RESULTS OF PRELIMINARY TESTS OF PAR BUNCH CLEANING*

CY Yao, N.S. Sereno, M. Borland, A.E. Grelick, A.H. Lumpkin
Advanced Photon Source, Argonne National Laboratory, Argonne, IL 60439 U.S.A.

Abstract

A particle accumulator ring (PAR) is used at the Advanced Photon Source (APS) to collect multiple linac bunches and compress them into a 0.3-ns single bunch for booster injection. A 9.77-MHz fundamental and a 117.3-MHz harmonic rf system (RF12) are employed for initial beam capture and bunch-length compression, respectively. Satellite bunches with very low charge form when the phase or loading of the rf systems drift. These satellites cause bunch purity deterioration in the storage ring. Storage ring and booster bunch cleaning has been tried but proved to be difficult due to top-up mode of operation in the storage ring and tune drift in the booster synchrotron.

Recently we implemented a PAR bunch cleaning system with tune-modulated harmonic rf knockout. The results showed that the cleaning method is feasible and can achieve the goal of bunch purity better than 10^{-8}. This report describes the system configuration, test results, and system performance.

INTRODUCTION

A particle accumulator ring (PAR) is used at the APS to collect multiple linac bunches and compress them into a single bunch for booster injection. The PAR is operated with a cycle time of 500 ms. A 9.77-MHz fundamental rf system captures several linac bunches to form a single bunch and damps it to about 0.85 nS rms in bunch length. The 12th harmonic rf (RF12) is then turned on, which compresses the bunch further down to about 0.3 nS for injection into the booster. Satellite bunches sometimes form after the RF12 compression starts, which pollute the storage ring (SR) bunch purity.

Recently we performed tests of PAR bunch cleaning with a tune-modulated harmonic rf drive during user operations. The system has improved the storage ring bunch purity to ~10^{-7} level. This report describes the system configuration, test results, and some of the issues we encountered during the process.

BUNCH CLEANING WITH HARMONIC RF DRIVE

Many different methods have been developed to clean satellite bunches in a circular machine [1,2]. One method uses a CW rf drive with a frequency matching the betatron tune of the low-current satellite bunches. In this case, the drive signal is applied to all bunches equally and only the low-current bunches are in resonance with the drive signal. The oscillation amplitude of these bunches grows to a large value and the particles are eventually lost. We did experiments with this method on the SR and booster. One of the main shortcomings of this approach is that the main bunches are also driven. If the tune difference between the main and satellite bunches is not large enough or there is tune fluctuation due to drift of magnet currents, part of the beam in the main bunches is also driven out.

Another method uses a tune frequency signal modulated by a pulsed signal that is ideally either completely on or completely off. The "on" part of the pulsed signal is aligned with the satellite buckets in timing, while the "off" part is aligned with the main buckets. This approach guarantees that only the satellite buckets are driven while the main buckets only see zero drive. This method typically requires wide-band amplifiers in order to preserve the pulse shape of the modulation signal.

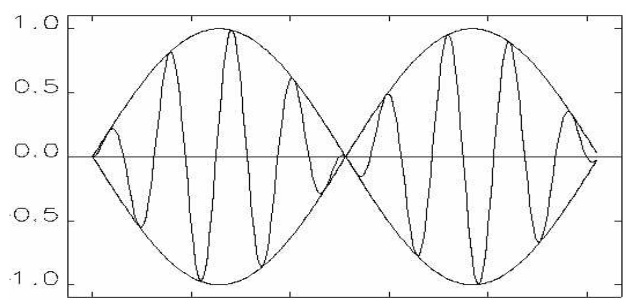

Figure 1: Tune-modulated harmonic drive signal.

Our tune-modulated harmonic rf drive method employed an idea similar to the pulse-modulated tune method. It uses a harmonic rf signal modulated by the tune frequency, an example of which is shown in Figure 1. The envelope is the tune signal while the carrier is the rf harmonic. In this case the main bunch is timed at the zero crossing of the harmonic rf signal and thus receives very little drive. The satellite positions coincide with the peak of the waveform. Particles at these locations thus receive a much larger drive and are driven out.

In order to clean the satellite bunches, the cleaning rf drive power is turned on after the formation of the satellites, i.e., sometime after RF12 is turned on and bunch is compressed to some extent and its phase is stabilized. The cleaning rf drive power remained for 20 ms to 30 ms and then is turned off several damping times before extraction so any residual excitation of the main bunch is damped down to an acceptable level prior to injection into the booster.

One of the concerns is blowing up of the main bunch due to rf drive. Even with the rf phase and bunch signal well aligned, the tail and head parts of the main bunch still experience some excitation. This may hurt the capture efficiency of the booster.

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Because of synchrotron oscillations, the head and tail of a bunch exchange positions every half synchrotron oscillation period. Therefore they are only driven in one phase for half of the synchrotron oscillation period, and the growth rate is much slower than that of a satellite bunch. If the timing alignment is accurate enough and sufficient damping time is provided after the cleaning power is turned off excitation of the main bucket should not be a problem.

SYSTEM DESCRIPTION

A schematic of the test system is shown in Figure 2. A DS345 arbitrary function generator (AFG) produces a ramped FM signal around 1.93 MHz, which is the n=0 horizontal tune sideband. A 29.3-MHz 3rd harmonic rf signal is derived from the 117-MHz RF12 source of the PAR rf system. The two signals are mixed and filtered to produce the desired modulated low-level rf, which is split, phase shifted, and amplified. The rf power is applied to four stripline blades in the PAR, which are configured as a horizontal driver. The stripline has a length of 16.7 cm. It was originally designed for tune measurement. Therefore, it is not optimized for this application. The decision to drive in the horizontal plane is necessary due to an ion trapping instability [3]. Alignment of the drive signal and beam timing are measured with the return signals of the stripline blades. A remote-controllable variable delay line is used to shift the drive rf timing. It has a resolution of 10 ps and a range of 0 to 10 ns.

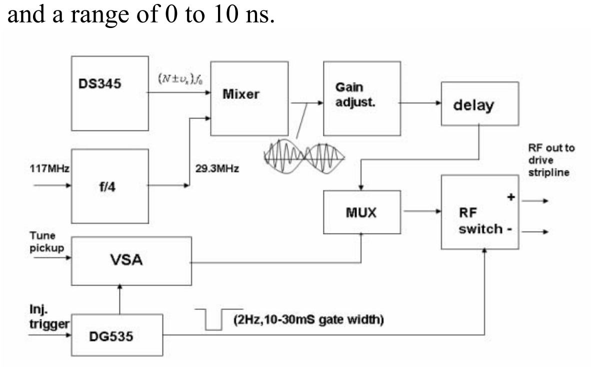

Figure 2: Schematic of the bunch cleaning system.

BUNCH CLEANING RESULTS

The system was employed during user operations for several weeks. APS bunch purity is measured with a photon counting system based on a fast X-ray avalanche photodiode detector [4]. The measured bunch purity values for different satellites are listed in Table 1. Figure 3 is a plot of measured storage ring bunch purity with three linac bunches selected for PAR injection with a total charge of 2.4 nC to the SR injection beam transport line (BTS). The booster injection efficiency did not show noticeable reduction when the drive was turned on. The optimized parameters are listed in Table 2.

The counts on the +1st and -1st satellites are relatively larger because the tails of a compressed bunch are captured by the booster as satellites. The bunch cleaning system does not clean them.

Table 1: Bunch Purity Results

Bucket number	Purity
+3rd, -3rd	2.9×10^{-7}
+1st,-1st	6.5×10^{-7}
+2nd,-2nd	$<1.6\times10^{-7}$

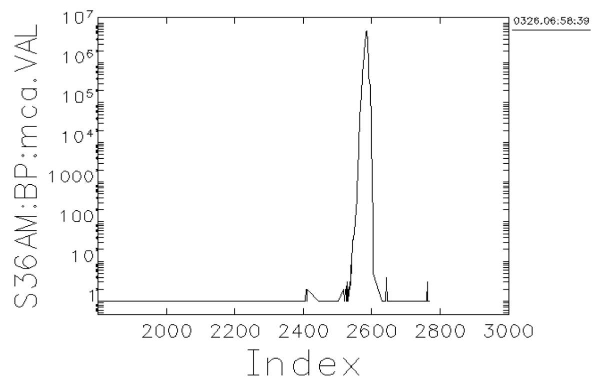

Figure 3: Storage ring bunch purity plot. The vertical axis shows the number of counts.

Table 2: Optimized Bunch Cleaning Parameters

Drive frequency	1.93MHz
Drive power	60 W per stripline blade
Frequency span	80 kHz
Modulation function	Up slope ramp
Gate start time	380 ms
Gate width	20 ms
Modulation mode	FM
Modulation rate	100 Hz

Phase alignment of the stored PAR bunch and the drive rf signal is critical to the quality of the main bunch after cleaning. Optimized timing is achieved by a beam current versus delay time scan. Figure 4 shows the result of a delay time scan. The best delay value is determined by setting the delay at the middle point of the pass-band of the waveform plot, in this particular case: 2.2 ns.

We found that the direction in which the tune signal ramps has strong impact on the performance of the bunch cleaning system. The system is much more effective when the AFG is programmed to ramp up. A measurement of horizontal tune shows that tune increases when beam oscillation amplitude increases. It is obvious that the drive signal frequency has to follow the tune in order to maximize the excitation.

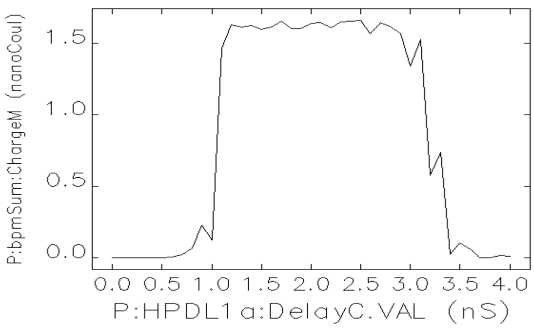

Figure 4: PAR charge versus delay line value.

TUNE MEASUREMENT

The bunch cleaning system is designed to include a tune measurement function. An rf multiplexer module is employed to switch the input to the amplifiers between the bunch cleaning source and the output of an HP vector signal analyzer (VSA). The VSA is in external trigger mode and triggered by a delayed trigger from injection so the tune spectrum of any part of the PAR cycle can be acquired.

BUNCH PURITY DURING TOP-UP

During top-up operation storage ring satellite pollution accumulates when a fill lasts several days. This is due to the short lifetime (5 to 6 hours) for the main buckets and the long lifetime (~100 hours) for low-charge satellite bunches. It appears that a bunch cleaning system in the SR is needed in order to maintain bunch purity during top-up.

VERTICAL INSTABILITY

A vertical instability exists in the PAR beam right after the capture of the first linac bunch [3]. The instability disappears in the later part of the PAR cycle. The cause of the instability is believed to be ion trapping. It is observed that beam is much more sensitive to vertical drive than horizontal, as clearly shown by the vertically blown-up image of the extracted main bunch on the first florescence screen of the PAR to booster (PTB) transport line when rf drive is on. Because of this sensitivity, we switched from the initially planned vertical drive to horizontal drive. This helped to maintain booster injection efficiency.

HARMONIC RF CAPTURE PROCESS

Substantial time was spent on understanding and controlling the RF12 capture process. Initially the RF12 power waveform was applied before the start of RF12 cavity tuner current waveform. We found that due to the beam loading effect, there was a period in which beam phase was not well controlled at the start of the power ramping, when beam-induced gap voltage and driven gap voltage in the RF12 cavity have comparable amplitude. For this reason we decided to switch to a new scheme in which the RF12 cavity tuner waveform is turned on first and the RF12 drive power is turned on after a self-bunching process stabilizes the beam phase. This change allowed better phase control and helped to improve compression and cleaning consistency.

CONCLUSION

PAR bunch cleaning system has improved the SR bunch purity. Further work is needed in order to achieve the goal of 10^{-8} level of bunch purity. In order to maintain SR bunch purity during top-up operations, an SR bunch cleaning system or other remedy is necessary.

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REFERENCES

[1] T. Aoki et al., “Bunched Beam Cleaning System of Spring-8 Booster Synchrotron,” Proceedings of the 2003 Particle Accelerator Conference, Portland, Oregon, May 2003, p. 2551, 2003.
[2] E. Plouviez et al., “Cleaning of Parasitic Bunches in the ESRF Booster Synchrotron for Time Structure Modes of Operation,” Proceedings of EPAC 2004, Lucerne, Switzerland, July 2004, p. 2341, 2004.
[3] C-Y Yao et al., “Investigation of APS PAR Vertical Beam Instability,” these proceedings.
[4] A. Lumpkin et al., “Bunch Purity Evolution During APS Storage Ring Top-up Operations,” Proceedings of the 2003 Particle Accelerator Conference, Portland, Oregon, May 2003, p. 2411, 2003.

 0-7803-8859-3/05/$20.00