USE OF A DEBUNCHER CAVITY FOR IMPROVING MULTI-BEAM OPERATIONS AT LANSCE*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) simultaneously provides both H^- and H^+ beams to several user facilities. Opposite polarity beams are usually accelerated in the linac during the same macropulse when beam-loading limits are not exceeded. Presently, the Weapons Neutron Research (WNR) H^- and Isotope Production Facility (IPF) H^+ beams are accelerated simultaneously during the same macropulse. The amplitude of the cavity field in the last 201-MHz buncher, located in the common transport just upstream of the DTL, is a compromise between the optimal values for each beam. Recent beam dynamics studies have shown that implementing a debuncher cavity in the H^- low-energy beam transport would allow for more optimal operation of both beams. For this application where space is limited, a compact 201-MHz quarter-wave cavity will be used. This paper will report on the beam dynamics simulations performed and the quarter-wave cavity design being developed to address this issue.

INTRODUCTION

The LANSCE facility comprises a pulsed, 800-MeV proton linear accelerator (linac) and proton storage ring (PSR) along with several target areas. The accelerator consists of two structures, a 201.25 MHz, 100 MeV drift tube linac (DTL) and an 805 MHz, 800 MeV coupled cavity linac (CCL). The DTL receives 0.75-MeV beams from both H^+ and H^- injectors. To best utilize the available linac duty factor, both beam species are accelerated simultaneously during the same macropulse when beam-loading limits are not exceeded. An example of duty factor sharing is the simultaneous operation of the Isotope Production Facility (IPF) H^+ beam and the Weapons Neutron Research (WNR) H^- micropulse beam.

Immediately upstream of the DTL there is a short, ~2 m, common beam transport where a 201.25-MHz single-gap buncher cavity, aka Main Buncher (MB), is located. The MB provides most of the longitudinal bunching required by all beams, except WNR, for efficient capture by the DTL. There is also a second identical cavity in each upstream transport to further increase capture for these beams. In contrast to the beams containing a contiguous string of micropulses at the linac base frequency, the typical WNR beam can be characterized by individual micropulses separated by ~1.8 µs. It relies predominantly on a 16.77-MHz buncher, aka low-frequency buncher (LFB), to squeeze 2-3 times the charge of a normal 201-MHz bunched beam micropulse into a single, 201-MHz rf bucket. The transport layout is shown in Figure 1. The MB provides a fixed field during a macropulse, with the set point chosen to best match the beam species into the DTL. However, during simultaneous H^+ and H^- operation the field setting is, in general, a compromise for both beams. This is especially true for the simultaneous IPF and WNR beam operation, where maximum capture requires high and low field amplitudes, respectively. In the present configuration, the MB must be operated at a high cavity field for low-loss operation of the higher-current IPF beam. Therefore, the focus was on modifications that could be made to improve the WNR beam performance.

One possible improvement would be to employ a debuncher cavity in the H^- low energy beam transport (LEBT) just prior to the common transport line. The debuncher would be used to effectively offset the deleterious effects of the MB on the WNR micropulse beam and thereby allow for more optimal operation of each beam.

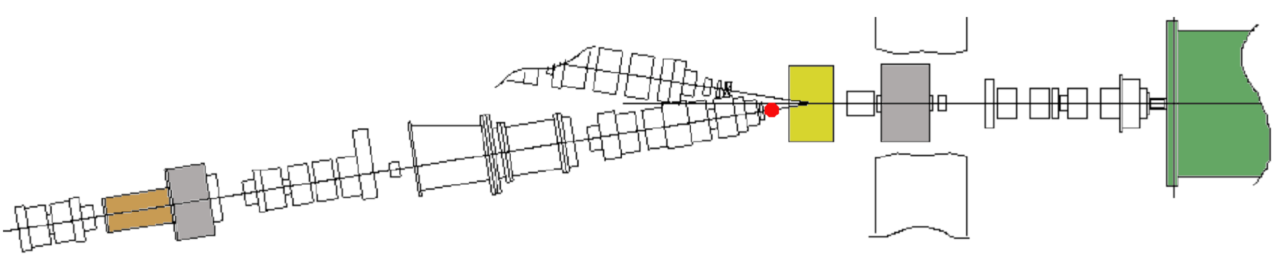

Figure 1: The LANSCE 0.75-MeV beam transport showing portions of H^-, H^+ and common lines. The beams move from left to right with H^- on the lower line and H^+ on the upper line. Also shown is Tank 1 of the DTL (indicated in green) on the far right. The common transport line is located between the merging dipole (shown in yellow) and the DTL and contains the MB (shown in gray). The H^- LEBT contains two additional bunchers, a 201.25 MHz device similar to the MB (also shown in gray) and a 16.77 MHz device (LFB) (shown in orange). The debuncher location is indicated by the red dot.

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BEAM DYNAMICS SIMULATIONS

The multi-particle beam dynamics code PARMILA [1] was used to investigate the effectiveness of a debuncher cavity in the H^- LEBT for improving the performance of the WNR beam. The PARMILA model begins at the start of the 80-keV transport following the ion source, proceeds through the 670-kV Cockcroft-Walton column and the 750-keV LEBT to the end of DTL tank 2, i.e. 40 MeV. This was done to include all aspects of the formation, i.e. chopping and bunching, of the WNR micropulse created in the 750 keV LEBT prior to injection into the DTL. Because PARMILA does not possess either DC column or slow-wave chopper elements, these functions had to be applied to the particle distributions separately, as intermediate steps in the overall simulation. The simulations were performed through the end of tank 2, so as to obtain an accurate estimate of the effect of the debuncher on beam capture (capture = ratio of accelerated beam/injected beam).

Baseline Model

Most beam line element parameters, e.g. transverse focusing element strengths, buncher amplitudes, etc., were taken from set points used in production beam operations. The field strength of the 750 keV LEBT quadrupoles and 80 keV LEBT solenoids were established for the higher average current H^- beam operation to PSR. The 201-MHz buncher cavity field amplitudes were estimated from operational setpoint values, i.e. drive powers, using measured Q and calculated field, power and Q values. Actual operating values for the DTL tank phase and amplitude settings were not available so these parameters were set at design values in the simulations. (Results from previous studies suggest that actual operating values are typically slightly lower than design.)

The initial transverse beam emittances were extracted from measurements made in the 80 keV transport. Although the actual peak beam current is ~15 mA, an effective peak current of 1 mA was initially used in the simulation over most of the transport to reflect the high degree of neutralization that is observed during operation with the standard H^- macropulses.

The model was validated by first simulating the capture of the standard H^- PSR beam. The simulation and measured results were in reasonable agreement. The simulated beam capture was 88% while the actual capture ranges between 80 – 83%. The larger simulated capture is likely due to several factors including actual field amplitudes in DTL tanks 1 and 2 that are below design, errors in buncher field values and uncertainty in the beam neutralization that actually exists along the transport.

WNR Micropulse Beam Simulations

After the basic model was validated, it was then augmented to incorporate the WNR single-beam operation. A traveling-wave chopper and LFB are used to produce a higher intensity micropulse for WNR. The chopper pattern width was set to match that from operations. The MB amplitude corresponded to the operational set point. The LFB amplitude was estimated from gap voltage versus power measurements and operational set points. For the simulation the actual LFB amplitude and the degree of space charge compensation appropriate for the WNR micropulse beam were deduced from a parameter search that resulted in a beam capture (~45%) and peak current that most closely matched measured values (capture ~50%). This established the best capture that could be achieved under the existing beam line configuration. The simulated longitudinal phase space of this beam at the entrance to the DTL is shown in the left panel of Figure 2.

The next simulation was done with a higher MB amplitude that reflected simultaneous IPF (H^+) and WNR (H^-) beam operation. The LFB amplitude was then adjusted for best H^- capture. The simulated WNR capture decreased to ~29% which is ~66% of the capture for WNR single-beam simulation. This reflects the degradation in performance as a result of dual-beam operation. The simulated longitudinal phase space of this beam is shown in the middle panel of Figure 2.

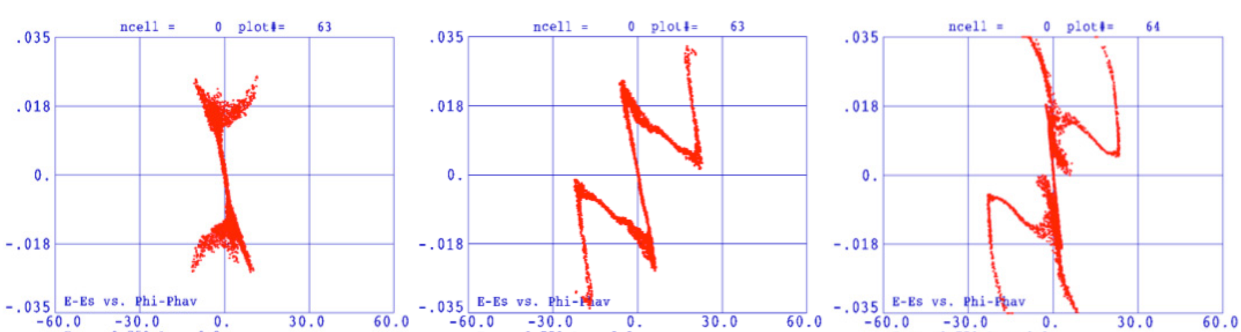

Figure 2: Simulated longitudinal phase space of the WNR beam at entrance to DTL. Distributions for WNR single-beam (left panel), WNR dual-beam (middle panel), and WNR dual-beam w/debuncher (right panel). Energy (ordinate) is in MeV and phase (abscissa) is in degrees of 16.77 MHz.

WNR Micropulse Beam Simulations with Debuncher

At this stage a 201.25-MHz debuncher cavity (DB) was introduced into the simulation in the H^- LEBT just upstream of the common transport as indicated in Figure 1. Its purpose is to mitigate the effect of the MB on the WNR beam capture. The LFB and debuncher amplitudes were adjusted to produce the best capture. The simulation results showed that a debuncher cavity was able to restore the capture to 98% of the WNR single-beam value. The simulated longitudinal phase space of this beam at the entrance to the DTL is shown in the right panel of Figure 2. The results of the simulations suggest that a debuncher cavity could be used to successfully overcome the deleterious effects associated with dual beam operation. With the MB operating at a maximum effective gap voltage of 12 kV, the debuncher required ~6 kV to be effective. The study also indicated that the debuncher cavity became less effective as it was moved further upstream in the H^- LEBT.

DEBUNCHER CAVITY

The optimal location for the DB is in the existing H^- LEBT closest to the common LEBT. Unfortunately, this area is very congested. Limited transverse space exists which makes installation of our standard 201.25-MHz TM_{010} re-entrant pillbox-style cavity impossible. Because a more compact cavity is needed for this location, a 201.25-MHz quarter-wave resonator cavity was selected. This resonator has a coaxial geometry with a central stem that supports a drift tube, and combined with additional half-drift tubes forms a two-gap cavity. The gap spacing, $\beta\lambda/2$ (where β is the normalized velocity of the particle and λ is the free-space wavelength of the rf), is 2.98 cm for 0.75 MeV protons, which allows the cavity to be significantly more compact than the TM pillbox style.

To compare performance with our TM pillbox style MB, a quarter-wave (QW) cavity with the same beam aperture size was designed and evaluated with Microwave Studio [2]. The resultant cavity has a length along the beam axis of ~8 cm, a inner bore diameter of 2 cm and a height of ~29 cm. By comparison the TM pillbox has a footprint of 28 cm length x 50 cm diameter. In the QW cavity the power is dissipated predominantly along the central stem. The transit time factor (TTF) for the QW cavity is 0.80 compared to 0.73 for the TM pillbox. However, the QW cavity (copper) has a lower unloaded Q_u, ~4000, compared to ~22000 for the TM pillbox (copper). The QW cavity model is shown in Figure 3. It requires approximately 2.5X more power for the same total maximum effective gap voltage, E_0TL, than the pillbox.

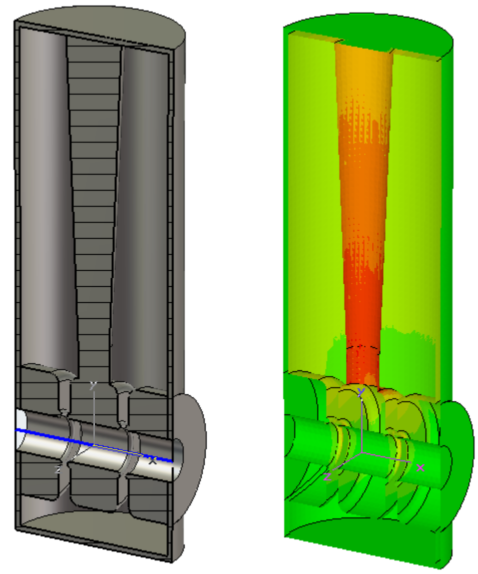

Figure 3: Quarter-wave cavity shown as cutaway and with results of EM model indicating surface currents (higher in red).

In the simulations the debuncher is located close to a quadrupole quadruplet. The beam envelope at this location would require a debuncher cavity with a larger beam aperture than the above model, to ensure beam is not lost on the drift tube. An increase in bore ID to 5 cm results in a lower TTF (~0.47) and higher power requirements for the same maximum V_{eff}. A larger bore will also allow the RF fields to penetrate further into the adjacent beam lines.

SUMMARY

Beam dynamics simulations were performed to study the effectiveness of a debuncher cavity for improving the performance of the WNR H^- beam under simultaneous operation with the IPF H^+ beam. The results of the study showed that a debuncher cavity located just upstream of the common transport could restore WNR beam performance to levels comparable to sole-use operation and therefore be beneficial for multi-beam operation. A compact quarter-wave cavity was designed and evaluated and was found to be capable of providing the requisite voltage while meeting the tight physical constraints.

REFERENCES

[1] H. Takeda and J. Billen, "PARMILA," Los Alamos National Laboratory report LA-UR-98-4478 (revised 2005).

[2] MicroWave Studio, v.2008, CST GmbH, 2007. (www.cst.com)