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Drift Tube Linac Tank 1 Beam Commissioning Plan

A U.S. Department of Energy Multilaboratory Project

SPALLATION NEUTRON SOURCE

Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory

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1. INTRODUCTION

This document presents the beam commissioning plan for the first Drift Tube Linac tank of the SNS linear accelerator. The accelerator system for this commissioning run consists of the Front-End Systems (FES) which were commissioned initially at Berkeley Lab in Spring 2002 and recommissioned at ORNL in Dec 2002-Jan 2003, Drift Tube Linac Tank 1, and the diagnostics plate (the "D-plate").

1.1 SYSTEM LAYOUT AND CONFIGURATION

1.1.1 Drift Tube Linac Tank 1

The integrated Front-End and DTL Tank 1 system for this commissioning run is shown in Figure 1. A shielding enclosure surrounds DTL tank 1, the D-plate and DTL tank 3. Tank 3 may be further RF processed during the tank 1 commissioning run. The Front-End Systems hardware is identical to that which was commissioned at ORNL earlier this year, with the addition of new diagnostic devices to the anti-chopper box. The Drift Tube Linac Tank 1 and the D-plate are new hardware which will be commissioned with beam for the first time. The basic parameters for DTL tank 1 are given in Table 1. The DTL tank 1 output beam parameters are summarized in Table 2. This table shows both the design parameters, where applicable, and the performance goal that we would like to achieve during beam commissioning.

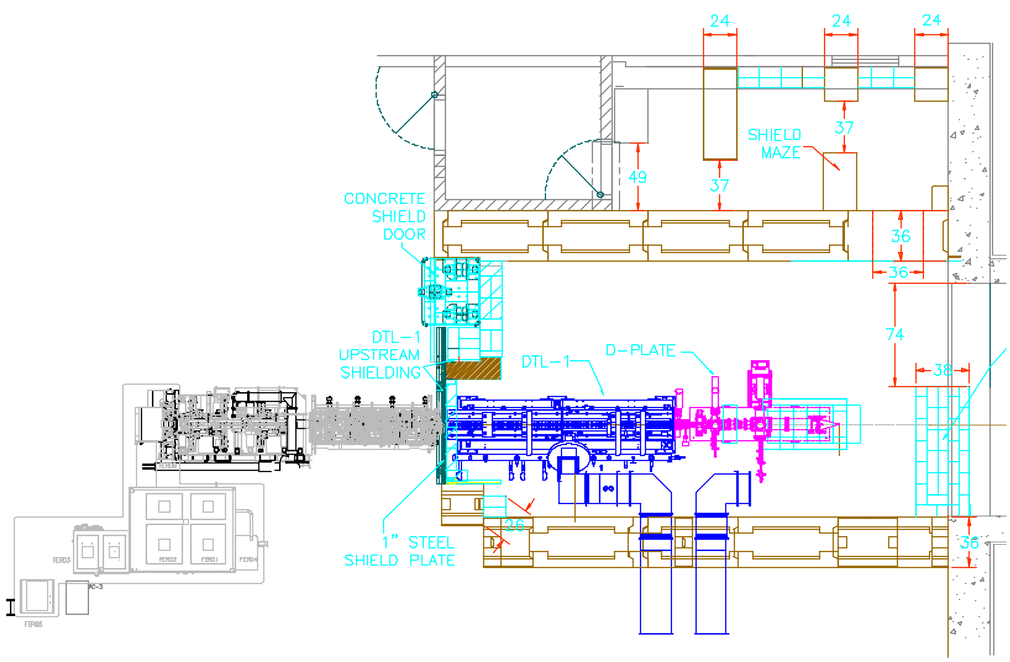

Figure 1. Layout of Front-End Systems, DTL tank 1 and the Diagnostics Plate for beam commissioning.

Table 1. Drift Tube Linac Tank 1 Design Parameters	
Resonant Frequency	402.5 MHz
Bore radius	12.5 mm
Tank Length	4.152m (between inside end walls)
Number of cells	60
Number of post couplers	19
Energy Gain	5.023 MeV
Stored Energy	4.78 J
Synchronous phase	-45° to -28°
Average E_0T	1.518 MV/m
Shunt Impedance ZT^2	28.22 MΩ/m
Loaded Quality Factor (design/measured)	14231 / 12066
Coupling Coefficient (design/measured)	1.524 / 2.213
Unloaded Q (design/derived from meas)	35891 / 38768
RF Structure Power (design/derived from meas)	346 / 319 kW
Beam Power (38 mA unchopped)	191 kW
Total Peak RF Power (structure + 38 mA beam)	510 kW
Focusing structure	FFODDO
Focusing period	6 βλ

Table 2. DTL tank 1 output beam parameters		
Parameter	Design Value	Performance Goal
Input Energy [MeV]	2.50	2.50 ± 0.10
Output Energy [MeV]	7.52	7.52 ± 0.03
Peak Macropulse Current [mA]	38	> 38
Beam pulse length [msec]	1.0	1.0
Repetition Rate [Hz]	60	60
Duty Factor [%]	6	6
Chopped Beam Gap [%]	32	32
RMS Normalized Transverse Emittance [π mm mrad]	N/A	< 0.3
Transverse jitter and variation within a pulse [mm]	N/A	< 0.3
Energy jitter and variation within a pulse [MeV]	N/A	< 0.004
Phase jitter and variation within a pulse [deg]	N/A	< 1.4
Longitudinal Emittance [deg MeV]	0.113	N/A
Unchopped output beam power [kW]	17.1	11.7
Chopped output beam power [kW]	11.7	11.7
Tank 1 Beamloss	< 4 W	< 4% (measurable loss threshold)

1.1.2 Beam stops

There are two beam stops which will be used in this commissioning run. The first is located in the anti-chopper box in the MEBT. This beam stop, constructed of carbon-carbon composite material, is electrically isolated and provides a current signal. The second beam stop, a Nickel absorber, is located at the end of the D-plate and also provides current readout capability. The maximum beam parameters for safe operation of each beam stop are given in Table 3.

Table 3. Beam power capability for beam stops and intercepting absorbers for DTL tank 1 commissioning				
	Single Pulse Energy (J)	Average Power (kW)	Unchopped Beam	Chopped Beam
MEBT Beam Stop*	50	0.005	38 mA, 50 µs, 1 Hz	38 mA, 65 µs, 1 Hz
D-plate Beam Stop§	195	11.7	38mA, 680 µs, 60 Hz	38 mA, 1000 µs, 60 Hz

*No active cooling

§Circular beam at stop only

1.1.3 Diagnostic Systems

The front-end systems' diagnostic suite is enhanced for this commissioning run with the addition of devices to the MEBT anti-chopper box (the "D-box"). These include an inline emittance device which uses slits located in the D-box and a nearby MEBT wire-scanner (with upgrade plans for a harp), a current-limiting aperture, a viewscreen and framegrabber system and possibly a Fast-Faraday Cup.

There are no diagnostic systems in DTL tank 1 proper. A diagnostics beam box, which includes a wire scanner (WS), energy degrader/Faraday cup (ED/FC) system, beam position monitor (BPM) and toroidal beam current monitor (BCM), is located between Tank 1 and the D-plate assembly. The D-plate diagnostic suite consists of beam position monitors, a wire scanner system, a slit/collector emittance system, a video/framegrabber system, an energy degrader and faraday cup system, a bunch shape monitor system (BSM), a halo monitoring system, and a full (chopped) beam-power Faraday cup. The layout of diagnostics devices is shown in Figure 2.

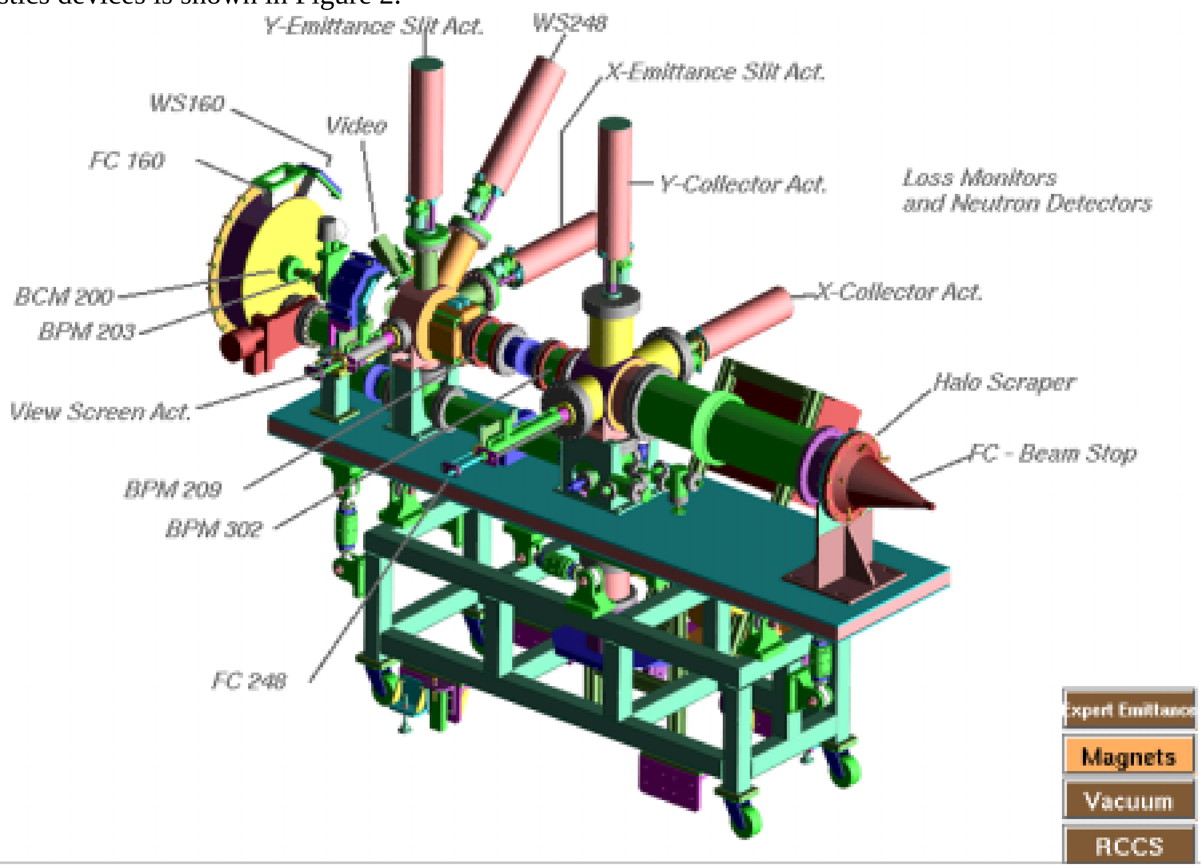

Figure 2. Layout of diagnostic devices for DTL Tank 1 Commissioning.

Several of the diagnostic systems in the MEBT and D-plate must be operated within narrow beam parameters to prevent damaging the devices. These operational limitations are summarized in Table 4. The Machine Protection System (MPS) ensures that these devices can be operated only in the appropriate machine mode to avoid damage to the devices.

Table 4. Beam capabilities of diagnostic systems*

System	Peak Current (mA)	Maximum Pulse Length (μs)	Maximum Repetition Rate (Hz)
MEBT Wire Scanners	50	50	5
MEBT Aperture	38	50	30
MEBT Inline Emittance	38	50	30
MEBT Viewscreen	20	6	1
DTL-1 Wire Scanners	38	34	10
DTL-1 Energy Degrader/Faraday Cup	38	95	10
D-plate Viewscreen	38	6	1
D-plate Wire Scanners	38	34	10
D-plate Emittance	38	34	10
D-plate Energy Degrader/Faraday Cup	38	120	10
D-plate Bunch Shape Monitor	38	50	1

*Longer pulse lengths are acceptable at lower peak current, such that the product of current and pulse length is maintained within the value shown in the table.

1.2 COMMISSIONING GOALS

The primary beam commissioning goals are the following:

- Bring DTL tank 1 and all associated sub-systems into beam operation
- Characterize the primary beam parameters and achieve the beam performance goals outlined in Table 2
- Develop and validate procedures which will be used for tuning subsequent portions of the SNS linac
- Deliver 11.7 kW beam power to the D-plate beamstop at nominal peak current and repetition rate
- Characterize the beam performance versus tuning variables, and
- Measure losses consistent with the measurable loss limit.

If time permits we would like to accomplish several secondary goals, namely

- Measure pulse-to-pulse jitter in beam parameters
- Commission the LEBT and MEBT chopper systems, and
- Measure parameters of the chopped beam.

1.3 COMMISSIONING BEAMS

Since the LEBT and MEBT chopper systems will be commissioned later in the commissioning run, we plan to use unchopped beam for the bulk of the commissioning studies. The beams will be consistent with the beam-handling capabilities of the diagnostics systems in use at the time.

1.3.1 Peak Current

We plan to commission in three phases with beams of three different peak currents. For initial injection into DTL tank1 we plan to insert the current-limiting aperture in the D-box to limit the peak current to less than 5 mA. Once we are assured of good transmission to the D-plate beamstop we will remove the aperture and perform the bulk of the commissioning studies with a 20 mA peak current beam. This is a current with which we have much experience in the MEBT and which is readily and routinely achievable from the ion source and front-end systems. Approximately midway through the commissioning run we will attempt to increase the peak current to the nominal 38 mA to obtain a set of DTL1 output beam parameter measurements. We may occasionally insert the current limiting aperture to perform other studies at low current, and may during the 38 mA run, drop the peak current to 20 mA for certain studies and operations.

1.3.2 Pulse Length

The pulse length will be set typically by the limitations of the diagnostic system and beamstop in use at the time. For initial injection into the DTL, we will use a pulse length less than 20 μsec until we are assured that the beam transmission to the beamstop is adequate. The bulk of the commissioning measurements will be carried out at less than 50 μsec pulse length, consistent with diagnostic limitations. We will extend the pulse length at various times for two functions: i) to observe the low-level RF system performance over nominal pulse lengths, ii) to measure beam parameters over nominal pulse lengths, and iii) to test the DTL1 systems at high duty-factor toward the end of the commissioning run.

1.3.3 Repetition Rate

Most of the commissioning program will be carried out at low repetition rate, typically less than 3 Hz. The repetition rate will be increased at certain stages in the commissioning run to i) check the performance of the RF system at nominal repetition rate (with a short pulse), ii) to measure pulse-to-pulse jitter in beam parameters, and iii) to test the DTL1 systems at high duty-factor toward the end of the commissioning run.

2. BEAM OPTICS

2.1 NOMINAL OPTICS

The nominal beam envelopes are shown in Figures 3 and 4 for 20 mA operation and 38 mA operation, respectively. The nominal rebuncher and quadrupole settings are given in Table 5.

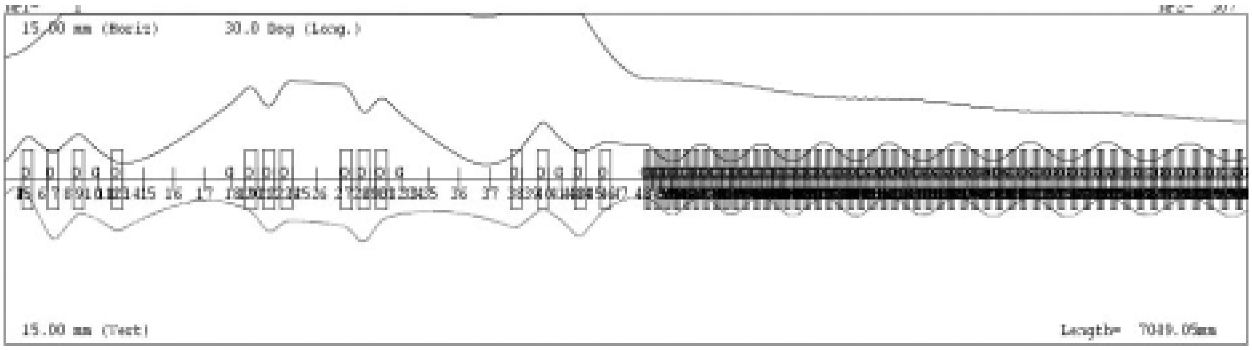

Figure 3. Trace3D beam envelope profiles for 20mA operation. The uppermost curve is the longitudinal profile, the middle curve is the horizontal profile and the lower curve is the vertical profile.

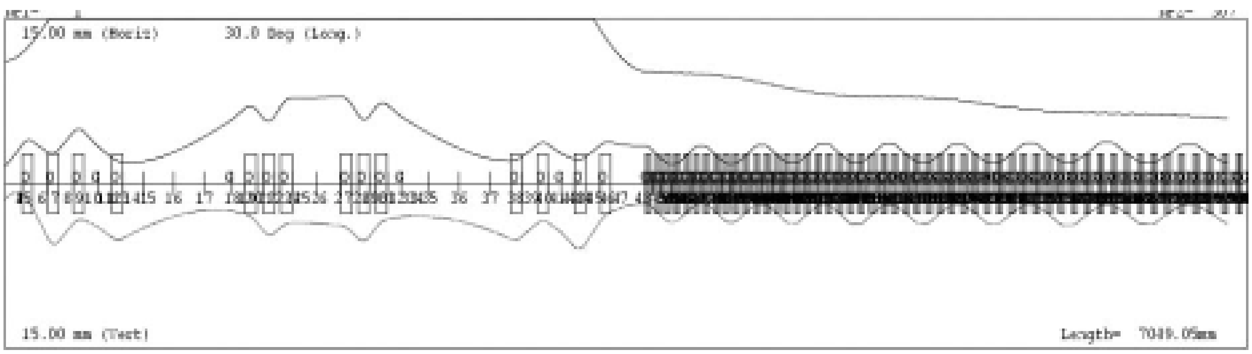

Figure 4. Trace3D beam envelope profiles for 38mA operation. The uppermost curve is the longitudinal profile, the middle curve is the horizontal profile and the lower curve is the vertical profile.

Table 5. MEBT quadrupole and rebuncher setpoints for 20 mA and 38 mA operation

QH01 [T/m]	-34.64	
QV02 [T/m]	36.81	
QH03 [T/m]	-28.33	
QV04 [T/m]	16.12	
QH05 [T/m]	-17.00	
QV06 [T/m]	26.20	
QH07 [T/m]	-11.70	
QH08 [T/m]	-11.70	
QV09 [T/m]	26.20	
QH10 [T/m]	-17.00	
Rebuncher 1 [kV]	75.00	
Rebuncher 2 [kV]	45.00	
	20 mA	**38 mA**
QV11 [T/m]	17.31	16.72
QH12 [T/m]	-29.39	-25.96
QV13 [T/m]	26.95	27.58
QH14 [T/m]	-13.60	-18.50
Rebuncher 3 [kV]	49.83	45.77
Rebuncher 4 [kV]	105.74	94.14

2.2 OPTICS TO INCREASE BEAMSIZE AT CURRENT LIMITING APERTURE

It may be desirable to install MEBT optics to produce a circular beam at the MEBT aperture. Table 6 shows the MEBT quadupole settings for these optics.

Table 6. MEBT quadrupole strengths to provide circular beam at the MEBT aperture

QH01 [T/m]	-34.64
QV02 [T/m]	36.81
QH03 [T/m]	-28.33
QV04 [T/m]	16.12
QH05 [T/m]	-17.00
QV06 [T/m]	26.20
QH07 [T/m]	-11.70
QH08 [T/m]	-0.04
QV09 [T/m]	-3.68
QH10 [T/m]	-2.40
QV11 [T/m]	18.44
QH12 [T/m]	-25.55
QV13 [T/m]	17.85
QH14 [T/m]	-4.94
Rebuncher 1 [kV]	75.00
Rebuncher 2 [kV]	45.00
Rebuncher 3 [kV]	45.77
Rebuncher 4 [kV]	49.10

2.3 D-PLATE QUADRUPOLE SETTING FOR EMITTANCE MEASUREMENT VS. BEAMSTOP TRANSPORT

The beamsize is made large for transport to the beam stop to reduce peak thermal stress on the beamstop. For D-plate emittance measurement, the quadrupole is adjusted to produce about 2mm horizontal and vertical RMS beamsizes at the slits. For transport to the beamstop, the quadrupole current is 110 Amps (2.02 kG/cm), while for emittance measurement the quadrupole current is 75 Amps (1.45 kG/cm).

3. COMMISSIONING TASKS

The list of commissioning tasks and the beam parameters required for each task are contained in Appendix A. The commissioning proceeds along the following broad outline. First, the Ion Source, RFQ and MEBT beams are prepared. The emphasis at this point is on reliable 20-25 mA source operation, rather than attempting to push the peak current. Once the MEBT beam is brought to the MEBT beamstop, the necessary measurements and tuning operatings are performed. This work is carried out in major tasks 1-2. In task 3, the MEBT beamstop is removed and a low-current, short pulse beam is transported through the remainder of the MEBT with the DTL RF off, in order to properly tune the last rebunchers and correct the latter portion of the MEBT trajectory. In this stage the beam that enters tank 1 is lost on the last several drift tubes. In task 4, tank 1 is powered and this low-current, short-pulse beam is transported to the D-plate beamstop. In task 5, several of the D-plate diagnostic systems are commissioned. Of particular importance is the setup and tuning of the differential current monitoring system that the MPS will rely upon, which takes place in this step. In task 6, various fault studies are performed with low-current beams to verify the loss predictions. In task 7, checkout of the RF system performance is carried out. In task 8 and 9 the RF setpoint of tank 1 is established by several different methods and the transverse matching conditions are determined at a peak current in the 20-25 mA range. The emphasis at this stage is in routine reliable front-end operations in order to test the various matching algorithms and RF setpoint routines. In task 10, the beam pulse length is extended to demonstrate long-pulse operation and to measure beam parameters throughout the pulse. In task 11 the DTL aperture is scanned with a pencil beam. In tasks 12 and 13, nominal 38 mA peak current conditions are established in the front-end and DTL and those conditions are characterized and parameterized as functions of the various tuning variables. In tasks 14 and 15 the LEBT and MEBT chopper systems are commissioned and the chopped beam parameters are measured and compared with those of an unchopped beam. Finally in task 16 the duty factor is increased to demonstrate high power operation of tank 1, and to measure various beam parameters at high repetition-rate.

The remainder of this section presents the detailed instructions for carrying out the individual commissioning tasks.

3.1 ION SOURCE AND RFQ STARTUP

3.1.1 Ion Source startup and cesiation

Follow the ion source startup procedure to produce a 20-25 mA beam.

3.1.2 RFQ conditioning

Condition the RFQ following the RFQ conditioning procedure.

3.1.3 MPS and timing checkout

Perform MPS system and timing system checkout without beam. Verify proper control of beam pulse-lengths for MPS modes. Verify time response of Fast Protect Auto Reset (FPAR).

3.1.4 Establish beam through RFQ

Insert the MEBT beamstop. Restore the nominal MEBT settings from the previous run. Set the MPS mode to 50 microseconds, the ion source pulse width to 100 microseconds and the repetition rate to 3 Hz. Make sure that the RF power for Tank 1 is turned off. Set the RFQ repetition rate to 3 Hz and pulse width to 50 microseconds. Observe the MEBT beamstop and BCM02 signals. Increase the RFQ forward power and observe the current signals. Leave the RFQ at nominal forward power (700 kW).

3.1.5 BCM02 checkout and adjustment

Provide beam for Diagnostics Group verification of BCM02 operation. Compare BCM02 and beamstop signals to ensure good transmission.

3.1.6 LEBT optimization

With beam safely transported to the beamstop, optimize the LEBT settings by observing the BCM02 signal. Measure the RFQ output beam intensity vs. source voltage and LEBT steering. Take an IS saveset at nominal conditions.

3.1.7 Commission MEBT differential current measurement for BCM02

Provide beam for Diagnostics Group commissioning of MEBT differential current measuring system. Provide beam for Controls group test of the MPS shutoff functionality. With beam stopped at MEBT beamstop, the BCM02 and BCM11 differential current is triggered. Measure all differential current functions and response times.

3.1.8 Measure RFQ transmission vs. excitation

With source and LEBT optimized for 50 usec, 20 mA, 3 Hz operation, record the BCM02 current vs. RFQ forward power in the range 400 kW to 700 kW in 50 kW steps. Be sure to record both feedforward setpoint and forward power readback. Compare to previous measurements obtained from the front-end startup, and set RFQ power appropriately for maximum transmission. Take an IS/RFQ saveset at nominal conditions.

3.1.9 Iterate LEBT optimization and RFQ transmission

With RFQ at nominal power, retune LEBT for maximum transmission and maximum peak current on the MEBT beamstop. Take a saveset.

3.2 TUNE BEAM TRANSPORT TO MEBT BEAM STOP

3.2.1 Commission MEBT BPMS #1-4

Generate 20 mA, 50 microsecond, 3 Hz beam. Observe beam position signals on BPMs 1-4. Adjust BPM timing as necessary. Tune correctors to verify change in beam position on MEBT BPMs.

3.2.2 Set phase of Rebunchers #1-3

With rebunchers set at nominal amplitude, check that the rebuncher LLRF phase and amplitude control loops are working properly. Verify that phase readback tracks command and that amplitude isn't affected and vice versa. Adjust feedback controls as necessary to achieve stable control. Use the MEBT Rebuncher Phase Scan program to find the bunching phase of Rebunchers 1-3. When finished, take a MEBT saveset. Note: Rebuncher 4 will be set in section 3.3.

3.2.3 Trajectory correction up to beam stop

Correct the MEBT trajectory using horizontal and vertical correctors. The trajectory error should be reduced below 1 mm. Record in the logbook the MEBT trajectory for LEBT steerers and MEBT correctors off, for LEBT steerers powered for optimum transmission and MEBT correctors off, and the corrected trajectory and the resulting corrector settings. Record a saveset.

3.2.4 Measure BPM phase noise with beam

With rebuncher phases properly set, scan the rebuncher phase recording the BPM phase on downstream BPMs. Measure the combined phase noise of beam + BPMs.

3.2.5 Commission Wire Scanners #1-3

Record beam profiles with wire scanners 1-3 to exercise the systems. Provide beam as necessary for the Diagnostics Group commissioning of the wire scanners.

3.2.6 Beam Envelope measurements and correction up to beam stop

Measure the beam profiles up to the beam stop. Compare with the MEBT model. Adjust quadrupole strengths as necessary to correct the beam envelopes. Record a saveset.

3.2.7 Beam based calibration of rebuncher #1-2 voltage

Using the MEBT Phase Scan software, perform the beam-based calibration of rebuncher cavity voltages. Obtain the calibration constants. Set the rebuncher cavity voltages at the nominal values based on the new calibration. Record a saveset.

3.2.8 Commission D-box aperture

Make sure beam power is in accordance with aperture limits. Insert the D-box aperture to the largest hole and attempt to locate a signal on the MEBT beamstop faraday cup. Adjust the aperture vertically and sweep the beam position across the aperture with correctors as needed to locate the hole. Record the position of the actuator once the hole is located. Proceed to the other holes in the same way, locating each hole and recording the actuator position.

3.2.9 Commission D-box video system and record profiles

Reduce beam pulse width to 6 μs. Insert viewscreen and observe beam profiles. Record images with framegrabber system and enter in logbook.

3.2.10 Verify BPM and Corrector Polarity

Power individually horizontal and vertical correctors to displace the beam at wire scanner locations. Run the wire scanners and observe the direction of displacement and compare to BPM readings to verify the sign of the horizontal and vertical BPM readings. Then confirm that the sign of the correctors provides the observed displacement using the online model.

3.2.11 Measure Orbit Response Matrix

Acquire orbit response matrix data for all available correctors and BPMs up to the MEBT beamstop.

3.3 BEAM TRANSPORT THROUGH MEBT

3.3.1 Tune MEBT for apertured beam

Make sure MEBT beamstop is in place. Check trajectory and profiles in MEBT up to beamstop. Reduce pulse length to 10 microseconds at 2 Hz. Insert MEBT aperture so as to produce about 5 mA transmitted current observed on the MEBT beamstop Faraday cup.

3.3.2 Transport beam through DTL1 to beam-box Energy Degrader/Faraday Cup

Summon an RCT to verify shielding with accelerated beam through Tank 1. Leave Rebuncher 4 OFF at this point since there is no way to properly set its phase until later. Insert the DTL beam-box Energy Degrader/Faraday Cup and observe the raw Faraday cup signal on a scope. Turn on RF to DTL Tank 1 and set at nominal amplitude. Remove the MEBT beamstop and adjust DTL1 phase to see a signal on the Faraday cup scope trace. Tune DTL1 phase and amplitude to maximize Faraday Cup signal.

3.3.3 Commission Beam-box Energy Degrader/Faraday Cup and software

Provide beam for commissioning of Energy Degrader/Faraday Cup System by Diagnostics group. The ED/FC systems have the following operational limits:

- DTL1 system: 38 mA, 95 µs, 10 Hz (or 26 mA, 140 µs, 10 Hz)
- D-plate system: 38 mA, 120 µs, 10 Hz (or 26 mA, 180 µs, 10 Hz)

Exercise ED/FC Matlab software. Verify proper readout of EPICS PVs and scanning capability.

3.3.4 Perform acceptance scan with Energy Degrader/Faraday Cup

Perform ED/FC acceptance scan with the Matlab software. Acquire acceptance scan data and compare with simulations to determine the nominal phase and amplitude setpoints. Set DTL1 phase and amplitude appropriately and tune-up MEBT to Faraday cup transmission. Record a saveset.

3.3.5 Commission MEBT BPMs 5 and 6

Make sure MEBT gate valve to DTL Tank 1 is open. Remove MEBT beam stop and observe beam signals on BPMs 5 and 6 in MEBT.

3.3.6 Tune MEBT Steerers/Correct MEBT trajectory

Correct the MEBT trajectory at BPMs 5 and 6 if necessary. Maintain trajectory error less than 1 mm. Tune last MEBT steerers to optimize transmission through tank 1 by maximizing ED/FC signal. Record a saveset.

3.3.7 Observe beam related signals on LLRF

Provide beam for LLRF initial checkout. Observe beam loading and beam power on LLRF signals for use in subsequent beam-loading scan.

3.3.8 Commission the Beam Loading Scan software

Exercise the beam loading software. Verify proper readout of signals and functionality of beam loading scan.

3.3.9 Perform beam loading scan

If a beam loading signal is available, perform scan using the Beam Loading Scan software. Compare to model predictions. Compare to ED/FC result and install new setpoint if necessary. Retune MEBT to DTL matching as necessary to optimize transmission at new setpoint. Record a DTL+MEBT saveset for optimum conditions.

3.4 BEAM TRANSPORT THROUGH DTL TO D-PLATE BEAMSTOP

3.4.1 Transport apertured beam to D-plate Beam stop

Summon an RCT to verify shielding with beam transported to D-plate beamstop. Make sure that the D-plate quadrupole is powered at the "beamstop-tune" setpoint. Put D-plate BCM and Faraday Cup signals on the CR scope. Power DTL Tank 1 at amplitude and phase established earlier. Remove the ED/FC and observe signals on the BCM and D-plate Faraday cup. Maximize BCM and FC signals.

3.4.2 Commission D-plate beamstop and Faraday Cup

Provide beam for Diagnostics Group verification of Faraday Cup signal and beamstop. Have the RCT verify the shielding performance with beam transported to the beamstop.

3.4.3 Commission Neutron Detectors and loss monitors

Observe neutron signals from beamstop on the neutron detectors. Record the signals in the logbook. Observe the loss monitor signals and exercise the beamloss display software.

3.4.4 Set rebuncher 3 and 4 phase and amplitude

Perform phase scan of rebunchers 3 and 4 using the MEBT phase scan application. Calibrate the rebuncher voltage. Record the calibration constants and set rebunchers at bunching phase and nominal amplitude. Record a saveset.

3.4.5 Tune for maximum transmission

Using D-plate beamstop Faraday cup signal (and D-plate BCM if available) maximize the transmission through DTL tank1 and D-plate. Tune DTL1 phase and amplitude, MEBT correctors, matching quads, MEBT rebunchers. Record a DTL+MEBT saveset for optimum conditions.

3.4.6 Remove MEBT aperture and transport to D-plate beamstop

Summon an RCT to verify shielding with increased beam current. Insert beam-box ED/FC. Remove the MEBT aperture and observe signal on ED/FC. Check phase and amplitude setpoint for this higher current with an acceptance scan. Remove ED/FC and transport beam to D-plate beamstop, observing beam signals on D-plate BCM and beamstop Faraday cup.

3.4.7 Tune for maximum transmission

Using D-plate beamstop Faraday cup signal and D-plate BCM maximize the transmission through DTL tank 1 and D-plate. Tune MEBT correctors, matching quads, and rebunchers. Record a DTL+MEBT saveset for optimum conditions.

3.4.8 Commission MEBT wire scanners 5 and 6

Record beam profiles on MEBT wire scanners 5 and 6 and exercise the system. Provide beam as necessary for diagnostics group commissioning of wire scanners.

3.4.9 Check MEBT beam profiles

Record all beam profiles in MEBT and compare envelopes with the model predictions. Check that MEBT output twiss parameters from fit to model are near expectations.

3.4.10 Verify BPM and corrector polarity for MEBT BPMs 5 and 6

Power individually horizontal and vertical correctors to displace the beam at wire scanner locations. Run the wire scanners and observe the direction of displacement and compare to BPM readings to verify the sign of the horizontal and vertical BPM readings. Then confirm that the sign of the correctors provides the observed displacement using the online model.

3.5 COMMISSION D-PLATE DIAGNOSTICS AND MACHINE PROTECTION

3.5.1 Commission BCMs and Halo Monitor

Provide beam for Diagnostic Group commissioning of BCMs and Halo Monitor signals. Center beam on beamstop if halo monitor signals allow.

3.5.2 Center beam on Beamstop using BPMs and Halo Monitors

Use D-plate correctors to center beam in BPMs and beamstop using Halo monitors.

3.5.3 Commission Differential Current Monitoring System

Provide beam for Diagnostic Group commissioning of Differential Current Monitoring System. The system will compare MEBT BCMs and D-plate BCM and Beamstop Faraday Cup signals. Setup the integrating current measurement for the D-plate beamstop. Measure differential current resolution.

3.5.4 Verify MPS functionality with beam inputs

Check that beam current loss as measured by Differential Current Monitoring System triggers the MPS.

3.5.5 Commission D-plate Energy Degrader/Faraday Cup

Provide beam for commissioning of Energy Degrader/Faraday Cup System by Diagnostics group. The ED/FC systems have the following operational limits:

- DTL1 system: 38 mA, 95 μs, 10 Hz (or 26 mA, 140 μs, 10 Hz)
- D-plate system: 38 mA, 120 μs, 10 Hz (or 26 mA, 180 μs, 10 Hz)

With the differential current monitoring system functional, the pulse length can be increased to 50 microsecionds.

3.5.6 Perform acceptance scan with both Energy Degrader/Faraday Cups and compare

Perform ED/FC acceptance scan with the Matlab software under the following beam conditions: 20 mA peak current, 50 microsecond pulse length and 2 Hz repetition rate. Acquire acceptance scan data and compare with simulations to determine the nominal phase and amplitude setpoints. Compare D-plate and beam-box ED/FC results. Set DTL1 phase and amplitude appropriately and tune-up MEBT to D-plate transmission.

3.5.7 Commission D-plate Emittance System

Provide beam for Diagnostics group commissioning of the D-plate Emittance System. The Emittance slits have the following operational limitations:

- Beam Current: 38 mA
- Pulse Length: 34 microsec
- Repetition Rate: 10 Hz

Adjust the D-plate quad current to ~75 Amps (the exact value of which was determined in step 3.5.8) to establish the "emittance-tune" for the D-plate. Establish the scan limits for full beam coverage and check that the beamsize at the scanner gives sufficient resolution.

3.5.8 Commission Emittance Software and Analysis

Test the Emittance scanning software. Adjust the timing as necessary for proper beam measurement. Record the timing information. Verify that the emittance in both planes is properly measured and that the beam coverage (in x and y) is sufficient.

3.5.9 Measure DTL output beam emittance

With nominal beam conditions (20 mA, 50 microseconds, 3 Hz) and properly tuned MEBT and DTL measure the output beam emittance in both planes. Ensure that the D-plate quadrupole is set at the "emittance tune."

3.5.10 Commission Beam-box and D-plate Wire Scanner Systems

Provide beam for Diagnostics Group commissioning of beam-box and D-plate wire scanner systems. Record beam profiles.

3.5.11 Commission D-plate wire-scanner software

Test the profile scanning software. Adjust the timing as necessary for proper beam measurement. Record the timing information. Verify that the beam profiles in both planes is properly measured.

3.5.12 Measure beamsize at wire scanner vs. D-plate quad setting and compare with model

Verify that the MEBT quad is properly set for the "beamstop tune". Measure profiles at a few quad settings about the nominal and compare with the design beamsize.

3.5.13 Measure beam profiles in MEBT and D-plate and compare with model

Record beam profiles in the MEBT and D-plate. Compare profiles to the model prediction.

3.5.14 Commission Viewscreen/Video System

Reduce pulse length to less than 6 μs and rep-rate to 1 Hz or less. Provide beam for Diagnostics Group commissioning of D-plate video system. Observe beam image on framegrabber video system. Record images in logbook.

3.6 PERFORM FAULT STUDIES

3.6.1 Power all MEBT correctors at full strength and observe transmission

Summon an RCT to verify shielding performance under these fault scenarios. Verify that full strength powering of all correctors doesn't result in beamloss in DTL1. Using the Scan application, power each corrector across its operating range, recording the D-plate FC signal. Verify MPS differential current shutoff functionality.

3.6.2 Measure DTL1 transmission vs. RF

Summon an RCT to verify shielding performance under these fault scenarios. Turn DTL1 power off and measure D-plate BCM and beamstop FC signal. Turn RF back on and record transmission vs. DTL1 phase. Compare results with model predictions. Verify MPS differential current shutoff functionality.

3.6.3 Measure DTL1 transmission vs. rebuncher settings

Summon an RCT to verify shielding performance under these fault scenarios. Measure DTL1 transmission with all rebunchers off, and with individual rebunchers powered on and scanned through 360 degrees in phase. Compare results with model predictions. Verify MPS differential current shutoff functionality.

3.6.4 Measure DTL1 transmission vs. MEBT quadrupole errors

Summon an RCT to verify shielding performance under these fault scenarios. Scan MEBT quadrupoles recording DTL1 transmission. Compare results with model predictions. Verify MPS differential current shutoff functionality.

3.7 RF SYSTEM CHECKOUT/VERIFICATION WITH BEAM

3.7.1 Tune/measure RFQ amplitude and phase stability and control with beam

Provide beam for RF group checkout of RFQ LLRF system with beam. Verify amplitude and phase loop stability and control with beam.

3.7.2 Tune/measure DTL1 amplitude and phase stability and control with beam

Provide beam for RF group checkout of DTL1 LLRF system with beam. Verify amplitude and phase loop stability and control with beam.

3.8 ESTABLISH PHASE AND AMPLITUDE SETPOINT

3.8.1 Tune up 20 mA standard conditions

Insert MEBT beamstop. Increase source current to 20 mA and pulse length to 40 microseconds at 2 Hz. Retune LEBT and MEBT conditions. Check that trajectory and profiles are sensible. Recheck the rebuncher phase setpoints. Remove the MEBT beamstop and tune transmission through DTL1 to the D-plate. Tune matching quadrupoles, rebunchers 3 and 4 as necessary to maximize transmission at 20 mA.

3.8.2 Commission D-plate BPMs

Provide beam for Diagnostics Group commissioning of D-plate BPMs. Measure BPM response to powered correctors and verify BPM and corrector polarity.

3.8.3 Measure full MEBT Orbit Response Matrix

Measure the Orbit Response Matrix in the MEBT for all correctors. Record both MEBT and D-plate BPM signals.

3.8.4 Perform acceptance scan with Energy Degrader/Faraday Cup

Perform ED/FC acceptance scan with the Matlab software under the following beam conditions: 20 mA peak current, 50 microsecond pulse length and 3 Hz repetition rate. Acquire acceptance scan data and compare with simulations to determine the nominal phase and amplitude setpoints. Set DTL1 phase and amplitude appropriately and tune-up MEBT to D-plate transmission.

3.8.5 Perform the Beam Loading Scan

If not already tested, exercise the beam loading software. Verify proper readout of signals and functionality of beam loading scan. Perform beam loading scan using beam of 20 mA, 50 μs and 3Hz repetition rate. Acquire beam loading scan data and compare with simulations to determine the nominal phase and amplitude setpoints.

3.8.6 Measure BPM phase resolution with beam

Provide beam for diagnostics group measurement of BPM phase noise. Determine the BPM phase noise floor using beam-based measurements. Measure common-mode noise.

3.8.7 Commission D-plate phase scan software

Exercise Matlab Phase Scan software. Verify proper readout of EPICS signals and functionality of phase scan for all available BPMs.

3.8.8 Perform phase scan with BPMs

Perform BPM phase scan measurements using Matlab Phase Scan software. Acquire single BPM phase scans and differential phase scans.

3.8.9 Refine transport with new RF setpoint

Establish new RF setpoints, if necessary, based on BPM phase scan results. Refine the MEBT to D-plate transmission based on the new setpoints. Observe the MEBT BCM11 and D-plate BCM to tuneup the transmission. Tune MEBT rebunchers 3 and 4 amplitudes to improve transmission. Adjust MEBT correctors as necessary. Take a new saveset of MEBT and DTL conditions.

3.8.10 Measure the Orbit Response Matrix for refined setting

Obtain the Orbit Response Matrix using the MEBT steerers, MEBT BPMs, D-plate BPMs. Compare with the model.

3.8.11 Time of flight measurement for output energy

At final RF setpoint, perform Time-of-Flight measurements to determine DTL output beam energy.

3.8.12 Commission Bunch Shape Monitor

Provide beam as necessary for Bunch Shape Monitor commissioning.

3.8.13 Commission BSM software

Exercise the BSM readout software. Verify proper readout of EPICS PVs. Record measured bunch profile in the logbook.

3.8.14 Perform RF setpoint with BSM

Scan DTL phase and amplitude recording BSM signals to determine RF setpoint. Check against other methods.

3.8.15 Tune MEBT longitudinal matching with BSM

Scan Rebunchers 3 and 4 amplitude and phase to tune longitudinal matching using BSM signals. Set at appropriate phase and amplitude and tune up transmission again if necessary.

3.9 ESTABLISH TRANSVERSE MATCHING CONDITIONS

3.9.1 Commission MEBT inline emittance hardware and software

Commission the MEBT emittance system. Maximum beam parameters for the slits are as follows: 38 mA, 50 microsec and 30 Hz. Commission the MEBT emittance scanner software and analysis software.

3.9.2 Minimize MEBT emittance

Minimize MEBT emittance by tuning quadrupoles, trajectory, RFQ power etc.

3.9.3 Measure DTL output beam emittance

With nominal beam conditions (20 mA, 50 microseconds, 3 Hz) and properly tuned MEBT and DTL measure the output beam emittance in both planes. Ensure that the D-plate quadrupole is set at the "emittance tune."

3.9.4 Improve transverse matching by minimizing RMS emittance

Minimize the RMS emittance of the DTL output beam by varying MEBT matching quadrupoles (Q11-14). Use the automated scanning capability of the Matlab emittance program.

3.9.5 Compare beam profiles w/model

Once matched conditions have been obtained, measure the beam profiles in the MEBT and D-plate and compare with the model predictions.

3.9.6 Measure the Orbit Response Matrix

Once matched conditions have been obtained, acquire the Orbit Response Matrix and compare with the model.

3.9.7 Test online model capabilities

Adjust MEBT quadrupole strengths and record profiles in MEBT and D-plate. Compare with online model predictions. Test online model capability for predicting trajectory and beamsize.

3.10 ESTABLISH LONG-PULSE OPERATION

3.10.1 Condition RFQ and DTL Tank 1 as necessary (without beam)

Extend the RF pulse length in each structure to 1 msec by following the conditioning procedures.

3.10.2 Increase beam pulse length and maximize transmission

With properly tuned 20 mA, 50 microsecond, 1 Hz beam to the D-plate beamstop, increase first the RF pulse length of RFQ and DTL1. Then slowly increase the ion source pulse length in steps of about 50 microseconds. Make sure that an RCT is present for this operation to verify proper shielding performance. Tune MEBT output parameters as necessary to improve transmission of longer pulse. Observe neutron signals and loss signals and tune to minimize as necessary. Record a saveset for long-pulse conditions once established.

3.10.3 Perform Beam loading scan

Observe beam-related signals from LLRF system. Make a pulse just long enough to get an acceptable beam power measurement. Perform beam loading scan to determine DTL1 phase and amplitude. Compare these results with those obtained from ED/FC scan and BPM scan. If the setpoint needs adjustment based on this measurement, tune up the transmission and record a saveset.

3.10.4 Measure RFQ and DTL LLRF phase and amplitude stability w/beam

Measure the RF system phase and amplitude stability during the beam pulse.

3.10.5 Measure the output beam phase, energy and position variation within a pulse

Record the D-plate BPM phase signals throughout the beam pulse to observe phase variation. Perform TOF measurements throughout the pulse to obtain the energy variation. Also record the D-plate beam positions throughout the pulse to determine the transverse centroid variation.

3.11 PERFORM APERTURE SCAN

3.11.1 Reconfigure MEBT quads for steering

Rewire the leads of the last two MEBT quadrupoles to provide horizontal and vertical beam steering.

3.11.2 Tune-up apertured beam in MEBT

Insert MEBT beamstop. Tune up MEBT conditions for reduced beam current: 10 mA, 30 microseconds, 2 Hz. Insert the MEBT aperture and center beam on the hole by observing MEBT beamstop current signal. With DTL RF at nominal setpoints obtain transmission of apertured beam to the D-plate beamstop. Observe beam on D-plate BCM and beamstop. Tuneup transmission as necessary.

3.11.3 Verify steering performance with D-plate BPMs

Taking small steps, adjust last two MEBT quadrupoles (re-wired as steerers) and observe D-plate BPMs to verify proper wiring. Make sure that horizontal steerer moves beam horizontally and obtain the steering calibration coefficients.

3.11.4 Scan DTL1 Aperture

Record the D-plate BCM and beamstop faraday cup signals. Scan the MEBT quadrupole steerers to obtain the aperture in horizontal and vertical.

3.11.5 Reconfigure MEBT quads for focusing

Re-wire the last two MEBT quadrupoles for focusing. Restore nominal 20 mA conditions which were previously characterized. Measure beam profile and emittance in D-plate to ensure that the cables have been properly reconfigured.

3.12 ESTABLISH NOMINAL 38 MA BEAM CONDITIONS

3.12.1 Achieve 38 mA source current

Cesiate source following Ion Source Operating Checklist. Insert the MEBT beamstop. Achieve highest possible beam current up to 38 mA current. Do not exceed this current at the MEBT output.

3.12.2 Tune MEBT for 38 mA output current

Retune the MEBT conditions for 38 mA current. Make sure the MEBT beamstop is inserted. Set the pulse width to 50 microseconds and rep-rate to 3 Hz. Optimize LEBT for maximum BCM02 current. Flatten MEBT trajectory. Measure beam profiles at available wire scanners and compare with model. Check RF rebuncher phase setpoints using phase scan software. Save tuned up conditions for MEBT.

3.12.3 Optimize transmission of 38 mA through DTL

Summon an RCT to the control room to verify shielding on D-plate with higher peak current. With 38 mA, 50 microsecond, 2 Hz beam in MEBT, remove the MEBT beamstop and observe beam on D-plate BCM. Optimize transmission to the D-plate by tuning MEBT parameters and tweaking DTL1 RF amplitude and phase. Ensure good transmission from D-plate BCM to beamstop Faraday Cup. Center beam on the beamstop as necessary.

3.12.4 Measure DTL output parameters

Measure beam profiles and emittance in D-plate. Compare to lower current measurements.

3.12.5 Re-establish RF setpoints and longitudinal matching

Check the RF setpoints by performing ED/FC acceptance scan, beam loading scan, BPM phase scan and BSM scan. Compare with lower current measurements. Check longitudinal matching with the BSM. If new setpoints are required, retune appropriately and save conditions in a saveset.

3.12.6 Re-establish MEBT to DTL transverse matching

Measure the beam emittance in D-plate. Check the transverse matching from MEBT to DTL by adjusting the matching quadrupoles to minimize emittance. Record baseline conditions in a saveset.

3.12.7 Measure beam profiles

Measure the beam profiles using the MEBT and D-plate wire-scanners. Check the beam size against the model.

3.12.8 Measure the Orbit Response Matrix

Measure the Orbit Response Matrix for the MEBT steerers and MEBT BPMs and D-plate BPMs. Check against the model.

3.13 CHARACTERIZE DTL1 NOMINAL OUTPUT BEAM

3.13.1 Characterize MEBT output beam for several currents

Measure beam profiles and emittance for a few beam currents. Perform measurements at 20 mA, 30 mA and 38 mA with a 50 microsecond pulse at 2 Hz rep-rate. Record conditions for each beam current in savesets.

3.13.2 Optimize transverse matching and DTL RF setpoint

If MEBT emittance measurements reveal larger than expected transverse emittances, then reoptimize the MEBT to achieve nominal emittance specifications. Reoptimize the transverse matching to DTL1 to minimize the DTL output emittance as necessary.

3.13.3 Measure output trajectory/profile/emittance vs. MEBT steering and compare w/model

Scan the last MEBT correctors (DCH14, DCV14) recording D-plate beam positions. Also record beam profile and beam emittance in the D-plate. Compare measured trajectories with model predictions.

3.13.4 Measure profiles and emittance vs. MEBT quad matching

Scan MEBT matching quads (Q11-14) recording D-plate beam profile and emittance. Compare profiles with model predictions.

3.13.5 Measure the Orbit Response Matrix

For the matched setting, measure the orbit response matrix and compare with the model.

3.13.6 Measure bunch shape vs. longitudinal matching and compare with model

Scan rebunchers 3 and 4, recording BSM signal. Compare profiles with model predictions.

3.13.7 Measure the DTL output emittance vs. beam current

Measure the DTL output emittance for 20 mA, 30 mA and 38 mA MEBT output.

3.13.8 Measure emittance along the beam pulse

Measure the emittance at a few points along the 50 microsecond beam pulse.

3.13.9 Halo Measurement

Increase the beam pulse length and record the Halo monitor signals for future comparison to model predictions. Use wire scanners to measure halo.

3.13.10 Measure energy/phase within a pulse and pulse-to-pulse jitter

Extend the pulse length up to the dump limit of 680 microseconds (for 38 mA; see Table 3). Observe the beam phase variation measured on the D-plate BPMs during a long RF pulse. Record also the differential phase for estimating the energy variation. Record a histogram of pulse-to-pulse variation of the BPM phase and energy.

3.13.11 Measure beam position within a pulse and pulse-to-pulse jitter

Record the beam position (as above) during a long beam pulse and also from pulse-to-pulse. Record the positions on all available D-plate BPMs.

3.13.12 Measure variation of beam parameters as a function of time

Over the course of one continuous shift, archive the beam position and phase. Periodically measure the beam profile and emittance over the course of the shift to determine the long term stability of output beam parameters.

3.14 COMMISSION CHOPPER SYSTEMS

3.14.1 Commission LEBT chopper system

Insert MEBT beamstop. Set LEBT chopper system for nominal voltage. Tune beam of pulse length less than 50 microseconds and repetition rate less than 5 Hz. Observe beam signal on MEBT BCM02. Load chopper waveform from chopper control screen and operate the chopper. Record scope display demonstrating chopper performance. Measure chopped beam signal on the RFQ "diagnostics plate."

3.14.2 Measure LEBT chopping efficiency and rise/fall times with beam

Record BCM02 and RFQ "diagnostics plate" signals as a function of chopper voltage. Estimate the chopping efficiency. Measure the rise and fall times of the chopped beam signals.

3.14.3 Commission MEBT chopper hardware

Prepare MEBT hardware for operation, including conditioning of the chopper plates. Reduce the peak source current to about 20 mA. Using a 30 microsecond pulse at 3 Hz, operate the chopper starting at low voltage and increasing to nominal voltage while observing the MEBT beamstop faraday cup signal to verify that the MEBT chopper is removing beam. Observe the thermocouple signal for the MEBT chopper target.

3.14.4 Set LEBT to MEBT chopper relative timing with beam

While observing the beam signal on the MEBT beamstop, turn on the LEBT chopper. Note the start and stop of the LEBT chopped beam on a fast scope looking at a single minipulse. Power the MEBT chopper. Adjust chopper pulse width and relative timing to maintain same chopped beam width and start time with MEBT chopper operating.

3.14.5 Measure LEBT+MEBT chopping efficiency and rise/fall times with beam

Use the MEBT beamstop Faraday cup signal to measure the chopping efficiency. Measure the rise and fall times with the beam. Adjust the relative timing to minimize the rise and fall times.

3.14.6 Transport chopped beam to D-plate

Turn off chopper systems. Remove MEBT beamstop and ensure proper transmission to the D-plate beamstop. Observe the D-plate BCM and beamstop signals. Record the beamloss monitor and neutron detector signals. Power the LEBT chopper first, noting the beam signals and loss monitor signals. Then power the LEBT+MEBT choppers observing loss monitors and beam signals. Tune MEBT and DTL1 as necessary to improve transmission and minimize losses.

3.15 CHARACTERIZE DTL1 CHOPPED OUTPUT BEAM

3.15.1 Re-establish baseline conditions without chopping

With choppers off, re-establish baseline machine conditions as determined above for nominal 38 mA beam. Use pulse length of 50 microseconds at 2 Hz.

3.15.2 Compare emittance, profiles and losses of chopped and unchopped beam

Record the loss monitor and neutron monitor signals for choppers off, LEBT chopper only and LEBT+MEBT chopper. Record the beam profiles for the same three sets of conditions. Record the emittance in MEBT and D-plate for the same three sets of conditions.

3.16 HIGH DUTY FACTOR MEASUREMENTS

3.16.1 Increase pulse length

Restore nominal 38 mA conditions with unchopped beam. With beam off, increase RFQ and DTL1 pulse width and condition structures if necessary. Summon an RCT to the control room to verify shielding at longer pulse length. With 38 mA peak current and 2 Hz rep-rate, increase beam pulse-length to 680 microseconds. Do not go beyond 680 microseconds due to D-plate beamstop limitations. Observe beam and LLRF signals. With choppers powered, increase pulse length to 1 msec, minimizing losses. Observe beam and LLRF signals over 1 msec beam pulse

3.16.2 Increase rep-rate

Reduce the pulse length to 50 microseconds. Slowly increase the repetition rate to 60 Hz, observing the loss monitor signals and tuning on losses as necessary. Summon an RCT to the control room to verify shielding at increased repetition rate.

3.16.3 Measure pulse-to-pulse variation of beam parameters

Measure the beam positions, beam phase and output energy from pulse-to-pulse.

3.16.4 Achieve highest possible source intensity

Cesiate source with Ion Source personnel to achieve highest beam current. Operate at 50 microseconds and 2 Hz, or at maximum pulse length as determined by diagnostics requirements. Transport to D-plate beamstop. Determine DTL1 phase and amplitude at higher beam current and compare with lower current results. Measure output emittance, beam profiles, etc.

3.16.5 Increase rep-rate and pulse length

Increase beam pulse length to 680 microseconds with choppers off and 2 Hz repetition rate. Summon an RCT to the control room to verify shielding at increased beam power. Slowly increase the repetition rate, monitoring the beam losses, beamstop thermocouples, drift-tube thermocouples etc. Repeat the same process for chopped beam up to 1 msec pulse length if the chopper systems are functioning.

3.16.6 Measure pulse-to-pulse variation of beam parameters

Measure the beam positions, beam phase and output energy within a pulse and from pulse-to-pulse.

3.17 OTHER MEASUREMENTS

3.17.1 Fast Farady Cup installation and characterization

If available, install Fast Faraday Cup in the MEBT anti-chopper box. Characterize the device, measuring the bunch length and adjusting rebuncher cavity amplitudes to vary the bunch length.

3.17.2 MEBT “round-beam” optics

Load MEBT “round-beam” optics. Tune up MEBT conditions at 20 mA, 50 microsec, 2 Hz. Transport beam to D-plate using nominal settings. Measure emittance in MEBT and D-plate and compare to 20 mA conditions in nominal MEBT optics.

APPENDIX A. DTL TANK 1 BEAM COMMISSIONING TASKS

	TASK	Duration (shifts)	Peak Current (mA)	Pulse Width (usec)	Rep Rate (Hz)	Beam Power (kW)	Beam stop
1	**Ion Source and RFQ Startup**	4.5	20	50	3	0.0075	MEBT
1.1	Ion source start up and cesiation (25 mA)	0.5					
1.2	RFQ conditioning	0.5					
1.3	MPS/timing checkout	0.5					
1.4	Establish beam through RFQ	0.5					
1.5	BCM1 checkout and adjustment	0.5					
1.6	LEBT optimization	0.5					
1.7	Commission integrating current measurement on BCM01	0.5					
1.8	Measure RFQ transmission vs. excitation	0.5					
1.9	Iterate LEBT optimization/RFQ transmission	0.5					
2	**Beam transport to MEBT beam stop**	10	20	50	3	0.0075	MEBT
2.1	Commission BPMs 1-4	1					
2.2	Set phase of rebunchers 1-3	0.5					
2.3	Trajectory correction up to beam stop	0.2					
2.4	Measure BPM phase noise with beam	0.5					
2.5	Commission Wire scanners 1-3	0.5					
2.6	Beam envelope measurements and correction up to beam stop	1					
2.7	Beam based calibration of rebunchers 1-2 voltage	1					
2.8	Commission D-box aperture	2					
2.9	Commission D-box video system/record profiles	1					
2.10	Verify BPM and corrector polarity	1					
2.11	Measure Orbit Response Matrix	1					
3	**Beam transport through DTL 1 to Energy Degrader/Faraday Cup**	6	5	20	2	0.0005	ED/FC
3.1	Tune MEBT for apertured beam	1	5	20	2	0.0005	MEBT
3.2	Transport beam through DTL1 to beam-box ED/FC	1					ED/FC
3.3	Commission beam-box ED/FC and software	1					
3.4	Perform Acceptance Scan with Energy Degrader/Faraday Cup	0.5					
3.5	Commission MEBT BPMs 5,6	0.2					
3.6	Tune MEBT steerers/correct MEBT trajectory	0.2					
3.7	Observe beam related signals on LLRF	1					
3.8	Commission Beam Loading Scan Software	0.5					

3.9	Perform Beam loading scan	0.5					
4	**Beam transport through DTL to D-plate Beamstop**	7	20	10	2	0.003	D-plate
4.1	Transport apertured beam to beamstop (&BCM signal)	1	5	10	2	0.00075	D-plate
4.2	Commission D-plate beamstop and Faraday Cup	1					
4.3	Commission Neutron detectors and loss monitors	1					
4.4	Set phase and amplitude of Rebunchers 3 and 4	0.5	5	20	2	0.0015	
4.5	Tune for maximum transmission	0.5	5	20	2	0.0015	
4.6	Remove MEBT aperture and transport to D-plate beamstop	1	20	20	2	0.006	
4.7	Tune for maximum transmission	0.5	20	50	2	0.015	
4.8	Commission MEBT Wire scanners 5 and 6	0.3					
4.9	Check MEBT beam profiles	0.3					
4.10	Verify BPM and corrector polarity	0.5					
5	**Commission D-plate Diagnostics and MPS**	17	20	50	2	0.015	D-plate
5.1	Commission BCMs and Halo monitor	1	20	20	2	0.006	
5.2	Center beam on Beamstop using Halo monitors	0.5					
5.3	Commission Differential Current System for MPS	2					
5.4	Verify MPS functionality with beam inputs	1					
5.5	Commission D-plate Energy Degrader/Faraday Cup	1	20	50	2	0.015	
5.6	Perform acceptance scan with both Faraday cups and compare	1					
5.7	Commission D-plate emittance system	2					
5.8	Commission Emittance Software and Analysis	2					
5.9	Measure DTL output beam emittance	1					
5.10	Commission Beam-box and D-plate Wire Scanner Systems	1					
5.11	Commission D-plate Wire Scanner Software	1					
5.12	Measure beamsize at WS vs. D-plate quad setting/compare model	1					
5.13	Measure beam profiles in MEBT and D-plate/compare with model	1					
5.14	Commission Viewscreen/Video System	1	20	6	1	0.0009	
6	**Perform Fault Studies**	4	10	20	2	0.003	D-plate
6.1	Power all MEBT correctors across full range/observe transmission	0.5					
6.2	Measure DTL1 transmission vs. RF amplitude and phase	0.5					
6.3	Measure transmission vs. rebunchers settings	0.5					
6.4	Measure transmission vs. quadrupole errors	1					
7	**RF System Checkout/Verification with Beam**	4	20	100	3	0.045	D-plate

7.1	Tune/measure RFQ amplitude and phase stability and control with bea	2					
7.2	Tune/measure DTL1 amplitude and phase stability and control with bea	2					
8	**Establish Phase and Amplitude Set-point**	23	20	50	3	0.0225	D-plate
8.1	Tune up 20 mA standard conditions	1	20	50	3	0.0225	D-plate
8.2	Commission D-plate BPMs	3					
8.3	Measure full MEBT Orbit Response Matrix	1					
8.4	Perform Acceptance Scan with Energy Degrader/Faraday Cup	1					
8.5	Perform Beam Loading Scan	0.5					
8.6	Measure BPM Phase Resolution w/beam	1					
8.7	Commission D-plate phase scan software	1					
8.8	Perform Phase Scan with BPMs	1					
8.9	Refine transport with new RF-setpoint	1					
8.10	Measure Orbit Response for refined settings	1					
8.11	Time-of-flight measurement for output energy	1					
8.12	Commission Bunch Shape Monitor	4					
8.13	Commission BSM Software	2					
8.14	Perform RF-setpoint with BSM	2					
8.15	Tune MEBT longitudinal matching with BSM	2					
9	**Establish Transverse Matching Conditions**	14	20	50	3	0.0225	D-plate
9.1	Commission MEBT inline emittance hardware and software	4					MEBT
9.2	Minimize MEBT emittance	2					
9.3	Measure DTL output beam emittance	1					
9.4	Improve Transverse Matching by minimizing RMS emittance	4					
9.5	Compare beam profiles w/model	1					
9.6	Measure Orbit Response matrix	1					
9.7	Test online model capabilities	1					
10	**Establish Long-Pulse Operation**	8	20	680	3	0.306	D-plate
10.1	Condition RFQ and DTL Tank 1 as necessary (No Beam)	1					
10.2	Increase pulse length / maximize transmission	1					
10.3	Perform Beam Loading Scan	1	20	100	3		
10.4	Measure RFQ and DTL LLRF phase/amplitude stability w/beam	2					
10.5	Measure output beam phase, energy and position variation during puls	1					
11	**Perform Aperture Scan**	7	5	10	2	0.00075	D-plate

11.1	Reconfigure MEBT quads for steering	0.5					
11.2	Tune-up apertured beam in MEBT	1					
11.3	Verify steering performance with D-plate BPMs	1					
11.4	Scan DTL 1 Aperture	3					
11.5	Reconfigure MEBT quads for focusing	0.5					
12	**Establish Nominal 38 mA beam conditions at DTL output**	13	38	50	3	0.04275	D-plate
12.1	Achieve 38 mA source current	2					MEBT
12.2	Tune MEBT for 38 mA output current	2					MEBT
12.3	Optimize transmission of 38 mA through DTL	0.5					D-plate
12.4	Measure DTL output parameters	0.5					
12.5	Re-establish RF setpoints and longitudinal matching	3					
12.6	Rematch MEBT to DTL transverse	3					
12.7	Measure Beam Profiles	1					
12.8	Measure Orbit Response Matrix	1					
13	**Characterize DTL 1 nominal output beam**	16	38	50	3	0.04275	D-plate
13.1	Characterize MEBT output beam for several currents	2	38	50	3	0.04275	D-plate
13.2	Optimize transverse matching and DTL RF setpoint	2					
13.3	Measure output trajectory/profile/emit vs. MEBT steering and compare	1					
13.4	Measure profiles and emittance vs. MEBT quad matching	1					
13.5	Measure Orbit Response matrix	1					
13.6	Bunch shape vs. longitudinal matching and compare w/model	1					
13.7	Measure emittance vs. beam current	1					
13.8	Measure emittance along beam pulse	1					
13.9	Make "Halo" measurements (insert scrapers?)	1	38	600	3	0.513	D-plate
13.10	Measure energy/phase within a pulse and pulse-to-pulse jitter	1	38	600	3	0.513	
13.11	Measure transverse position within a pulse and pulse-to-pulse jitter	1					
13.12	Measure variation of beam parameters as a function of time	1					
14	**Commission Chopper Systems**	15	38	50	3	0.04275	MEBT
14.1	Commission LEBT chopper system	3					MEBT
14.2	Measure LEBT chopping efficiency and rise/fall times with beam	1					
14.3	Commission MEBT chopper hardware	3					
14.4	Set LEBT to MEBT relative timing with beam	2					
14.5	Measure LEBT+MEBT chopping efficiency and rise/fall times with bean	2					
14.6	Transport chopped beam to D-plate	1					D-plate

15	**Characterize DTL 1 chopped output beam**	9	38	50	3	0.04275	D-plate
15.1	Restore baseline conditions without chopping	1					
15.2	Compare emittance, profiles, losses of chopped and unchopped beam:	8					
16	**High Duty Factor Measurements**	18	38	680	30	5.814	D-plate
16.1	Increase pulse length	3	38	680	2	0.3876	
16.2	Increase rep-rate	3	38	50	60	0.855	
16.3	Measure pulse-to-pulse variation of beam parameters	2					
16.4	Achieve highest possible source intensity	2	50	50	2		
16.5	Increase rep-rate and pulse length	6	38	680	60	11.628	
16.6	Measure pulse-to-pulse and within pulse variation of beam parameters	2					
17	**Other Measurements**						
17.1	Fast Faraday Cup installation and characterization		20	20	3	0.009	
17.2	Try MEBT "round-beam" optics		38	50	5	0.07125	
	Total Shifts	175.5					
	Total Days	58.5					