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ONLINE MULTI-PARTICLE MODEL FOR LANSCE PHYSICS TUNE-UP WITH HPSim*

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Abstract

The accelerator at the Los Alamos Neutron Science Center (LANSCE) delivers beam to five user facilities, including the Isotope Production Facility (IPF), the proton Radiography (pRad), Ultra-Cold Neutron (UCN), Lujan Center and the Weapon Neutron Research (WNR). The high-power operation of the LANSCE accelerator is often limited by the level of beam losses, especially for IPF and the Lujan Center which require higher average current. Longitudinal halos and tails, one of the major source beam losses, could be easily generated via longitudinal mismatch under present bunching scheme and the large uncertainties of cavity power measurements. We present a GUI with an online multi-particle model based on HPSim. This could potentially help the beam physicists intuitively determine the quality of the longitudinal capture after each phase scan, and therefore, reduce the beam losses due to longitudinal mismatch.

INTRODUCTION

The acceleration and bunching scheme of the LANSCE linac contains the following steps (Fig. 1): Both H^+ and H^- DC beams are accelerated by their respective Cockcroft–Walton (CW) generator to 750 keV. An H^- beam chopper creates the desired timing structure for different user facilities, and the WNR beam goes through an additional low-frequency buncher [1]. Afterwards, both species are bunched by their respective Pre-Buncher (PB) before entering a common Main Buncher (MB). The bunchers transform the DC beam into the basic 201.25-MHz micro-bunch structures before the beam enters the Drift Tube Linac (DTL). During operation, around 20-30% of the beam falls outside of the DTL longitudinal acceptance and is lost in the DTL. Furthermore, since the beam fills almost the whole phase range of the initial DTL acceleration bucket, halos and tails could easily form from a longitudinal mismatch in the subsequent accelerating modules in both DTL and the 805-MHz Side-Coupled Cavity Linac (CCL).

To clean up the tails and halos generated by the longitudinal mismatch, it normally takes operators 1-2 weeks to fully ramp up the current and lower the beam losses to acceptable range every year after the initial physics tune-up. Empirically, the first three of the four DTL modules were adjusted the most to reduce tails/halos formed in the early stage. LANSCE relies on the physics tune-up at the beginning of each run cycle, as we still yet cannot reliably return to past stable operation points. However, the physics tune-up procedures do not currently address the halos/tails. For the DTL, an absorber/collector pair [2] is used to measure the beam current above a given energy threshold under a phase scan. The present procedure only considers three measured parameters: the Full Width Half Maximum (FWHM), which represents the phase width of the acceleration bucket, the relative phase in the bucket, and peak-to-valley ratio (PVR) for the first module to constrain the effects of the bunchers. For the CCL, we use Beam Position and Phase Monitors (BPPMs) for signature matching of a phase scan. This ensures the beam, on average, is correctly accelerated [3]. However, this method does not easily demonstrate the picture of the longitudinal capture. While many other facilities rely on power measurements for each cavity to return to known amplitude setpoints, LANSCE has also attempted such effort [4]. However, LANSCE has yet to reliably reproduce cavity amplitude setpoints based on power measurements due to aging cavities and the problematic performance of klystrons [5]. Therefore, beam-based signature matching is the only reliable method for us to determine the amplitude setpoints of each CCL module.

Therefore, an online multi-particle model for the physics tune-up is critical for LANSCE to reduce the initial optimization time by operators for every run cycle. In this proceeding, we present an online software tool based on the GPU-based HPSim [6-8] that quickly converts the phase scan results into intuitive pictures of the longitudinal capture.

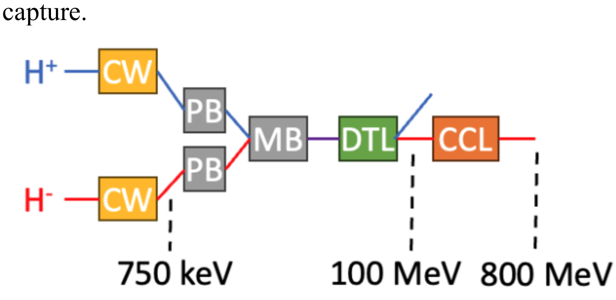

Figure 1: A schematic of LANSCE acceleration and bunching scheme. Both H^+ and H^- beam go through their respective Cockcroft–Walton (CW) generator and Pre-Buncher (PB), and merge into the same Main Buncher (MB). The beam delivered to WNR also goes through a Low Frequency Buncher (LFB) before the PB. The Drift Tube Linac (DTL) accelerates both H^+ and H^- to 100 MeV while the Side-Coupled Cavity Linac (CCL) accelerates H^- to 800 MeV.

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ONLINE HPSIM MODEL

While HPSim is the powerhouse for the simulation, several internal python modules are integrated into the online model to analyze the phase scans and applies the EPICS readbacks (Fig. 2).

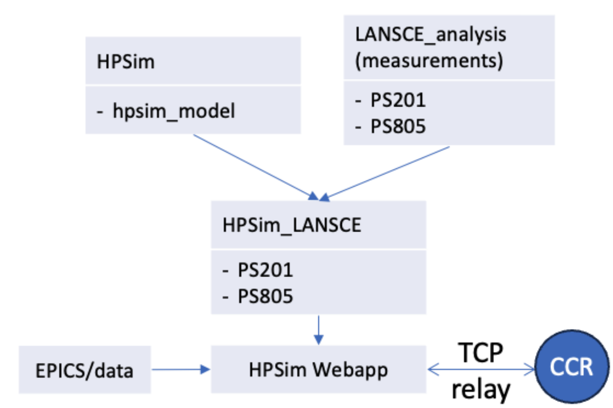

Figure 2: The software structure for the HPSim online model aiming to help the physics tune-up of the linac. See text for more detail.

Backend Structure

HPSim is a GPU-based multi-particle model developed at the Los Alamos National Laboratory. The major computation happens in the CUDA© core, which is wrapped with a C++ layer that process the serial procedures and create a python binding library. An additional python layer is built upon the binding library to provide user-friendly interface. HPSim is designed to quickly monitor the machine status, and therefore, HPSim takes inputs from the EPICS channels and uses pre-determined calibrations to derive physical quantities. A new `hpsim_model` class was recently added to allow fast setup of HPSim using a YAML configuration file.

A separate internal python module `hpsim_lansce` establishes the phase scan routine for the DTL (PS201) and the CCL (PS805) based on the actual measurements provided by the `lansce_analysis` module, which provides basic measurements of the phase scans. For the DTL, it calculates the FWHM, the relative phase, and the PVR. For the CCL, it uses a single-particle model to fit the measured phase scan and obtains fitted incoming energy offset, phase offset, and the module's RF fractional amplitude compared with the design value [3]. Figure 3 shows the importance of determining the longitudinal RF bucket and the bunch size using a multi-particle simulation. It is not uncommon for LANSCE to have a lower RF amplitude at module 5, the very first module of the CCL, due to insufficient klystron power. With the RF amplitude set to 90% of the design value, significant longitudinal tails would develop. Without an online model, operators would spend weeks to clean up the tails or evenly spread the tails (i.e., beam losses) along the linac to keep local radiations under the limit. The CCL phase scan analysis using HPSim is presented in another proceeding [9].

Phase Scan Under HPSim

For the DTL, six phase cans are normally conducted to adjust the amplitude and phase setpoints of six RF cavities, that is, PB, MB, and the four modules in the DTL. For module 2-4, a specific absorber/collector pair designed for their respective output energy is used. The FWHM and the relative phase are very good indicators of the longitudinal capture, and therefore, the fitting process is straight-forward. However, the phase scans of the PB, MB, and the module 1 trio are much more unsettled. First, they do not have a distinctive absorber/collector pair designed for the module 1 energy output at 5.44 MeV. They utilize the absorber designed for module 2. Since this absorber was designed to reject beam with energy below 36 MeV, there is no current on the collector. Therefore, for the PB/MB/T1 trio, it relies on past simulations of the beam transmission (or beam losses equivalently) through module 2.

Moreover, while the standard procedure only considers the FWHM, phase offset, and PVR (to a lesser degree), the interplay between MB/PB/M1 creates various shapes of the phase scan. The physics tune-up aims to create a square-like phase scan, indicating that the bunch is well contained within the acceleration bucket. However, analyses of past phase scans at the end of run cycles show that the scans appear more triangular, indicating the beam is over-bunched by the MB and PB before going into the DTL.

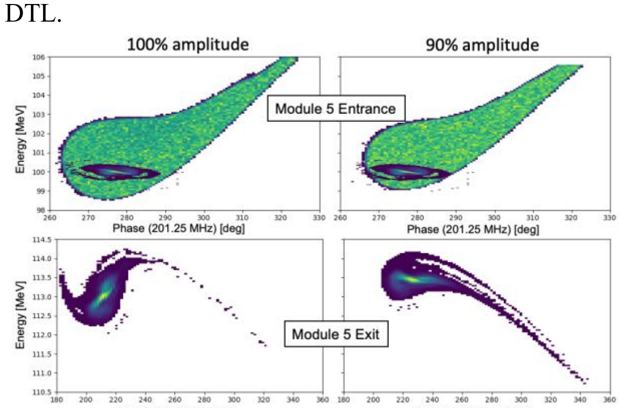

Figure 3: An example of the importance to determine the bunch size and the acceleration bucket at module 5, the first module of the CCL. The left column is for the RF amplitude at 100% of the design value, while the right column is at 90%. The top row is at the entrance of module 5 with the corresponding acceleration bucket, while the bottom row is the simulated bunch in energy and phase. With aging klystrons and the insufficient power, an online model during the physics tune-up is critical in balancing the klystron power limits and the beam quality.

Figure 4 shows an example of the phase scan aiming to tune up the MB while the PB is off. Since the amplitude and phase setpoints at LANSCE are not calibrated numbers with physical meaning, the software keeps the setpoints from EPICS untouched while changing the calibration values during the fitting. The simulated scan was first aligned with the measurement via the FWHM and phase offset from the standard procedure. Afterwards,

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optimization based on either `scipy` or `Xopt` [10] is conducted with user-selected variables.

To generate the acceleration bucket of each module after a fit to the data, the beam is simulated up to right before the module (for MB and PB, only the capture into M1 is considered), and an even distribution of random energy and phase values are assigned to the particles. The beam is then propagated through the module, and a mask is created via selecting the particles that are not lost and above a certain energy threshold, depending on the module. The mask is then applied to the original random energy and phase distribution to mark the particles that are properly accelerated. A contour in the energy and phase parameter space is drawn to show the acceleration bucket. We currently align the left edge of the phase scan with the left edge the bucket. The incoming beam distribution is also plotted to demonstrate the capture.

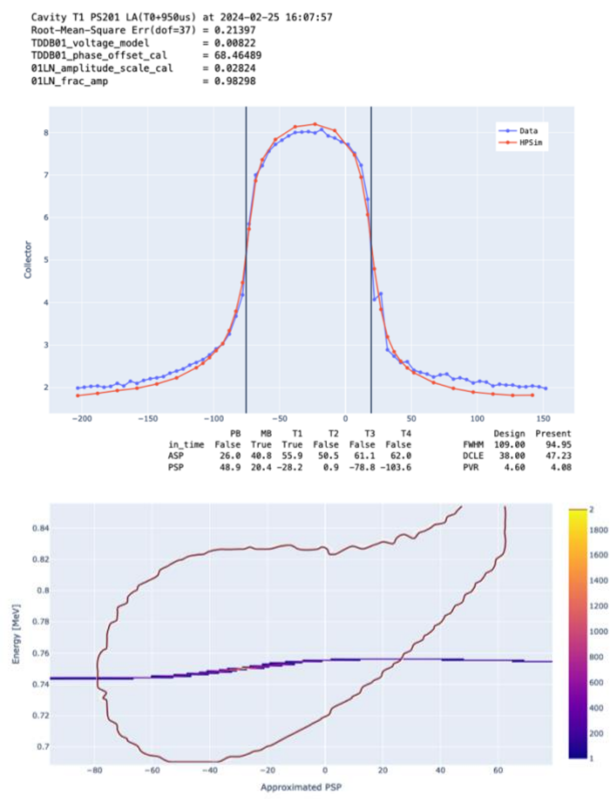

Figure 4: An example of the DTL phase scan with the focus on the MB tune-up. The top figure shows the phase scan comparison of the measurements (blue) and the simulation (red). The bottom figure shows the simulated acceleration bucket and the bunch size. At this stage the PB is off, so the beam appears much less bunched.

Frontend Webapp

We adopted the open-source python package `streamlit` for quick development and a simple and intuitive interface. The webapp and the backend HPSim simulations run on a GPU dedicated server which is external to the accelerator network. We can reach this server by utilizing a socat TCP relay to pass packets between the networks. This relay/process is always running to allow on-demand access to the webapp. The webapp can upload measurements from the accelerator network. Beam physicists can choose the measurement file and determine which calibrations to use for fitting. Both plots in Fig. 4 are shown in an interactive mode. After the fitting, a new YAML configuration file, containing the present EPICS values and the new calibration numbers, is created. The new configuration file will be loaded in preparation for the next module. With all the calibration numbers determined, another existing web-based application can run as an online monitor to predict the beam distributions at the end of the linac or at target stations. The beam distribution can also be compared with the Low Momentum Detector, currently under installation at the end of the linac for benchmark.

CONCLUSION

Due to aging, insufficient diagnostics, and other issues, the LANSCE accelerator cannot return to the prior year's stable operation immediately, but an initial physics tune-up must be conducted every year. The current tune-up procedure that relies on a few simple derived variables is inadequate in addressing the formation of beam halos and tails, especially with changing klystron capability year over year. In this proceeding, we demonstrate an online multi-particle model built upon HPSim that can align the simulations with actual measurements during the physics tune-up process. This will help the beam physicists determine the capture quality by each module and use it as virtual diagnostics to observe output beam distributions. We have demonstrated it with historical data and will experiment it during actual tune-up in the upcoming run cycle(s).

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