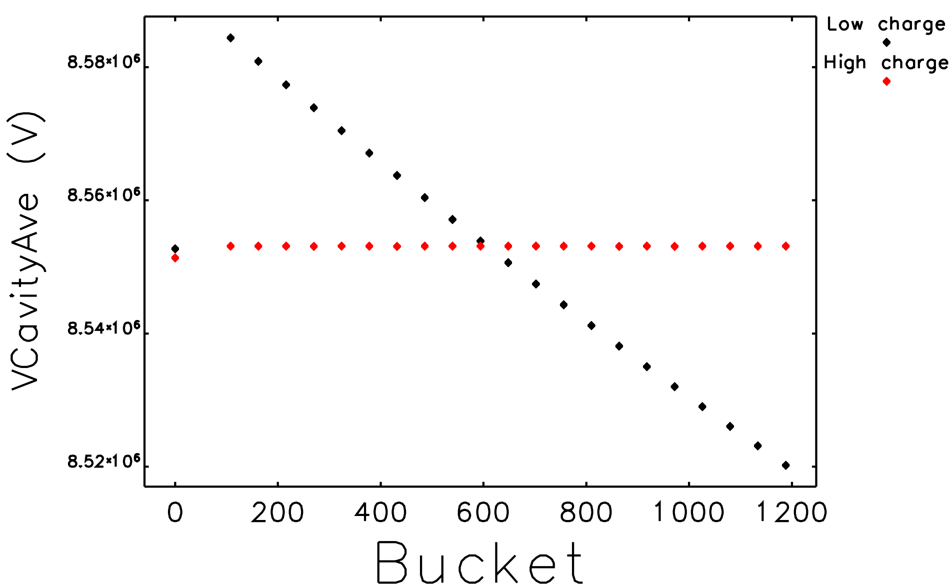

Figure 3: Bunch-by-bunch voltage for APS 1+21 hybrid modes, showing low and high charge options for the isolated bunch.

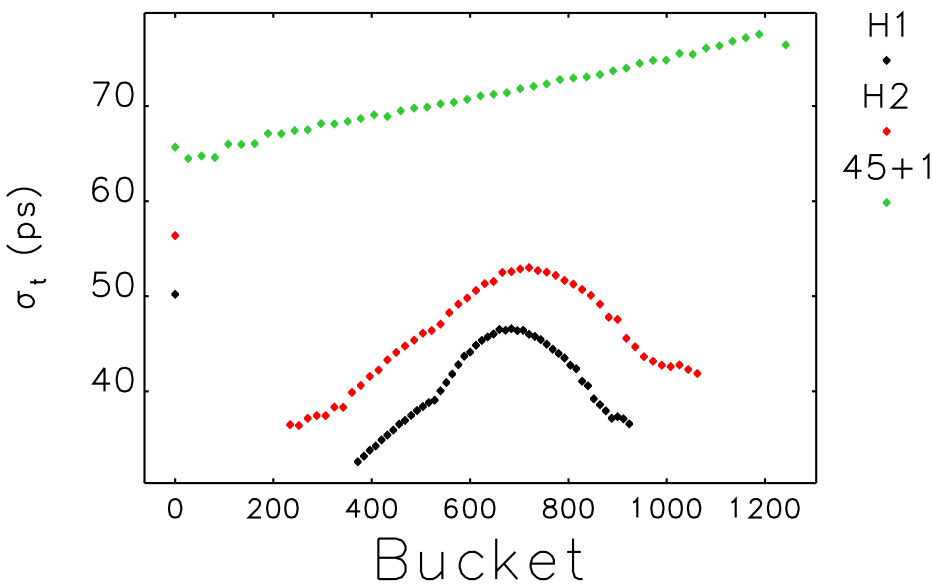

Figure 4: Rms bunch duration for various hybrid modes for APS-U. The bunch duration for 48-bunch uniform fill is 77 ps.

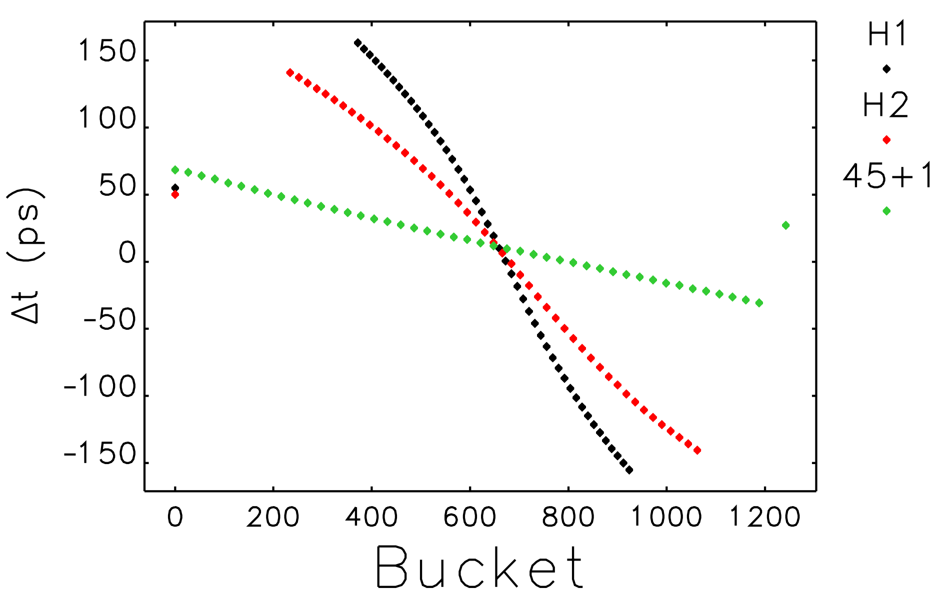

Figure 5: Arrival time offsets for various hybrid modes for APS-U.

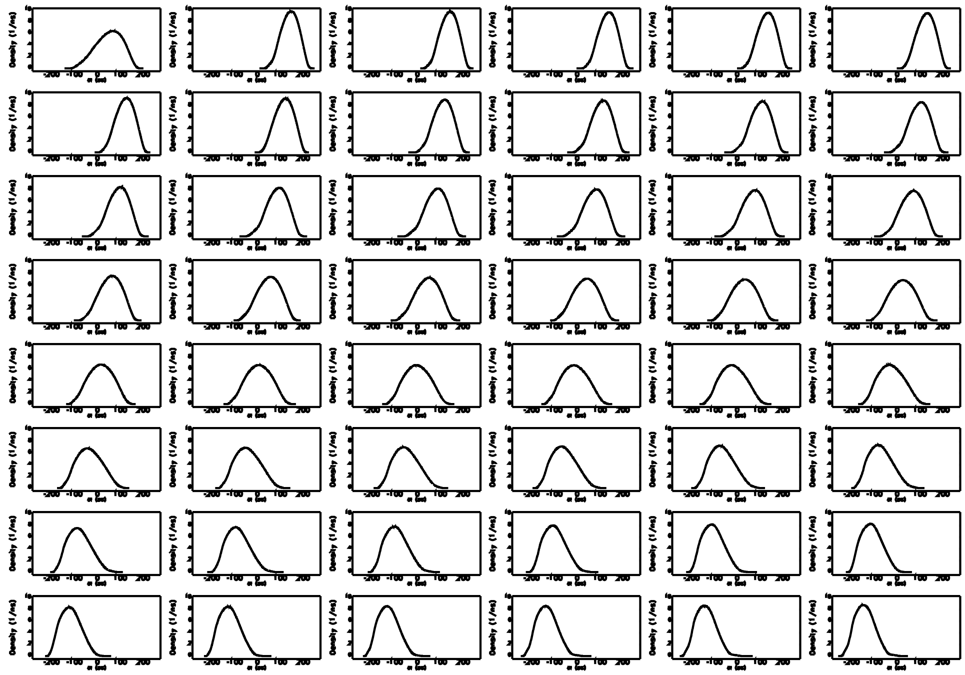

Figure 6: Bunch shapes for Hybrid2 mode for APS-U.

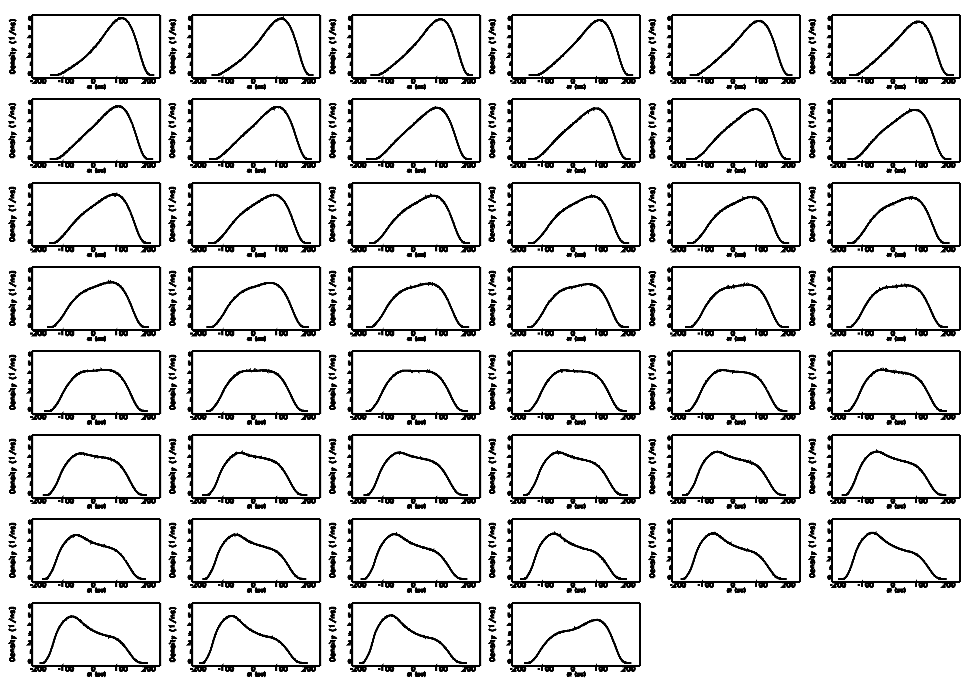

Figure 7: Bunch shapes for 45+1 mode for APS-U.