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LINAC MODULE PHASE SCAN IN HPSim*

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Abstract

The side-coupled cavity linac (CCL) at the Los Alamos Neutron Science Center (LANSCE) is tuned by matching a single-particle model to the RF phase signature of the modules. In the future, the High-Performance Simulator (HPSim), a GPU-powered, 6-D particle tracking code, will be used to reveal additional information that will assist with tuning. In this proceeding, the status of the HPSim-based Phase Scan Signature Matching (PSSM) routine is presented, along with the outlook for its future implementation.

INTRODUCTION

The LANSCE accelerator at Los Alamos National Laboratory (LANL) supplies beam to five user facilities and simultaneously accelerates H^+ and H^- [1]. The CCL is made up of 44 accelerating modules, which accelerate the H^- beam from 100 MeV to 800 MeV (Fig. 1). The 805-MHz RF field that powers each module is supplied by a different klystron, causing the amplitude and phase of the RF inside one module to be independent of all others. As a result, each module must be tuned individually before the start of the run-cycle. PSSM is used to tune the CCL modules, in which the phase of the H^- beam after a module is measured while the RF phase is scanned over a full cycle [2]. A fitting algorithm then attempts to match the output of a single-particle model to the measured phase scan signature to extract parameters necessary to tune the module.

The High-Performance Simulator (HPSim) code will compliment the single-particle model used in PSSM by revealing additional information about the tune. HPSim is a 6-D particle tracking code that is powered by GPUs [3]. The code was developed at LANL and contains a detailed model of the LANSCE linac. The signature feature of HPSim is its speed, which allows it to be used as an online simulation tool to assist with beam recovery during startup [4, 5]. HPSim can give information about the bunching and RF capture quality that the single-particle model cannot. In this proceeding, it is shown that HPSim reproduces an archived phase scan signature measurement as accurately as the single-particle model, while also retaining the full 6-D beam distribution.

CCL MODULE TUNE-UP

Tuning a CCL module amounts to ensuring the RF field amplitude and output beam energy are at the design values and that the beam exits the module properly bunched. The two "knobs" available for tuning are the RF amplitude setpoint (ASP) and phase setpoint (PSP). Although neither is

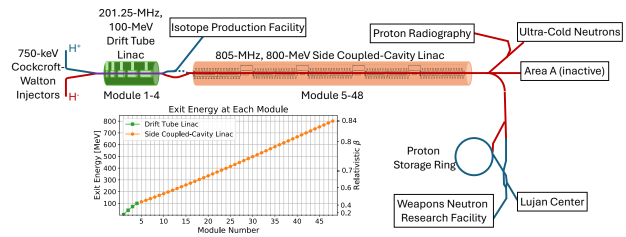

Figure 1: The LANSCE accelerator and user facilities.

calibrated to match the actual value, there is a one-to-one relationship. Tuning a CCL module is an iterative processes that uses PSSM to determine the correct ASP and PSP.

Phase Scan Measurement

PSSM requires the beam phase to be measured at a point after the module. A beam position and phase monitor (BPPM) measures the phase of the beam relative to a 201.25-MHz reference signal (Fig. 2). First, the RF is turned off, and the BPPM measures the phase of the beam after it drifts through the module. Then, the RF is turned on, and the BPPM measures the phase of the accelerated beam while the PSP for the RF is scanned between $\pm 180°$. The difference between the phases measured with the RF on and off is plotted over the range of PSPs to produce the phase scan signature curve.

Phase Scan Signature Matching

A fitting algorithm then attempts to reproduce the phase scan signature with a single-particle model. An example of a fit for CCL module 5 is shown in Fig. 3. The fit is used to extract three parameters: the fractional amplitude of the RF field, the input beam energy offset, and the input beam phase offset. The best-fit values of those parameters are used to calculate the output energy of the beam at each

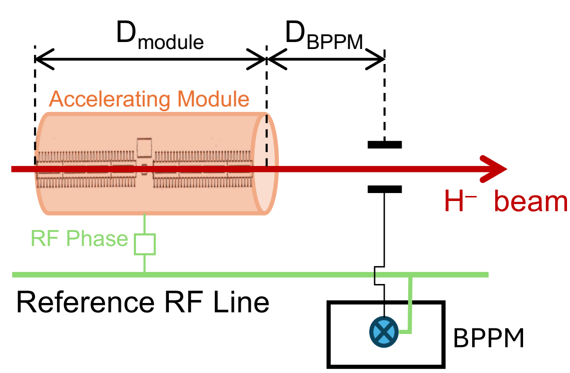

Figure 2: Phase scan measurement setup.

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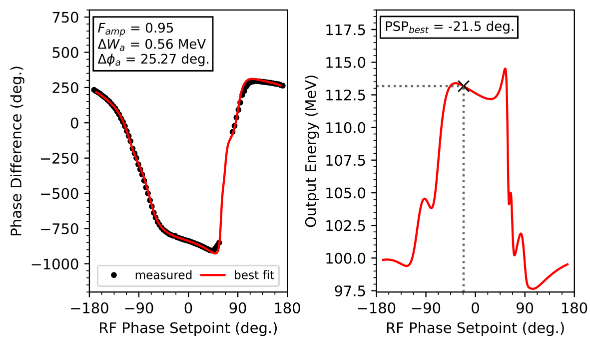

Figure 3: PSSM results for CCL module 5.

PSP. The fractional amplitude from the fit indicates whether the ASP should be increased or decreased. During tune-up, the ASP would be adjusted accordingly, a new phase scan measurement would be taken, and PSSM would be repeated until the fractional amplitude is close to 1. After the correct ASP has been found, the optimal PSP is determined by comparing BPPM phase measurements with design values, which should give the correct output energy of the module.

The optimal PSP corresponds to a point where the output energy matches the design value (113.17 MeV for module 5) and where the slope is negative and away from the edge where the output energy falls off rapidly. This ensures the beam is on the bunching side of the RF and that small adjustments to the PSP by operators will not move the beam to the de-bunching side. The energy and phase offsets of the input beam are useful as diagnostics and for determining whether the previous module needs re-tuning.

The single-particle model used for PSSM exists as an in-house Python class. It contains a number of methods used to transport a single particle through the numerous cells and drifts inside each CCL module. The method used as the fit function takes the fractional RF amplitude and the energy and phase offsets at the input as arguments and calculates the energy and phase of the particle after the module. The best fit to the phase scan signature is found using the curve fitting routine included in the SciPy optimize Python package [6].

PHASE SCAN SIGNATURE MATCHING WITH HPSIM

Though the single-particle model is faster, HPSim will be a complementary tool to verify the quality of bunching and capture by the module. HPSim generates a 6-D beam distribution and takes into account the effects of transverse motion and space charge. For a phase scan simulation, HPSim creates a beam distribution from archived emittance measurements and transports the beam to the entrance of the CCL module. To compare with the single-particle model, the energy and phase of the distribution at the input are transformed so that the mean values match the designs for that module. For module 5, the design input energy is 100 MeV, and the design phase will be defined here as 0°. The 6-D

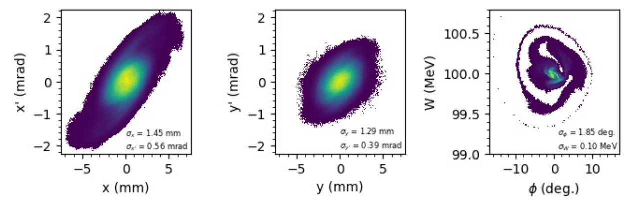

Figure 4: 6-D phase space of the design H^- beam at the input to CCL module 5.

phase space of the design beam input to CCL module 5 is shown in Fig. 4.

At the start of a phase scan simulation, HPSim applies the user-provided energy and phase offsets to the design beam. The beam is transported through the module once with the RF amplitude set to zero (no acceleration). Then, the RF amplitude is set to the product of the design value and the fractional amplitude (also provided by the user), and the simulation is repeated until the PSP has been scanned between $\pm 180°$ in 5° intervals. The beam phase at the location of the BPPM is recorded at the end of each run. Because of the limited longitudinal capture of the CCL modules, particles within the halo and tails of the beam fall out of the RF bucket and become separated from the core by the time it reaches the BPPM. As a result, taking the average of all particle phases gives an erroneous centroid. Instead, the average phase is calculated from particles contained within

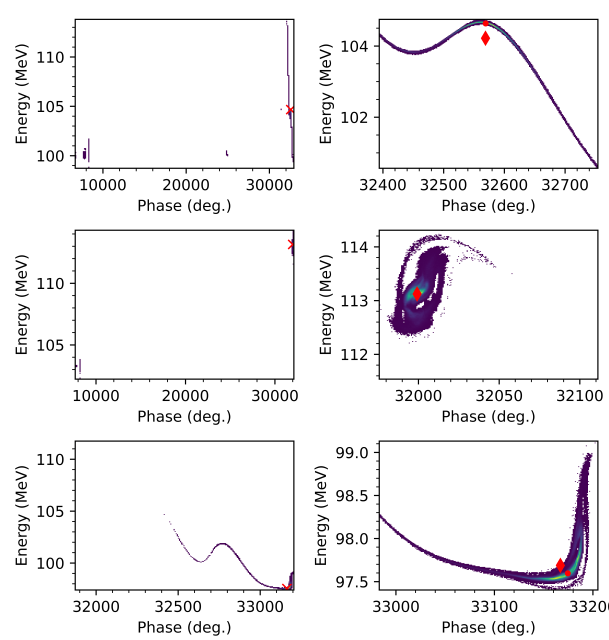

Figure 5: Longitudinal beam distribution at the BPPM. Each row is for a different PSP. The left plots show all particles in the distribution, and the right plots show the core region. The highest density bin in the left plots (red "x") is used to identify the core. In the right plots, the red diamond represents the average within the core region, and the red dot represents the HPSim reference particle.

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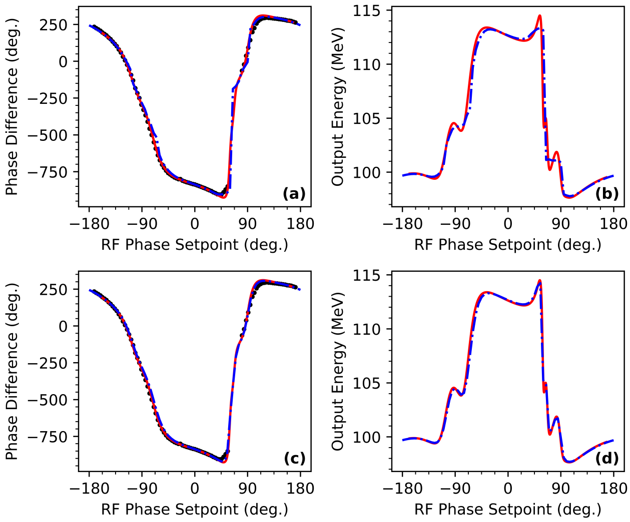

Figure 6: HPSim phase scan (blue) superimposed over the measurement (black dots) and fit (red) from Fig. 3. Phase difference and output energy (a,b) averaged over the core region and (c,d) of the HPSim reference particle.

a 360°-wide region of phase space centered on the beam core.

Figure 5 shows the longitudinal phase space of all particles and those within the region around the core for three PSPs. For each PSP, there are some particles that have fallen out of the acceleration bucket. Excluding those particles from the averaging gives a phase centroid that is representative of the part of the beam of interest. One also sees that the phase and energy centroids of the core region are close to the reference particle in phase space.

HPSim was run with different values of the fractional RF amplitude and input energy and phase offsets until a combination that produced a phase scan signature that closely matched the measurement in Fig. 3 was found. The output of the most closely-matching simulation is shown in Fig. 6. The simulated phase scan signature is plotted for the phase centroid of the core region and for the phase of the HPSim reference particle. The core-averaged and reference particle phases both match the measurement well. It cannot be said which gives the more accurate output energy, as there is no measurement to compare to, but the reference particle energy closely matches the output energy curve for the single-particle model, as one would expect.

The core-averaged output energy matches the general shape of the single-particle model curve, but the local peaks and valleys appear to have been smoothed out. This smoothing effect could be explained by the de-bunching that occurs for certain PSPs, as seen in Fig. 5. The fractional RF amplitude and energy offset that produced the best fit for the single-particle model also produced the best fit in HPSim; however, the phase offsets differed by about 8°. This discrepancy is interesting, considering how closely the two models agree on the fractional RF amplitude and energy offset. The difference in the phase offsets is approximately equal to the width of the H^- beam and may be due to ambiguity in how the the origin of the phase axis is defined. The exact reason for this disagreement will be investigated in future work.

CONCLUSION

It has been shown that HPSim can accurately reproduce a measured phase scan signature while also providing the full 6-D distribution of the beam. In order for HPSim to be utilized effectively, an algorithm must be developed to find the fractional RF amplitude and energy and phase offsets of the input beam that produce the most closely matched phase scan signature. The effect each parameter has on the shape of the phase scan signature curve will be investigated in detail so than an efficient PSSM algorithm can be developed for HPSim. The criteria used for defining the "good" particles in the beam with which to calculate the phase centroid could also be refined.

The method used in this work inarguably captures all particles of interest when the beam is well bunched, but when de-bunching occurs, the definition of good particles becomes ambiguous. A better understanding of the BPPM measurement will be acquired so that the region-of-interest can be refined to reflect what is detected by the BPPM. The work outlined in this paper is an encouraging first step towards implementation of HPSim in PSSM. With some refinement and testing, HPSim promises to be a useful tool that will expedite beam recovery and tune-up for the CCL at LANSCE.

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