

COMMISSIONING PLAN FOR A HIGH-CURRENT PROTON LINAC*

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Abstract

High-power proton linacs ($E > 500$ MeV) are potentially useful for transmutation applications, such as the production of tritium. In production applications, high availability is essential. Achieving high availability requires an accelerator design that simplifies maintenance and accommodates commissioning procedures designed to minimize tune-up time. These are worthwhile goals for any accelerator, but the high beam powers (170 MW) and heavy beam loading of the Accelerator Production of Tritium (APT) [1] linac introduce significant new challenges. This paper will describe the commissioning plan, as developed to date.

1 INTRODUCTION

The APT accelerator is an integrated normal conducting - superconducting (NC/SC) linac [2]. It has a final beam energy of 1700 MeV and a CW beam current of 100 mA. It starts with a 75-kV injector. Acceleration up to 217 MeV is provided by a RFQ accelerator and a coupled-cavity NC linac. From 217 to 1700 MeV, acceleration is provided by two sections of SC linac: the medium-b and high-b linac sections.

The APT accelerator must demonstrate high reliability and availability. To achieve this, designers must know how the accelerator will be commissioned and operated. The design, commissioning plan and operating plan must be developed in concert to ensure that the required beam instrumentation, controls, and access will be available.

The goal of commissioning is to safely, quickly and reproducibly bring the beam to full current and energy with minimum beam loss, to verify that all systems are working correctly, and to develop a physics model of the beam dynamics that will permit computer-aided automatic beam tuning.

A good physics model and automatic beam tuning are important for achieving high availability. The most difficult source of "emittance noise" to control is the degree of the neutralization [3] in the LEBT, upstream of the RFQ [4]. RFQs have been observed to be effective "emittance filters". Because RF accelerating systems downstream of the RFQ are well understood and known to

be capable of consistent performance with good commissioning protocols, automatic beam tuning is believed to be achievable.

2 IMPORTANT ELEMENTS OF COMMISSIONING PLAN

The commissioning plan has been developed using recent commissioning experience from the FNAL linac upgrade and CEBAF. It is also based on the operating experience at the Los Alamos Neutron Scattering Center (LANSCE).

The 170-MW APT linac can quickly activate or destroy components. Therefore, it is therefore essential to approach full power with a low averaged power pulsed beam. Table 1 shows the different beam formats that will be used. A pilot beam is the lowest power beam used for equipment checkout when commissioning begins. Its minimum power is limited by the response of the diagnostics and the pulse rate of the ion source. A calibration beam is used for calibrating the amplitude and phase of the accelerating structures. Its power level is defined by the minimum beam power required by each calibration method. A tuneup beam brings the peak current to 100 mA without exceeding the design power of the full-energy beamstop at the end of the linac (Figure 1) of 3.4 MW. The average power levels of the pilot and calibration beams are comparable to that used for LANSCE tuneup. The LANSCE tuneup beam is a 480-W pulsed beam of 4 Hz, 1-mA peak, and 150- μ m long.

Table 1: List of Pulsed-Beam Formats

Beam Types	Repetition Rate (Hz)	Max. Peak Current (mA)	Pulse Length (ms)	Maximum average Power
Pilot	1	1	0.1	170 W
Calibration	1	10	1	17 kW
Tuneup	10	100	1	1.7 MW
APT	(CW)	100	(CW)	170 MW

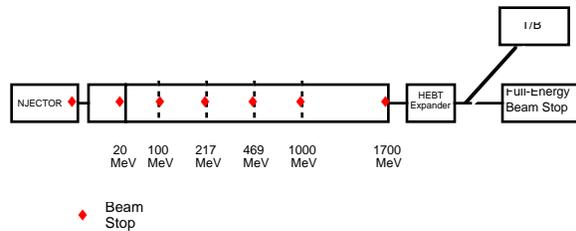


Figure 1. Schematics of APT Linac for Commissioning

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Different beamstops (Table 2 and Figure 1) will be required at each commissioning step. A full power beamstop will be installed at the Injector for beam setup and beam abort. A full-power beamstop is required at the 20-MeV point because the beam dynamic up to this energy is highly space-charge dominated. Good beam quality at this point is critical to the beam quality for the rest of the linac. The short APT schedule calls for linac installation by sections. Commissioning of a section will take place while later sections are being installed. To accomplish this, a low-average power beamstop that can be moved to the end of a section is needed. The radiation safety aspect of such a beamstop is currently under study. There is a full-energy, 2% full averaged power, beamstop at the end of the linac. The target/blanket will be used as a beamstop for CW beam tuning at power level from 2 to 100% of the full beam power.

Table 2: List of APT Beamstops

Location	CW or Pulsed	Average Power	Peak Current (mA)	Energy (MeV)
Injector	CW and Pulsed	10 kW	130	0.075
20-MeV	CW and Pulsed	2 MW	100	20
End of Sections	Pulsed	17 kW	10	1700
End of Linac	Pulsed	1.7 MW	100	1700

Measurements using beam diagnostic instrumentation will be used to develop the physics model for automatic tuning. A list of measurements and measurement methods is given in Table 3. A description of the APT beam diagnostics can be found in Reference [5].

3 COMMISSIONING STEPS

The APT-linac commissioning plan has the following steps (Figure 1):

Table 3: Diagnostics for Beam Measurements

Measurements	Method
Current	
CW	Multi-core toroidal
Pulsed	Single-core toroidal
Peak current	Summed BPM signals
Beam loss	Ion chamber
Fast Protect	Ion chamber
Beam centroids	
Position	BPM
Angle	Δ between BPMs
Phase	Capacity probe
Energy	Time of flight
Beam width	
Transverse	Gas Fluorescence or Flying wire
Energy	Dispersive Magnet
Phase	Image Current Probe
Halo	Scraper

1. Installation of linac sections. Sections of linac are defined temporarily at beam energies: 75 kV, 20, 100, 217, 469, 1000, and 1700 MeV. A section will be installed. Equipment will be checked without beam and with the pilot beam. Accelerating structures will be calibrated using the calibration beam.
2. The first 20 MeV will be commissioned to full current using procedures developed in the Low-Energy Demonstration Accelerator.
3. After completing steps 1 and 2, the pulsed tuneup beam will be tuned to design peak current at the full energy beamstop.
4. A CW beam will be tuned to the Target/Blanket System. The current will increase from 2% to 100% in steps.
5. Linac physics-model study and beam-loss minimization will take place.

Methods used in these steps are described in the following subsections.

3.1 Steering

A pilot beam will be used. The principal diagnostics that will be used to establish alignment are the beam position monitors (BPM), of which about 210 will be permanently installed.

Several steering strategies have been investigated [6], of which two are particularly promising: dipole pair and least squares steering. Both are equally effective in keeping the beam centered in the beam channel, but the latter, although it requires somewhat more power supplies, reduces the demands on the steering magnets.

This stage will be carried out with the accelerating cavities detuned to minimize their interaction with the beam. It will be done by linac sections

3.2 Cavity Field Amplitude and Phase for NC Structures

In the normal conducting systems, over the physical region between two beam monitors, a series of phase scans and delta-t measurements [7] will establish the field phase and amplitude required to achieve design longitudinal beam dynamics. The minimum length for this process is one RF “supermodule” [8]. A plot of the beam energy and output phases as a function of the RF amplitude and phase will be compared with simulation to determine the amplitude and phase of the RF cavity field.

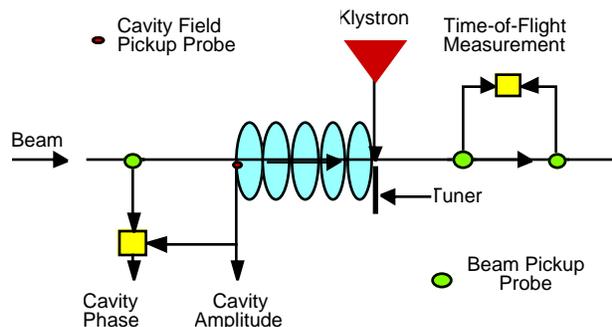


Figure 2. A schematic of the setup for calibrating phase and amplitude of SC cavities

3.3 Cavity Field Amplitude and Phase for SC Cavities

The APT SC linac can operate with some cavities idle. This flexibility requires phase calibration of cavity independent of the number of cavities operating upstream to the cavity being calibrated. Figure 2 shows a schematic of the setup used for calibrating the amplitude and phase of an SC cavity. Capacity pickups will be used immediately upstream of the cryomodule to provide the beam arrival phase. The phase of the cavity field will reference to this arrival phase. By directly referencing to the beam arrival phase, the dependence on the number of operating cavities of cavity phase calibration is minimized. The first step of the calibration procedure is to establish a RF field in the cavity using the klystron while the cavity is resonant in frequency. A calibration beam will then be injected. The calibration of the phase is achieved by adjusting the phase of the RF field until minimum beam induced phase changes of the cavity field are reached. At that time, the RF field is orthogonal to the beam in phase.

Calibrating field amplitude is conceptually more straightforward. The RF field amplitude is measured by field probes that are weakly coupled to the RF field. The field probe is calibrated to $\pm 10\%$ by measuring RF powers before installations of the cavity. Final calibration of the probe will be achieved by measuring the change in beam energy using the time-of-flight method with beam pickups along the accelerator.

3.4 Tuneup of Full Peak and Average Current

After the accelerating structures have been calibrated in RF phases and amplitudes, beam tuneup of the linac will start. The peak current will be increased to 100 mA. The repetition rate will be increased while keeping the average beam power below the design power of the beamstop at the end of the linac. Once acceptable performance has been achieved at this power level, further increases in beam power will take place with the switchyard configured to send the beam to the Target/Blanket.

At the beginning of the tuneup to the Target/Blanket, the peak current will be reduced to less than 2 mA. The reduction of beam current will not affect the component settings along the linac because the linac has been designed for current independent matches [9].

Throughout the process, accelerator performance will be compared to simulations. Beam transmission, transverse beam position, beam energy, transverse and longitudinal beam sizes, transverse match, and beam halo will be measured. Finally, a physics model will be confirmed using the data obtained. Algorithms for minimizing beam loss will be tested.

4 SUMMARY

Work is underway to develop a commissioning plan for the integrated normal/superconducting linac of the APT. If this is developed in concert with the linac design and operation plan, it will lead to high availability. To date, commissioning steps have been determined. Pulsed-beam formats, beamstops, and diagnostics required have been specified. Calibration methods of phase and amplitude of accelerating structures are being investigated.

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