DIAGNOSTICS FOR THE LANSCE RFQ FRONT-END TEST STAND*

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Abstract

Plans are underway at the Los Alamos Neutron Science Center (LANSCE) to replace the existing H^+ Cockcroft-Walton injector with a modern 4-rod Radio-Frequency Quadrupole (RFQ) based front end. This will provide protons for injection into the downstream linac, where H^- ions are also accelerated. This dual-species operation of the linac imposes constraints on the injectors, resulting in particular requirements on the transverse and longitudinal emittances and phase-space distributions of the beam from the RFQ proton injector. Good measurements of these quantities are therefore required during the testing phase of the RFQ injector. In this paper we describe the measurements to be made and plans for the systems for carrying out the measurements.

INTRODUCTION

The existing injectors at LANSCE for protons and H^- ions are based on Cockcroft-Walton (CW) generators and have been in use since the initial construction circa 1970. These CW-based injectors provide unbunched beams of protons and H^- ions at 750 keV with very little uncertainties in the beam energies. Precise matching of the beam energies is required for good dual-beam operation of the subsequent portions of the linac consisting of drift-tube linac (DTL) and coupled-cavity linac (CCL) sections. Additionally, the high average currents of the beams require good transverse matching from the injectors into the DTL to prevent large beam spill that results in high radiation fields.

An effort is underway to replace the proton injector with an RFQ-based system [1]. The initial phases of commissioning this system will involve operation in a test stand to characterize the system and to ensure that it operates as desired prior to installation in the production environment.

The present 750 keV beam-transport lines from the CW injectors to the DTL are rather long, at about 16m. The two beam species are merged in a 9° dipole magnet about 2.3 meters upstream of the DTL and pass through an RF buncher and a 4-quadrupole matching lens in the common section after the merging magnet. The 18° separation between the two beamlines upstream of the merging magnet limits the transverse space available for equipment in the two beamlines. For this reason, the RFQ must be placed rather far upstream of the DTL, about 4 meters. This distance, combined with the large energy spread of the beam produced by the RFQ, necessitates the use of 2 additional RF bunching cavities in the new proton transport line (shown in Fig. 1) in order to maintain a bunch length that will fit easily into the acceptance of the DTL. For this reason it is imperative that we measure the longitudinal bunch shape of the beam; ideally a full longitudinal phase-space distribution would be measured.

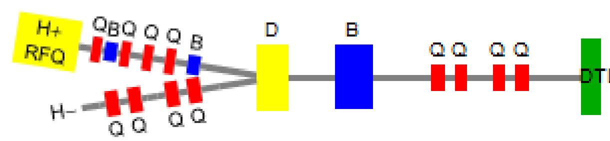

Figure 1: The proposed beam transport line from the proton (H^+) RFQ to the DTL. Also shown is a portion of the H^- transport line. Beamline elements are denoted by letters: Quadrupole magnets (Q), Dipole magnets (D) and Bunchers (B). Three of the bunchers are quarter-wave resonators, and one is a larger pillbox-style cavity.

The stringent requirements on the performance of the system drive the requirements for beam-measurement systems. In particular, we intend to measure beam current, transverse phase space, longitudinal bunch shape, and energy. The diagnostic systems for characterizing the beam produced by the new injector are described in the following sections.

TEST STAND

The RFQ-based proton injector will consist of a duoplasmatron proton source, a 35 kV accelerating column, a two-solenoid low-energy beam transport (LEBT), the RFQ, and a 750 keV medium-energy beam transport (MEBT) to the DTL.

We plan a phased approach to development of the RFQ test stand. The first phase will allow characterization of the LEBT that will transport the 35 keV beam from the source and extraction column to the entrance of the RFQ. The second phase will allow measurements of the beam delivered by the RFQ to assess its performance. The third phase will test the MEBT that will transport the beam from the RFQ to the DTL. Figure 2 shows the test stand phases and the associated beam measurements.

In the first phase, where the beam is not bunched, beam current and transverse emittance are of greatest importance. The beam energy is determined by the column voltage which can be measured precisely. The current and emittance provide input to models of the beam evolution in the LEBT. These models will be used in the process of transverse matching of the beam into the RFQ. We plan to have an emittance-measurement station near the middle of the LEBT; this apparatus will remain in place when the system transitions to the production

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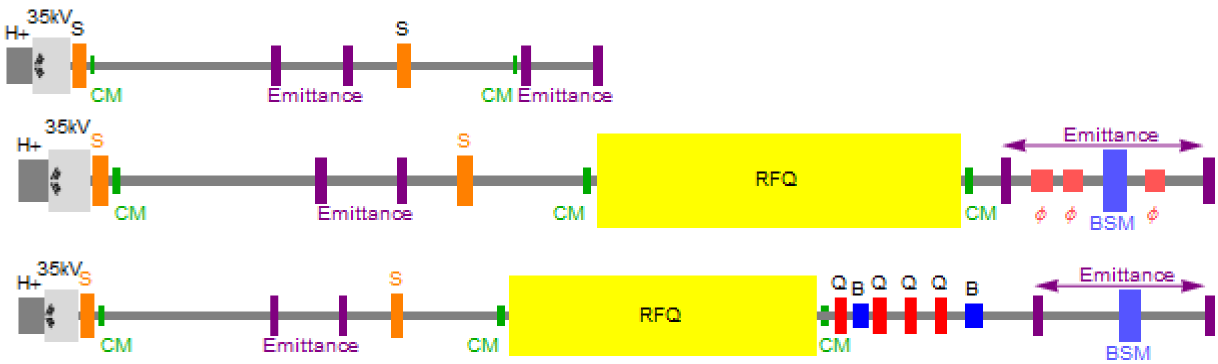

Figure 2: Phases 1 (top), 2 (middle), and 3 (bottom) of the RFQ test stand. Shown are the H^+ source, the 35kV accelerating column, two solenoid magnets (S), quadrupole magnets (Q), bunchers (B), beam-current monitors (CM), bunch-shape monitors (BSM), beam-phase monitors (ϕ), emittance-measurement stations, and the RFQ. Phase 1 allows testing the performance of the source and LEBT, including transverse matching into the RFQ. Phase 2 allows assessment of the RFQ performance, and Phase 3 allows characterization of the MEBT.

environment. An additional emittance station will be placed at the eventual location of the RFQ entrance. This will allow a direct measurement of the transverse phase space of the beam and provide a test of our models for predicting the match based upon measurements with the upstream emittance station.

The transverse evolution of the beam in the LEBT depends strongly upon space charge. The presence of multiple ion species (H^+, H_2^+, H_3^+) complicates modeling of the beam. We plan to remove most of the contaminating species near the middle of the LEBT in order to simplify the modeling of the beam within the RFQ. Beam-current monitors will be placed at a few locations along the LEBT, with one very close to the RFQ entrance.

TRANSVERSE PHASE SPACE

Presently at LANSCE we use several slit-and-collector emittance-measurement systems [2] in the 750 keV transport lines. These have proven to be very successful in tailoring the beams for injection into the DTL and for establishing other transverse conditions needed for proper beam bunching and collimation.

The slit-and-collector technique requires device actuators and many channels of analog signal conditioning and digitization; therefore they are costly. They also require scanning the slit across the beam, so a single measurement requires many beam pulses, making a single-pulse measurement impossible. However they also provide a complete phase-space measurement, allow an direct comparison to our existing LEBT performance, and the ability to distinguish the desired proton beam from other ions that are produced by the duoplasmatron proton ion source [3]. Additionally we have a great deal of experience with dealing with the subtleties of emittance measurement with this type of device, in particular the influence of secondary electrons produced by the beam interactions with the slits and collectors. While this type of scanner is relatively expensive to produce, several spares exist at LANSCE that can be exploited for the RFQ test stand.

Two other types of emittance measurement systems are under consideration: the Allison-type scanner [4] and the pepper-pot method [5]. These two methods have advantages and disadvantages in comparison to the slit-and-collector method, but the prospect of developing a new system and quickly gaining experience with it make it relatively unattractive from financial and logistical viewpoints.

BEAM CURRENT

Beam-current measurements are necessary for assessing the performance of the injector and provide space-charge information for the models of the beam evolution in the transport system. The LANSCE injectors typically produce 800µs-long beam pulses at 120Hz. The standard beam-current measurements are made using 100-turn toroidal current transformers with integrating electronics to provide an output signal that reproduces the beam-current time structure with a bandwidth of about 100 kHz. This system will meet most of our needs. Additional Pearson-type off-the-shelf current transformers may be used where higher bandwidth is needed for diagnosing problems.

BUNCH LENGTH

We have purchased a bunch-length measurement system [6] from INR and it is currently in fabrication. As mentioned above, the bunch length is a critical parameter for this injector due to the long distance from the RFQ to the DTL. While a full longitudinal phase-space measurement would be necessary to predict the evolution of the bunch, the projection of bunch length can validate models of the RFQ and beam-transport line.

The system will have a resolution of 1° of the 201.25 MHz RFQ frequency; this will fulfill the purpose mentioned above. This type of measurement requires partial interception of the beam by a tungsten wire, so it can be used with minimal impact during production operation.

BEAM ENERGY

Measurement of the beam energy is especially important for this system due to the use of two beam species in the linac. Directing both beams into the center of the linac acceptance provides a less problematic beam downstream in terms of uncontrolled beam spill.

A few options are available, but finding a technique to measure the RFQ output energy with high resolution is difficult. Options under consideration are: 1) magnetic spectrometer, 2) beam phase / time of flight, 3) solid-state detectors with scattered beam particles.

Detecting primary-beam protons scattered from a gaseous or solid target with solid-state detectors has been used previously in the commissioning of RFQs [7,8]. Resolution of a few keV is typical. While high-purity germanium detectors cooled to liquid-nitrogen temperature would be capable of <1keV resolution, this cooling is not possible without interposing some material in the path of the beam particles; this material would harm the resolution and provide a source of uncertainty in the absolute energy measurement.

A time-of-flight measurement using beam phase monitors [9] can provide energy resolution of a few hundred eV. Calibration of the system to provide an accurate absolute measure of kinetic energy is non-trivial, but can be accomplished.

Beam phase measurements can be made with a precision of <0.25°. To preserve this precision, mechanical alignment tolerances need to be about ±40μm. Uncertainties in cables lengths and in RF components could easily spoil the precision. We envision an in-situ absolute calibration using a metal conductor along the center of the beampipe.

The Fermilab PIP RFQ project, [9] used a system of three phase monitors to measure their RFQ output beam energy. Two of them were spaced at about 15 cm to provide a coarse measure of the beam velocity, and another was placed about 56 cm from the first to provide a fine measurement. Precision improves with greater spacing, but two complicating factors increase with the spacing: 1) Uncertainty in the number of RF cycles between the detectors; 2) De-bunching of the beam as it travels. We are evaluating these two factors to determine a set of phase-monitor spacings that will provide acceptable precision and accuracy for our measurements.

While beam-phase measurements can provide a precise measure of the average beam energy, it doesn't easily provide information on the energy distribution. We are evaluating the need for this type of measurement. A magnetic spectrometer is a good candidate to provide information on the energy distribution. To get good resolution in a magnetic spectrometer, two optical conditions are required: a small monochromatic spot size and high dispersion. Additionally, precise information about the path of the incoming beam is required. This can be accomplisheded with a pair of collimating slits. A fine map of the magnetic field is also needed to develop a map of the beam energy versus position at the exit of the magnet.

A magnet designed for use as a low-energy spectrometer is available at LANSCE; it has a bend angle of 120° and the pole faces are oriented to provide good focusing in the bend plane. Initial studies indicate that this magnet could provide sub-keV resolution, though space charge can compromise the resolution considerably.

A multi-wire electronic readout of the system would provide good dynamic range. Sub-millimeter wire spacing would be required in order to maintain resolution. The system used for the emittance scanners is a good candidate for the readout. Another possibility for readout is a phosphor/camera system.

SUMMARY

Several types of measurements are needed on the test stand for the new LANSCE proton RFQ in order to characterize the system performance, especially because of the dual-species operation of the downstream linac. We have identified systems for each measurement that can be implemented without extensive system development.

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