ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS119

APS LINAC INTERLEAVING OPERATION*

Yine Sun†, K. Belcher, J. Dooling, A. Goel, A. Hillman, R. Keane,
A. Pietryla, H. Shang, A. Zholents, Advanced Photon Source, Argonne National Lab, Lemont, USA

Abstract

Three s-band RF guns are installed at the front end of the Advanced Photon Source (APS) linac: two thermionic cathode guns (RG2 and RG1), and one Photo-Cathode Gun (PCG). During normal operations, RG2 provides electron beams for the storage ring to generate x-rays for APS users. The PCG generates high brightness electron beams that can be accelerated through the APS linac and transported into the Linac Extension Area (LEA) for advanced accelerator technology and beam physics experiments. The alternating acceleration of the RG2 and PCG beam in the linac is possible, as most of the time, RG2 beam is only needed for 20 seconds every two minutes. This mode of interleaving operation of RG2 and PCG beams through the APS linac requires some modifications/additions to several systems of the linac, including RF, magnets, controls and Access Control Interlock System etc. In this paper we report our interleaving design and present the commissioning results of the two beam interleaving operation.

INTRODUCTION

Electron beams for APS storage ring operation is generated by one of the two thermionic cathode guns (RG1 and RG2), each equipped with its own alpha-magnet to send the beam to the APS linac. A new Photo-Cathode Gun (PCG) has been installed at the frontend of the APS linac, and the PCG beam can be used for experiments in the LEA, see Figure 1. Each gun has a gate valve that isolates the gun from the rest of the linac.

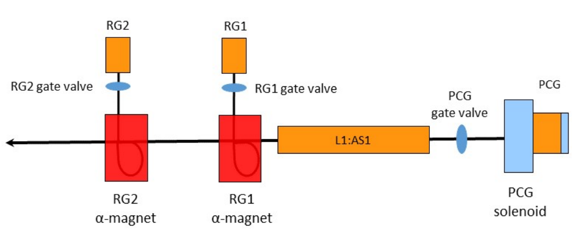

Figure 1: The three RF guns of APS linac: thermionic cathode gun RG1 and RG2, and photocathode gun (PCG).

During the APS storage ring top-up operations, the linac is needed for ~20 seconds every two minutes most of the time to inject the thermionic RF gun beam into PAR/Booster/SR. There is no thermionic RF gun beam in the linac during the rest of the two minutes – the linac can be used to accelerate the PCG beam for experiments in the LEA; see Figure 2. This mode of interleaving operation of two beams through the APS linac – thermionic RF gun beam for PAR/Booster/SR and PCG beam for LEA, requires some modifications/additions to several systems of the linac, including RF, magnets, controls and Linac/PAR Access Control Interlock System (ACIS). To reduce the complexity of interleaving operation of the beamline magnets, an interleaving lattice is designed to accommodate the drastically different beams generated by the thermionic RF gun and PCG [1].

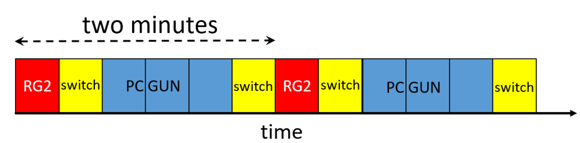

Figure 2: Interleaving operation between the RG2 and PCG beams in the APS linac every two minutes.

INTERLEAVING DESIGN AND FEASIBILITY STUDIES

Beam Trajectory Control: Magnets and Power Supplies

The thermionic RF gun beam changes its travel direction several times as it is compressed by the alpha magnet, injected into and extracted out of PAR via dipole magnets LTP:B1 and PTB:B1, and sent to the booster by dipole PTB:B2. While these magnets are also on the path of the PCG beam, they should apply no magnetic field to the PCG beam to allow it to go straight to LEA; see Figure 3.

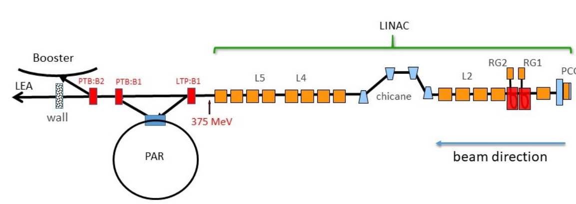

Figure 3: The gun alpha magnets, interleaving dipole magnets LTP:B1, PTB:B1 and PTB:B2 (all shaded in red) only bend the trajectory of the thermionic RF gun beam and provide no deflection to the PCG beam.

While the thermionic RF guns RG1 and RG2 are identical, their alpha magnets are significantly different. RG2 has a traditional half-quad style alpha magnet, while RG1 has a Panofsky style alpha magnet [2]. Both alpha magnets have solid cores and relatively strong residual fields. However RG2 alpha magnet trim is a set of separate coils, which can be set at a DC value to compensate the remnant main

* Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.
† yinesun@anl.gov

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS119

alpha magnet field. For interleaving trajectory control, we run the trim coil at a DC current and ramp the main alpha magnet current up/down for RG2/PCG beam to go through the linac. Less than 15 seconds is needed for the two gun beam position to recover at the end of the linac.

As depicted in Figure 3, three fast switching interleaving dipole magnets can be used to switch beam trajectories during interleaving operations: Linac to PAR dipole LTP:B1, PAR to booster dipoles PTB:B1 and PTB:B2. The magnetic fields of the three interleaving dipoles are only needed for PAR/Booster beams. To send PCG beam to the LEA, these dipoles are put to standby.

Interleaving Operation of the LINAC RF Systems

Klystron 1 (K1) Interleaving Operation Mode The thermionic rf guns and the first accelerating structure L1:AS1 share the same RF source, Klystron 1 (K1). For PCG operations, L1:AS1 is used to accelerate the PCG beam and is crucial for beam capture and brightness. During interleaving, we keep K1 RF flow path through L1:AS1 to RG2 all the time, while the low level rf gate start timing interleaves between PCG and RG2 operating parameters.

Klystron 2 (K2) Interleaving Operation Mode We plan to keep the same energy of RG2 and PCG beam in the chicane. The PCG beam exits the PCG with higher energy and more importantly, it goes through an extra accelerating structure (L1:AS1) compared to RG2 beam. At the entrance of the L2:AS1 accelerating structure, the RG2 beam energy is about 3 MeV, while PCG beam energy is about 40 MeV. To match with RG2 beam energy at the chicane, the PCG energy gain through L2 section is reduced. This is achieved by lowering the L2 PFN. The transient time between the two levels of RF power of L2 is found to be ~ 10 seconds. During interleaving operation, K2 modulator PFN voltage ramps up/down for RG2/PCG beams correspondingly.

INTERLEAVING ACIS

As the ACIS is an essential part of the radiation safety of the APS operations, no changes can be made to this system without the most thorough analysis. In this section, the ACIS modifications made to accommodate interleaving are discussed in detail.

Each RF gun has a corresponding gate valve where the closed status of the gate valve is used by the ACIS to determine which gun is providing beam to the linac. The locations of the ACIS gate valves are shown in Figure 1. The gate valve status together with the RF waveguide switch position are used by ACIS to select either K1 or K3 as the trigger source for the three Beam Emergency Shut-Off Current Monitors (BESOCMs) and to enforce the radiation safety envelope of the Linac, PAR and Booster enclosures. The ACIS trigger select signals are sent to the Interleaving Trigger Control chassis to pass the proper RF modulator timing pulse to the BESOCMs.

Under normal operation, ACIS only allows one gun gate valve to be open during beam operations, otherwise the ACIS will generate a gun inhibit and disable the RF into the RF guns and the first accelerating section. For interleaving operations, the PCG gate valve and RG2 gate valve must remain open for the two gun beams to interleave in the linac. Therefore, ACIS modification was needed to allow L1:PC1:GV2 and L1:RG2:GV1 to remain open simultaneously. This is due to the ACIS BESOCM trigger select logic no longer being able to determine which gun is providing beam with the gun gate valve status and waveguide switch positions alone. Additional signals must be provided to the ACIS to confidently determine the trigger source during interleaving operations. It is also important to not allow PCG and RG2 generated beam to occur within 100μs otherwise the 2nd pulse will not be detected by the BESOCM and the radiation safety envelope may be exceeded.

It was determined that the RG2 alpha-magnet current can be used as an ACIS input for BESOCM trigger select logic as well as to eliminate the chance of the PCG and RG2 beam concurrently being accelerated in the linac. When the alpha magnet is above a certain value (high threshold), the thermionic rf gun beam is sent into the linac and PCG RF is disabled, thus K1 (thermionic gun RF source) is chosen as the BESOCM trigger source and electrons from PCG are not possible. When the alpha magnet current drops below certain value (low threshold), the PCG beam is allowed to travel down the linac, and the thermionic gun beam can be eliminated from the linac by disabling the RG2 gun kicker, therefore K3 (PCG RF source) can be chosen as the BESOCM trigger source and electrons from RG2 can not be present in the linac. To ensure no two beams are present in the linac simultaneously or within 100μs, a dead zone can be created between the low and high thresholds of the alpha magnet current – RG2 beam can be eliminated by disabling RG2 kicker when alpha magnet current is below its high threshold, and PCG RF power can be disabled to eliminate beam generated by PCG when the alpha magnet current is above its low threshold; see Figure 4.

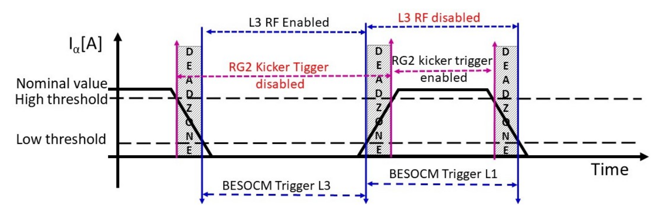

Figure 4: BESOCM trigger selection is determined by the RG1 alpha magnet current: Choose RG2 RF source (K1) when RG2 alpha magnet current is above the low threshold and PCG RF source (K3) when below. Beam is inhibited between the low and high thresholds of the alpha magnet currents.

Current sensing circuits for the RG2 alpha magnet are installed. High and low currents thresholds signals are provided to ACIS. An interleaving Trigger Control (ITC100)

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS119

chassis was designed, fabricated and installed. Linac/PAR ACIS is modified to monitor RG2 alpha magnet current thresholds, and provide signals to the ITC100 to enable or disable the RG2 kicker trigger, K3 RF modulator trigger and K3 RF drive amplifier trigger, and inform ITC100 to selected the BESOCM trigger either from K1 or K3 RF source.

With this modification, the LINAC/PAR BESOCMs ACIS is successfully commissioned for interleaving operations.

INTERLEAVING OPERATION COMMISSIONING

The interleaving operation commissioning started upon the successful installation and validation of the interleaving ACIS. Based on the interleaving feasibility studies, RG2 beam is sent to PAR/Booster and the PCG beam straight ahead to PAR-bypass. L2 is interleaving between two different RF power levels and phase, and L1 between different LLRF timing. An automated script has been developed to control the alternating magnets and RF parameters for interleaving operation.

The APS storage ring top-up control is modified to check if the linac is in interleaving mode. In interleaving mode, the top-up control program sets the RG2 alpha magnet current to its nominal value, and linac ACIS will then enable the RG2 kicker trigger once the alpha magnet current is above the high-threshold; upon the completion of injection to the storage ring, it sets the alpha magnet current to zero, and the linac ACIS will then disable the trigger to the RG2 kicker once the alpha magnet current is below the high-threshold.

With linac in interleaving mode, RG2 beam and PCG beam are accelerated to the end of the linac reaching 375 MeV. At the end of the linac, RG2 beam is sent to the PAR and bunch charge extracted from PAR as measured by the Par-to-Booster current monitor is shown in Figure 5. PCG beam travels through the PAR-Bypass beamline and its position in the Par-bypass beam position monitor (PB:PM1) is also plotted in Figure 5.

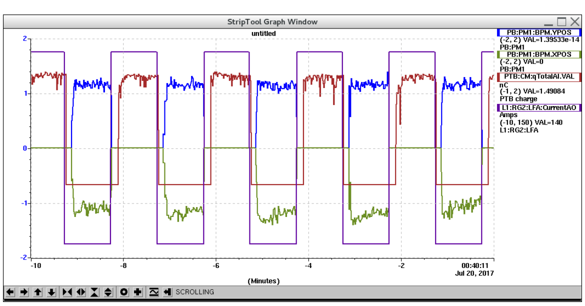

Figure 5: Par-To-Booster bunch charge from RG2, as measured by the current monitor (PTB:CM); and PCG beam position at Par Bypass beam position monitor (PB:PM1) during interleaving operations.

The storage ring injection with linac operating in the interleaving mode is verified – RG2 beam is injected into the PAR/Booster and storage ring, same as when the linac is only accelerating RG2 beam. In Figure 6, the storage ring current is increasing after each injection while the linac is in interleaving mode.

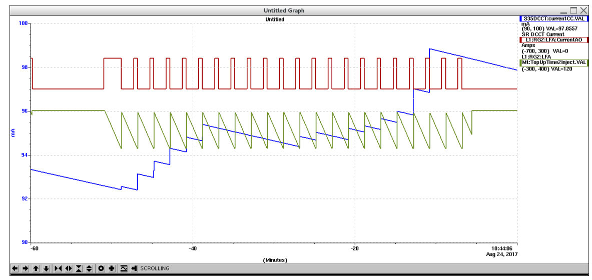

Figure 6: Storage ring top-up operation with linac in interleaving mode: The missing shots between [-40, -20] minutes are due to the automatic 15 minutes RG2 kicker time-out; the last couple of larger current increase steps are the result of testing increasing the number of pulses injected into the storage ring.

We successfully tested the storage ring top-up operation with the linac operating in the interleaving mode. During top-up when the linac interleaving mode is enabled and storage ring injection is required, RG2 beam is accelerated through the linac and injected into PAR/Booster/SR, and once injection is completed, RG2 beam is disabled and the PCG beam is accelerated though the linac. If the linac interleaving is disabled, the linac has only RG2 beam present when injection is needed.

ACKNOWLEDGEMENTS

The authors would like to acknowledge our colleagues for their support throughout of the interleaving operation project including N. Arnold, R. Bechtold, B. Berg, M. Borland, D. Bromberek, J. Cross, D. Donkers, L. Emery, R. Flood, J. Grimmer, J. Hoyt, J. Lang, J. Lenner, G. Markovich, L. Morrison, A. Nassiri, S. Pasky, V. Sajaev, N. Sereno, S. Shin, T. Smith, J. Stein, J. Vacca, J. Wang and CY Yao.

REFERENCES

[1] S. Shin *et al.*, "Interleaving Lattice Design for APS Linac", in *Proc. NAPAC'16*, Chicago, IL, USA, Oct. 2016, pp. 713–715.

[2] J. W. Lewellen *et al.*,"A Hot-Spare Injector for the APS Linac", in *Proc. PAC'99*, New York, NY, USA, Mar. 1999, paper WEA40, pp. 1979–1981.