DEVELOPMENT OF A COMMISSIONING PLAN FOR THE APT LINAC*

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Abstract

The Accelerator Production of Tritium (APT) facility [1,2,3] utilizes a high-intensity CW linear accelerator consisting of both normal-conducting and superconducting (SC) RF structures to accelerate a 100-mA CW proton beam to an energy of between 1030 and 1700 MeV depending upon tritium production needs. The accelerator will be commissioned in stages defined by these different normal and superconducting modules. Different commissioning modes developed to set the transverse and longitudinal beam parameters, require pulsed operation of the accelerator over a wide range of beam currents. These stages and modes and the different techniques utilized to tune the phase and amplitude of the modules are described. Beam-dynamics simulations of the tuning process for the phase and amplitudes of the RF structures in the low energy (LE) Linac will be presented.

1 INTRODUCTION

The major considerations in the commissioning of the APT Linac have been addressed in prior papers [3,4] and this paper will describe the present status of this work. The commissioning plan for the APT Linac describes the process through which the Linac components are operated with beam for the first time and the setpoints for the RF structures and magnet power supplies are determined. Each module of the linac will be commissioned sequentially in order of increasing energy. The LE Linac consists of 13 modules including the RFQ and injector. The present plan is to commission the LE Linac in six stages defined by five beam stop locations. A major objective in commissioning the first few stages is to fully characterize the beam properties. At low energies, it is especially important to understand the beam properties to validate the beam dynamics simulation codes or, if necessary, update the codes. The modules and stages for the LE Linac are presented in Table 1. Beam stop designs are under development to support these commissioning stages. The last commissioning stage of the LE Linac includes the first 4 or 5 cryomodules of the SC Linac. This will allow for testing the match between the FODO lattice in the LE Linac and the doublet lattice in the SC Linac.

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Table 1: Commissioning Stages of the LE Linac

Stage	Module (s)	Energy Range (MeV)	Beam Power (kW)
1	Injector	.075	8.5
2	RFQ	6.7	50[a]
3	CCDTL1	6.7 - 10.05	50[a]
4	CCDTL2	10.05 – 21.3	50[a]
5	CCDTL3-6	21.3 – 96.7	10
6[b]	CCL7-11	96.7 – 250	25

[a]The same beam stop will be used for these stages
[b]Includes first cryomodules of HE Linac

The SC Linac will accelerate the beam to 1030 MeV with an option to increase the energy to 1700 MeV. The accelerator layout for 1030 MeV is shown in Figure 1. Initially, the SC linac will be commissioned in a single stage with a 0.1% duty factor beam stop located at 1030 MeV and then to a 2% beam stop located after a 90° achromatic bend.

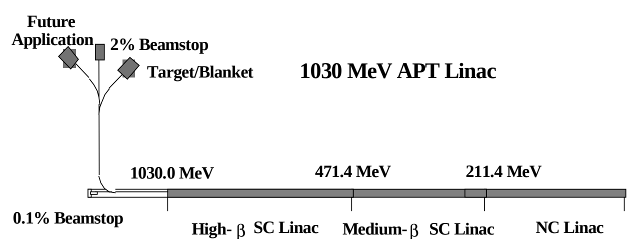

Figure 1: APT Linac Layout for 1030 MeV

There are three cryomodule designs in the SC Linac defined by the velocity interval, β, with the number of cavities and the period length as presented in Table 2. The cryomodules will be commissioned sequentially one module at a time and the high-β cryomodules will be commissioned one klystron at a time.

Table 2: SC Linac Cryomodule and RF Configuration

β	Cavities	Period	Klystrons/ Cryomodule	Cryo-modules
0.64	2	4.88 m	1	6
0.64	3	6.18 m	1	30
0.82	4	8.54 m	2	35

2 COMMISSIONING PROCESS

Commissioning will be done with pulsed beams and cw RF power. The pulse length will be at least 200-μs with a repetition rate from 1 to 10 Hz. The injector and RF systems require up to 100 μs to stabilize depending on peak current. The pulsed beam format will depend on the commissioning procedure. The peak current will initially be very small (< 10 mA) consistent with stable beam operation. Commissioning will consist of the following beam operations as each stage and/or module is commissioned:

- Steering and Alignment - low peak current (< 10 mA) and duty factor (1 Hz and 0.2 ms)
- RF phase and Amplitude Scans - low peak current (< 10 mA) and duty factor (10 Hz and 0.2 ms)
- Increase peak current to 100 mA at low duty factor
- Measure beam properties
- Validate beam dynamics codes
- Develop operations database

The quadrupole gradients will be set according to the beam dynamics model based on precise magnetic field measurements prior to turning on the RF. Checking the alignment and setting the steering will then take place and is expected to be straightforward. Determining the proper setpoints for the cavity phase and amplitude will be a major part of the commissioning process and will be described in detail in the next section. Once the cavity phase and amplitude is set the peak current will be slowly increased to full current. As the peak current is increased, the intent will be to eliminate beam losses and understand the transverse beam profile. Beam losses or beam profiles inconsistent with predictions will identify problems, which may include either component errors or physics effects not included in the beam dynamics model. A major consideration will be whether beam halo requires the focusing lattice to be adjusted from the nominal settings, as is the case at LANSCE. The first stages of the LE Linac, where space-charge effects are especially significant, must be understood because discrepancies between measurements and simulation may indicate problems that could lead to beam loss at higher energies. The same beam stop will be used for the RFQ, CCDTL1 and CCDTL2 (2^{nd} to 4^{th} stages of Table 1). This beam stop, designed to be movable with a beam transport line and diagnostics, will operate at duty factors up to 10%.

A commissioning transport line and beam diagnostic package located just upstream of each beam stop will be developed to measure the beam current, beam loss, transverse beam profile, transverse rms emittance, transverse beam halo, final beam energy centroid, and bunch length. This comprehensive set of measurements of the beam properties will be made after each module in the LE Linac is commissioned and periodically in the SC Linac once all components have been set to their nominal values. These measurements will be used to validate the beam dynamics codes as well as to develop an operational database. While there is inadequate space in the beam line to install the beam diagnostics needed to fully characterize the beam except at the two beam stop locations shown in Figure 1 there will be an assortment of beam profile monitors and beam phase probes throughout the linac. Measurements made with these in-line diagnostics will be correlated and calibrated with the detailed measurements made with the commissioning diagnostics package. The objective is to develop an effective and efficient process by which each module may be turned on and performance validated after a shutdown in the absence of a comprehensive diagnostics package. Various failure modes will be simulated and the beam response will be also measured with these in-line diagnostics.

3 RF PHASE AND AMPLITUDE SCANS

The cavity RF amplitude and phase in a given module are optimized by changing the cavity phase and measuring the detected beam signal for different cavity amplitudes. Different phase scan methods are presently under investigation for the different modules. These include:

- Absorber Collector
- Phase Measurement (single phase probe)
- Energy Measurement (two phase probes)

One or more of these techniques will be used to commission the RF structures. Simulations of the commissioning process for the RF structures have been performed for each module of the APT Linac using combinations of these techniques to determine the most effective and efficient approach to commissioning each module. Each of these techniques is described below.

The absorber collector measures the beam transmission through a degrader placed at the end of a module. The thickness is chosen to be the range of a proton a few MeV less than the nominal output energy of the module. The measurement of the transmission as a function of the cavity phase produces a curve as shown in Figure 2. The FWHM and the phase of the 50% transmission are determined from simulation of the ideal module. The RF amplitude and phase are then adjusted to achieve these design values. This technique is very straightforward but is suitable only on the LE Linac at low beam power.

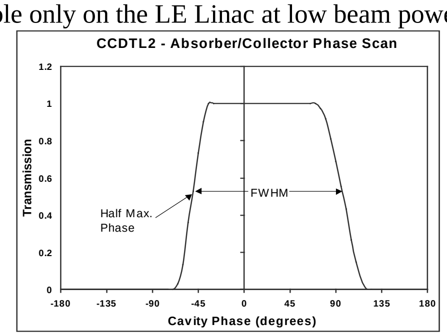

Figure 2: Absorber Collector Phase Scan

Phase scans using a single phase probe measurement result in a curve of the beam phase measured at the phase probe as a function of the cavity phase adjustment. The placement of the probe is at an odd multiple of 90° phase advance in the module. At this location the beam phase is insensitive to small changes in the RF phase resulting in a characteristic curve as shown in Figure 3. This technique appears best suited to the CCDTL structures where the total phase advance ranges between 360 and 1000 degrees and there are many intertank locations where a probe can be located. Figure 3 shows the results after cavity 172 although it is cavity 173 where the phase measurement shows little sensitivity to the cavity phase at the nominal amplitude. The beam phase is insensitive to cavity phase at a unique amplitude of 1.024 nominal as shown and this curve intersects the curve for the nominal amplitude at a phase of –7.66°. This information, obtained from simulations of the ideal machine, is used to define the RF amplitude and phase setpoints for this module. The procedure would be to identify the "signature" curve corresponding to an amplitude of 1.024 nominal, scale the cavity amplitude by this amount and measure the curve at the nominal amplitude to determine the phase and then adjust the phase to –7.66°. A similar phase scan in cavity 173 would result in two curves that are almost parallel where they intersect which would introduce a large uncertainty in setting the cavity phase.

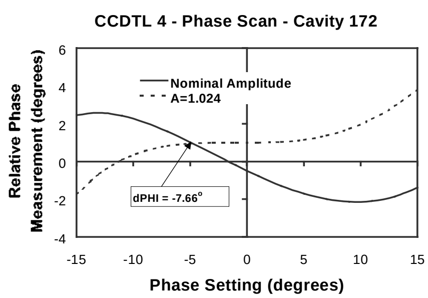

Figure 3: Single Phase Probe Measurement

Perhaps the most versatile and effective type of phase scan measurement is to use two phase probes whereby one can measure the beam time-of-flight (TOF) and infer the beam energy. This measurement appears to be well suited for all modules of the APT Linac. In one application of this measurement, the beam energy is measured as the cavity phase is scanned over a wide range (~ ± 90°). The results are similar to an absorber collector phase scan as seen in Figure 4 except that the width and phase are measured at a specific beam energy.

Another type of phase scan using two phase probes can be performed by measuring the energy as a function of the phase difference between the cavity phase and the phase measured in one of the probes [6] as shown in Figure 5. At a specific amplitude the phase difference remains constant as the energy changes. This is similar to the single phase probe measurement in that the ratio of this amplitude to the nominal amplitude is well known and that the intersection of this curve with that for the nominal amplitude defines the cavity phase setpoint. The spacing between the two phase probes must be chosen carefully so that there is a clear distinction between these two curves.

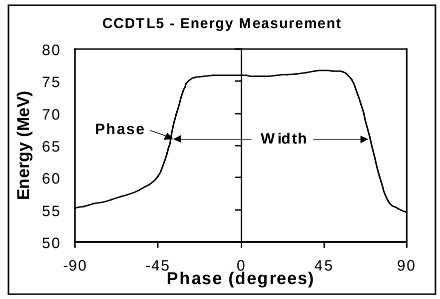

Figure 4: Energy measurement with two phase probes

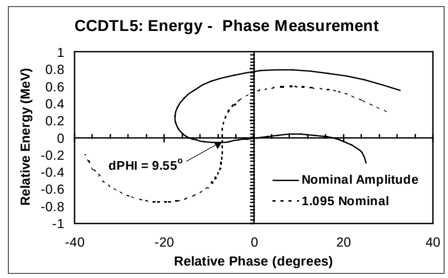

Figure 5: Phase scan of relative energy vs. relative phase

It is anticipated that the RF structures of the SC linac will also be commissioned using two phase probes. In the SC linac, the energy gain in a module is only a small percentage of the total energy and the results of a phase scan similar to that shown in Figure 4 will be a "skewed" sinusoid. The intent is to measure the peak of this curve from which the energy gain and synchronous phase can be determined.

4 REFERENCES

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