

CLS COMMISSIONING – PHASE I

LINAC and LTB (to OP2)

Technical Procedure 8.7.90.1 Rev. 1

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LINAC and LTB (to OP2)

1.0 PURPOSE

This report describes the principal components of the linear accelerator (linac) and the actions required to commission the linac to meet its requirements as the first stage of the injection system of the Canadian Light Source (CLS). Those requirements are to produce a pulse train of electrons from 2 to 136 ns in duration with a beam energy of 200 to 250 MeV and an average beam current of 60 mA in the pulse train. The pulse train must consist of “packets” of electrons typically 0.5 ns in duration at a frequency of 500 MHz (every 2 ns). Since the linac operates at a frequency of 2856 MHz the beam packets will be achieved by using a 500 MHz chopper.

The beam produced by the linac must have horizontal and vertical emittances not exceeding 0.3 mm-mrad, an energy spread of 2% or better and phase spread (at 2856 MHz) of about 12 degrees. The energy spread and phase requirements are necessary for subsequent reduction of the energy spread to 0.15% by the Energy Compression System (ECS). The small energy spread and transverse emittances are required for efficient transport to and injection into the CLS booster.

This report also describes the requirements for safely commissioning and operating the linac. This includes conventional and radiation safety requirements. Due to the levels of radiation produced by the linac when it is in operation the linac must be enclosed in a secure area (linac vault). The vault serves to exclude access to the linac environment while the linac is in operation and to shield the environment external to the secure area from the radiation that is produced. As well access to the secure area must be restricted until the residual levels of radiation have been measured and safe working conditions have been established.

This report also describes the transport of the beam to Optical Point 2 (OP2) of the Linac-to-Booster (LTB) transfer line. This brings the beam to the end of its transport in the linac vault. From this position the beam is bent upward into the booster tunnel in the new CLS building.

2.0 BACKGROUND

The purpose of this report is to provide an overview of the commissioning and operational procedures of the CLS linac required to safely and efficiently produce a beam of electrons suitable for injection into the CLS booster. The linac is composed of many components that have to be tested and deemed ready for the commissioning process. Details of these components are found in the references provided throughout the report.

The report includes all aspects of linac operation up to and including the Energy Compression System (ECS) and transport to optical point two (OP2) of the Linac-To-Booster (LTB) transfer line. Thus, all the components required to produce a beam suitable for transport to and injection into the CLS booster are described. OP2 is located in Experimental Area 3 (EA3 or room 004) and is the last optical point before the beam is bent vertically for transport to the CLS booster tunnel. **Commissioning of the section of the LTB that transports the beam vertically will take place at a later date.**

3.0 DEFINITIONS AND ABBREVIATIONS

p	pico (1×10^{-12})
n	nano (1×10^{-9})
μ	micro (1×10^{-6})
m	milli (1×10^{-3}) or meter
k	kilo (1×10^3)
M	mega (1×10^6)
G	giga (1×10^9)
eV	electron Volt
rad	radian
s	sec
A	Ampere
W	Watt
Hz	Hertz
RF	Radio frequency
ECS	Energy Compression System
ESS	Energy Spectrometer System
LTB	Linac-To-Booster (transfer line)
EA3	Experimental Area 3 (Room 0004)
OP1	Optical Point 1
OP2	Optical Point 2
TR	Transition Radiation
RTD	Resistance Temperature Device
HV	High Voltage

4.0 REQUIRED EQUIPMENT

The linear accelerator (linac) includes the electron gun, chopper, buncher and six (6) accelerating sections. Steering magnets and focusing elements are used to guide the beam through the accelerating sections. A variety of diagnostic tools enable the proper alignment and focusing of the beam as well as monitoring of the beam current. Determination of the beam energy is accomplished with the ECS and the ESS.

The gun and sections are dynamic in nature. Thus stable operation of the linac hinges upon proper set up of these components.

Set up starts with a specified beam objective. Five accelerating sections will be used to produce a beam with an energy between 200 and 250 MeV. A train of electrons from 2 to 136 ns in duration will be required. The nominal value is 136 ns. This is the maximum pulse length that can be efficiently accelerated by the CLS booster ring. The minimum value is small enough to occupy a single "bucket" in the booster or CLS storage ring.

The pulse train is chopped at 500 MHz to produce "packets" of beam suitable for injection into the booster. Sufficient current is required from the gun to meet the design goal of 10 mA of current

extracted from the booster. This means an average beam current, in the pulse train from the linac, of 60 mA. Details of the current requirements at each stage of acceleration are given in the following sections. These requirements assume certain beam losses in each stage of the acceleration process. The assumed beam losses are taken from shielding requirement calculations¹.

The beam energy is determined by three factors

- 1) the number of sections used
- 2) the RF power run to each of the sections used
- 3) the amount of current from the gun

4.1 (LINAC) RF DRIVE

The RF drive² is the common RF source for each klystron. A low power RF signal at a frequency of 2856 MHz from the RF drive is split seven ways and fed to six klystrons for amplification (with the seventh feed going to a test stand). After splitting, the amplitude of the RF power fed into each klystron can be adjusted by an attenuator. As well, the phase of the RF drive power, at each klystron, can be adjusted by a phase shifter. The duration of the RF drive signal is about 2 μ s. The repetition rate of the RF drive can be from a minimum of a 0 Hz to a maximum of 3 Hz. (Above 3 Hz the RF power delivered to the accelerator sections is reduced and section design goals cannot be met.)

4.2 (LINAC) TRANSMITTERS

Each transmitter consists of a modulator and a klystron. The modulators^{2,3} determine the duration and amplitude of the high power RF signal supplied by each klystron. Each modulator supplies a high voltage pulse to a klystron for about 1.5 μ s. The amplitude of the high voltage from the modulator together with the amplitude of the RF drive signal determine the amount of RF power delivered by each klystron to the accelerator sections. Optimization of the power delivered to each section is a key factor for stable operation. RF power is produced by each klystron when the RF drive and modulator high voltage are both present.

The klystrons provide the RF power that is supplied to the accelerating sections of the linac. The distribution of RF power is as follows:

- | | | |
|-----|------------|---|
| (a) | Klystron 1 | Prebuncher, Section 0, Section 1, ECS (Section 7) |
| (b) | Klystron 2 | Section 2 |
| (c) | Klystron 3 | Section 3 |
| (d) | Klystron 4 | Section 4 |
| (e) | Klystron 5 | Section 5 |
| (f) | Klystron 6 | Section 6 |

4.3 TIMING SYSTEM

The timing system^{4,5} coordinates the timing among the major systems of the CLS including the linac, booster and the storage ring. For the linac, an array of timing signals are used to set up the proper sequence of events and to optimize the performance.

Triggers from the timing system are used to adjust the timing of each of the transmitters to optimize the RF power from each klystron. Details of the timing are given in the sections that follow. The timing system produces triggers that can be adjusted over hundreds of microseconds with a resolution better than 1 ns. Typically, delays of a few microseconds are used.

For proper phasing of each section, the RF power to each section must be controlled within one degree of phase at 2856 MHz (about 1 ps). This part of the timing is achieved with the phase shifters that are part of the transmitters described above.

4.4 ELECTRON GUN

For nominal operation the gun must supply 6.4×10^{11} electrons in a 136 ns pulse. This corresponds to a DC current of 760 mA for the pulse duration. The energy of the electrons from the electron gun is 220 keV. For commissioning shorter pulses may be required and for some storage ring applications pulses as short as 2 ns may be required. The gun pulse duration is controlled by timing signals to both the GUN and the VIDEO deflectors. The pulse shape and amplitude is optimized by use of the steering controls (BIAS and GUN) and the focusing controls (LENS1 and LENS2).

The repetition rate of the gun can be set separately from the RF repetition rate. The gun repetition rate, however, must be adjusted so that RF is present in the accelerating sections when the gun is fired. Therefore, gun repetition rates of 1/1, 1/2, 1/3 etc. of the RF repetition rates are permitted.

4.5 CHOPPER

The chopper⁶ “chops” the beam from the gun into packets suitable for injection into the booster. Thus the chopper operates at a frequency of 500 MHz. The chopper typically allows 90 degrees of phase at 500 MHz to pass, producing a total of 68 0.5 ns long packets of electrons in the 136 ns pulse. Therefore, 75% of the beam current produced by the gun is lost in the chopper leaving 1.60×10^{11} electrons to continue to the acceleration stage. This corresponds to an average current of 190 mA in the 136 ns pulse. Without the chopper in operation (i.e., for commissioning up to, but not including, the booster) the gun current can be reduced to keep the average current around 190 mA. For the initial commissioning of the linac the chopper will not be used.

4.6 ACCELERATING SECTIONS AND RF POWER

The accelerating sections operate at a frequency of 2856 MHz. Each section is fed by a waveguide delivering RF power from the klystrons described earlier.

4.6.1 Prebuncher, Section 0 and Section 1

Section 0, together with the prebuncher, bunches the beam into bunches with phase duration suitable for efficient acceleration through the remaining sections. With the chopper in operation these bunches exist within the packets produced by the chopper. As well as bunching the beam, section 0 accelerates the electrons to an energy of about 13 MeV. During the bunching and acceleration process about one third of the beam is lost, leaving 1.07×10^{11} electrons in the pulse train. This corresponds to an average current of 126 mA in the pulse train.

The prebuncher and Section 0 are supplied with RF power from klystron 1. The RF power is distributed in the following way. First about one third of the RF power from klystron 1 is split off to be used in section 7 which is part of the ECS. The remaining two thirds of the power is used to feed the sections 0 and 1. A small part of this RF power is split off to operate the prebuncher. RF power levels in the prebuncher can be controlled by an attenuator. The remaining power is fed to section 0 and through to section 1 where it is absorbed by an RF load. Thus, section 0 and section 1 are set up together since the RF loading can only be observed at the end of section 1.

Section 1 mainly serves to accelerate the beam. Under optimum conditions the beam energy after section 1 is about 43 MeV.

4.6.2 Sections 2 thru Section 6

Four of the remaining five accelerator sections will be used to accelerate the electron beam to an energy between 200 and 250 MeV. In the limit of no current (zero loading) the energy gain in each section is as follows:

Section	0	1	2	3	4	5	6
Energy Gain (MeV)	13	30	55	55	55	50	50

For ease of operation of the transfer lines, booster and storage ring, it is desirable to establish a set beam energy from the linac that will be used for all future operation. Linac commissioning will establish the best operation energy considering a variety of accelerator section combinations. For this purpose, sections 2 through 6 should be set up so they each will accelerate the beam by the same amount. Considering 50 MeV per section a total of 243 MeV can be reached (in the zero loading limit and operating with one section off). With beam loading a final energy of about 230 MeV might be more practical.

It may also be possible to use all six sections, with some at lower RF power, to produce the same final energy. This would have the advantage of reducing the work done by some klystrons and thus increase their operational lifetime. As well, lower electric fields in a section reduces the possibility of arcing.

It is expected that the beam loss through the acceleration process will be 5%. This leaves 1.01×10^{11} electrons or an average current of 119 mA in the pulse train.

The beam current will be further reduced by the emittance slits at the end of the linac. To produce a low emittance beam, the slits will be set to an aperture of a few millimeters. This is estimated to reduce the beam current by a factor of two, leaving 5.07×10^{10} electrons or an average current of 60 mA in the pulse train.

4.7 FOCUSING AND STEERING

A number of focusing and steering elements are required to efficiently transport the electron beam through the various stages of acceleration. These include the solenoids, quadrupole magnets and a number of steering magnets.

4.8 DIAGNOSTICS AND MEASUREMENTS

A variety of diagnostic elements are used to monitor the transport of the electron beam through the acceleration stages. These include current monitors (toroids) and position monitors. The position monitors include a pop-monitor after section 1 and transition radiation monitors at other positions along the linac.

For commissioning and setting up the linac, the beam will be allowed to proceed directly to beam dumps where the beam current can be measured.

4.8.1 Current Monitors

The current monitors measure both the beam current and the pulse duration. A fast current transformer (Bergoz) capable of measuring the pulse structure will monitor the beam directly after the video deflector to aid in confirming the chopper and video deflector operation.

4.8.2 Transition Radiation Monitors

The transition radiation (TR) monitors⁷ will be used to precisely measure the size of the electron beam and beam position along the linac and LTB transfer line.

4.8.3 Strip-line Monitors

Strip-line monitors will be used to precisely measure the position of the electron beam in the LTB transfer line.

4.8.4 Pop-up Monitors

“Pop-up” monitors are required where the beam energy or the beam intensity is too low to produce a good TR signal. Initially, pop-up monitors will be installed at locations along the linac. Pop-up monitors crudely measure both the size and position of the electron beam.

4.8.5 Radiation Monitors

Radiation monitors will be used along the length of the linac to detect beam spills that could indicate mis-steering, poor focusing or poor phasing of the accelerator sections.

4.8.6 Temperature Monitors

Thermocouples and RTD temperature sensors will be used to monitor the temperature of accelerator sections. Thermostat switches are used to detect over temperature conditions for magnet coils.

4.8.7 Energy Measurement

The initial measurement of the beam energy will be done using the first dipole of the ECS (see 4.9). The beam energy is proportional to the magnetic field required to bend through the exit port of the dipole. A more precise measurement of the beam energy will be made with the ESS (see 4.8.9).

4.8.8 Emittance Measurement

Emittance measurements are made as described in reference 8. The process utilizes part of the linac to booster transfer (LTB) line immediately after the ECS. This part of the LTB will have to be operational for the linac commissioning.

4.8.9 Energy Spectrometer System (ESS)

The ESS will be used to measure the energy and the energy spread of the electron beam from the linac. The ESS is physically located after the ECS and will be used to measure the characteristics of the beam that has undergone energy compression. A description of the ESS is given in reference 9.

4.9 ENERGY COMPRESSION SYSTEM (ECS)

The ECS compresses the energy spread of the electron beam delivered by the linac. The process takes place in two stages. First the beam is passed through three dipole magnets that have the net effect of increasing the phase spread of the beam bunch (at 2856 MHz) from 12

degrees to 120 degrees. At this stage the phase of the electron in each bunch is directly correlated with the relative energy of the electrons, with the more energetic electrons at the head of the bunch and the least energetic at the tail. In the second stage the electrons passed through an accelerating cavity (section 7) where the electrons are differentially accelerated in such a way that the energy spread of the beam is reduced from 2% to <0.3%. Details of the ECS are described in reference 10. The ECS will reduce the beam current by about 10%, leaving 4.56×10^{10} electrons or an average current of 54 mA in the pulse train.

4.10 LTB TRANSFER LINE

The linac-to-booster (LTB) transfer line transports the beam from the ECS to the CLS booster as described in references 8 and 11. For the linac commissioning the beam will be transported through the first leg of this system to a beam dump at the location of OP2. OP2 is located just before the first dipole magnets that bend the beam upward to the booster tunnel. Beam losses to this point should be about 2.5% leaving 4.45×10^{10} electrons or an average current of 53 mA in the pulse train.

Note: Using a pulse train of 136 ns, 25 mA are required to “fill” the booster with an average current of 10 mA. Expected additional losses in the remainder of the LTB transfer line and losses in the booster injection process determine the current required at OP2.

5.0 COMMISSIONING PLAN

ATTENTION: Before any part of the linac is turned, on both machine protection and personal safety interlocks must be in place. See Sections 6.0 and 7.0.

5.1 RF DRIVE

The RF drive is turned ON. To prepare for optimization of the transmitters the RF START trigger is selected.

5.2 TRANSMITTERS

The transmitters that are to be used are selected. As described earlier this will include transmitter 1 and four of the remaining transmitters. The transmitters are adjusted before the electron gun is turned on. Turn on the modulators and wait for tube filaments to heat up (20 minutes.)(Note: the accelerating sections that are to be used must be at the correct operating temperature. Those that not to be used are “detuned” by setting them off temperature.)

5.2.1 Transmitter 1

Transmitter 1 is used as the timing reference. Modulator 1 High Voltage is turned ON and the RF drive is enabled. The modulator output voltage is displayed on an oscilloscope. The output of klystron 1, as measured on the RF forward, is displayed on the same oscilloscope. The RF START trigger is adjusted so that the RF forward signal is more or less symmetrically nested in the modulator output voltage signal. Next the attenuator for the RF drive signal to klystron 1 is adjusted so that the amplitude of the klystron output is peaked and stable. If necessary, the amplitude of the klystron output can be adjusted with the supply to the modulator. Changing the modulator high voltage will require readjusting the RF drive attenuator so the klystron output is once again peaked and stable.

5.2.2 Transmitter 2

Assuming transmitter 2 is to be used: Modulator 2 is turned ON. The modulator output voltage is displayed on an oscilloscope. The output of klystron 2, as measured on the RF forward, is displayed on the same oscilloscope. The transmitter 2 trigger is adjusted so that the RF forward signal is more or less symmetrically nested in the modulator output voltage signal. Next the attenuator for the RF drive signal to klystron 2 is adjusted so that the amplitude of the klystron output is peaked and stable. The amplitude of the klystron output can be adjusted with the supply to the modulator. Changing the modulator high voltage will require readjusting the RF drive attenuator so the klystron output is once again peaked and stable.

5.2.3 Transmitters 3 through 6

For the transmitters that are selected: The same procedure is followed as given above for transmitter 2. For "2" read "3", "4", "5" or "6".

5.3 ELECTRON GUN

Adjust the tube filament and HV to proper levels. The injected current is set by adjusting the control: PULSER KV. (The relationship between the pulser and the injected current can be found in "Gun Running Data".)

The gun controls are hard-wired and labeled as they came from the manufacturer. The elements they control follow the new CLS naming and numbering convention. The correlation is as follows:

GUN (steering)	ST0001-01
BIAS	STH0001-01 and STV0001-01
DRIFT	ST0001-02
ACCEL	ST0001-03
LENS1	SOL0001-01
LENS2	SOL0001-02
LENS3	SOL0001-03
SOLENOID 1	SOL0001-04
SOLENOID 2	SOL0001-05
SOLENOID 3	SOL0001-06

- 1) Set up usually starts with degaussing all the dipoles where the beam is required to pass straight through in subsequent set up procedures. This includes the ECS dipoles, the first dipole of the ESS and the first dipole of the "switchyard".
- 2) With the gun repetition rate set at 1 to 3 Hz, view the Fast Current Transformer FCT0001-01 signal on an oscilloscope. (If this is difficult see step 5) (Note: the gun repetition rate can be different than the RF repetition rate. Since acceleration will only take place when the RF is on, the gun rate should be an integer fraction of the RF rate. E.g., 1/1, 1/2, 1/3 etc.)
- 3) The gun timing is set up next. The video deflector triggers (VIDEO ON and VIDEO OFF) have to be moved away from the pulse (VIDEO ON towards 0 ns and VIDEO OFF >10 μ s). With the GUN ON trigger set to approximately 3 μ s, the GUN OFF trigger is adjusted to get a 5 μ s pulse on the oscilloscope

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- 4) LENS1 and LENS2 and the BIAS and GUN (steering) are adjusted to maximize the pulse amplitude on the oscilloscope. (NOTE: steering controls are dual function and can be selected to steer in either plane.) These controls require a substantial amount of adjustment in order to obtain a good pulse.
 - 5) If the beam is not found on FCT0001-01 check the following:
 - A. The GUN KV AUTO button must be on.
 - B. The GUN KV must be up to (-)220 kV.
 - C. The injector and deflector controls must all be on.
 - D. The programmable controller must be ready for gun operation.
 - 6) The beam pulse can now be adjusted to create a 136 ns duration pulse.
 - A. The VIDEO ON trigger is cut in to eliminate (about) the first 500 ns of beam in order to obtain a very sharp leading edge to the pulse.
 - B. The VIDEO OFF trigger is then cut in to obtain a 136 ns pulse.
 - C. If the VIDEO ON trigger and/or the VIDEO OFF trigger do not cut into the beam this means the beam is being steered around the deflectors. This can be corrected by more adjustment of the BIAS, GUN (steering), LENS 1 and LENS 2.
 - D. Note the current measured by FCT0001-01. Without the chopper in operation an average current (in the pulse train) of 95 mA is required.

5.4 CHOPPER

For initial commissioning of the linac, the chopper will not be used. The chopper will be used for the commissioning of the CLS booster at a later date. When the chopper is running properly the beam current from the gun will be increased since the chopper will eliminate about 75% of the gun current. (see Sec. 4.5) Since the chopper eliminates 75% of the beam current from the gun, the gun current may be increased by a factor of four when the chopper is used. This results in the same current in the accelerating sections as when there is no chopper used.

5.5 ACCELERATING SECTIONS

The RF power to each section that will be used has to be adjusted as described earlier. Proper acceleration in each section requires that each section is running at the correct temperature. The heat exchangers for each section must be operating and regulating the temperature as required. Sections that are not used for acceleration are detuned by changing the temperature of the section.

In the following description (up to the ECS) the various elements and diagnostics will be designated with a shortened label eliminating the area designation. A few examples are:

ST0001-01	ST1.1
FCT0001-01	FCT1.1
Q0001-01	Q1.1

5.5.1 Prebuncher, Section 0 (Buncher) and Section 1

RF to the Prebuncher, Section 0 and Section 1 is delivered via the waveguide from klystron 1. Klystron 1 also supplies RF power to Section 7 that is part of the ECS.

The amount of RF power delivered to the prebuncher is set by adjusting the prebuncher attenuator (ATN1).

5.5.1.1 Timing and Phasing

The timing of transmitter 1 has been adjusted as described earlier. Now the gun timing must be adjusted to ensure the beam passes through the accelerating sections when the RF power is present. This is achieved by observing the electron beam at FCT1.1 and the RF load (RFL1.1) of section 1 on the same oscilloscope. The electron beam should be nested in the RF pulse. This is done by assigning the four gun triggers (GUN ON/OFF and VIDEO ON/OFF) to the same control “knob” and moving the electron beam relative to the RF pulse.

At this time the beam pulse is measured at toroid TCT1.1. The ratio of the currents measured at FC1.1 and TCT1.1 should be $I_{TCT} / I_{FCT} = 0.66$. The TCT1.1 current can be optimized by using the gun focusing controls: LENS 3 and solenoids SOL1.1, SOL1.2 and SOL1.3.

Once the timing is adjusted the phasing of the section 1 RF is adjusted to maximize the loading as seen on the load of section 1. This must be done in conjunction with steering and focusing described below.

5.5.1.2 Steering and focusing

Use steering magnets STH1.6 and STV1.6 and gun steering ACCEL and DRIFT to maximize the signal on TCT1.2 and center the beam on view screen VSC1.1. Use quadrupoles QF1.1, QD1.1 and QF1.2 to focus the beam on VSC1.1. QF1.1 and QF1.2 are controlled together. Use the quadrupole “triplet” to maximize the signal at TCT1.2. Try to obtain the smallest spot with the lowest quadrupole values. QF1.1 and QF1.2 should be about 2.5 to 3 A and QD1.1 should be about 7 to 8 A (when PULSER is set between 0.1 to 0.7 kV). At this stage, the signal on TCT1.2 may be optimized by adjusting the gun timing and section 1 RF phase as described earlier. Next oscillate the quadrupoles of the triplet to see if the beam is steering at VSC1.1 and remove the steering by using STH1.6 and STV1.6. After the steering is removed the beam can be centered (again) by using STH1.7 and STV1.7.

The beam should now be visible on VSC1.2. Use STH1.7 and STV1.7 to center the beam on this viewer. This should maximize the current measured on TCT1.3. Double check the steering by oscillating the quadrupole triplet. Use solenoids SOL1.4, SOL1.5 and SOL1.6 to further focus the beam and maximize the beam current.

5.5.2 Sections 2 and 3

5.5.2.1 Cooling

If section 2 or 3 is to be used the temperature is set to the correct operating temperature. If section 2 or 3 is not to be used it is detuned by setting the temperature well away from the operating temperature (55°C).

5.5.3 Timing and phasing

If the section is being used for acceleration, the timing of transmitter 2 or 3 has been adjusted as described earlier. The phasing of the section RF is adjusted to maximize the loading as seen on the load of the section (RFL1.2 or RFL1.3). This must be done in conjunction with steering and focusing described below.

5.5.3.1 Steering and focusing

Use the STH1.8 and STH1.9 to approximately center the beam on VSC1.3. Use the STH1.9 and STV1.9 to fine tune the position. Use SOL1.7 and SOL1.8 to focus the beam. The steering and focusing can now be adjusted to maximize the signal on TCT1.4.

5.5.4 Sections 4,5 and 6

5.5.4.1 Cooling

If section 4,5 or 6 is to be used the temperature is set to the correct operating temperature. If section 4,5 or 6 is not to be used it is detuned by setting the temperature well away from the operating temperature.

5.5.4.2 Timing and phasing

Assuming the section is being used for acceleration, the timing of transmitter 4, 5 or 6 has been adjusted as described earlier. The phasing of the section RF is adjusted to maximize the loading as seen on the load of the section (RFL1.4, RFL1.5 or RFL1.6). This must be done in conjunction with steering and focusing described below.

5.5.4.3 Steering and focusing

Use STH1.10, STV1.10 and SOL1.9 to center and focus the beam on VSC1.4. Use SOL1.9 to focus the beam. The beam should now be observed by the current monitor ICT/FCT10003-01 located beyond the ECS. The current observed at this current monitor should be about 95% of the current observed at TCT1.1.

Failing to transmit 95% of the current through the accelerating sections indicates more steering, focusing and phasing adjustment is required in each section.

5.6 ENERGY COMPRESSION SYSTEM (ECS)

In the following description in the ECS region and beyond the various elements and diagnostics will be designated with a shortened label eliminating the area designation. A few examples are:

ST0002-01	ST2.1
FCT0002-01	FCT2.1
Q0002-01	Q2.1
ST0003-01	ST3.1
ICT0003-01	ICT3.1
Q0003-01	Q3.1

5.6.1 Straight Through Operation

Open the emittance slits, CLH2.1 and CLV2.1 to 20 mm for setting up the ECS. Before the ECS is used, the ECS magnets must be degaussed so that the beam can be transported straight through.

5.6.1.1 Steering

Using STH2.1, STV2.1, STH3.1 and STV3.1 center the beam at TRM3.1. (Note: for initial commissioning TRM3.1 may be a view screen.) Look at the ICT/FCT3.1 signal to aid in the initial steering. Now use the ST3.1 steering magnets to maximize the current on the current monitor and to obtain a square pulse. Now adjust the emittance slits to 8 mm and use the steering magnets to maximize the beam current.

5.6.1.2 Focusing

Squeeze the beam with quadrupoles QD3.1 and QF3.1. Oscillate the quadrupoles to remove the steering while keeping the beam centered on TRM3.1 (view screen).

5.6.1.3 Dumping the Beam

Proper set up of the straight through operation should allow the electron beam to proceed down the beam pipe beyond the ECS to the straight through dump. At this stage however, the beam is not focused for optimum dumping of the beam (BST3.2). Focusing of the beam can be done with the "phase space" quadrupoles, (QD1.1, QF3.1, QB3.1 and QD3.2) and the quadrupole just before the dump (QF3.3) to optimize the dumping of the electron beam.

5.6.2 ECS Operation

5.6.2.1 B2.1

Using dump BST2.1, set the first ECS dipole (B2.1) close to the approximate beam energy. The dipole should be set with the established cycling procedure. That is, run the dipole to full current and then return it to the appropriate value. To determine the maximum energy of the linac, adjust the phase of each section while changing B2.1 to obtain the field where a stable square pulse is observed on BST2.1. At this stage, the four gun triggers (ganged together) and transmitter delays can be "tweaked" to optimize the dump signal. As well, the prebuncher phase and attenuation may be adjusted.

5.6.2.2 B2.2

Open the energy slits (CLH2.2) to 20 mm. Adjust B2.2 to maximize the signal on dump BST2.2. B2.2 should be set with the established cycling procedure described above. Check the energy spread of the beam by observing the current on BST2.2 for two CLH2.2 slit settings. The dump signal with the slits at 7 mm should be about one half the signal that is observed for a setting of 14 mm. This can be optimized by using the section phases and may require readjusting dipole B2.1. (The signal at 14 mm should be close to 100% transmission.)

5.6.2.3 B2.3

To avoid emittance blowup B2.3 must be set to the same field as B2.1. After B2.3 is set the beam should be observed on TRM3.1 (viewer). If the beam is not seen B2.2 should be adjusted until the beam is observed and the current maximized on ICT/FCT3.1. B2.3 should be set with the established cycling procedure described above. The current measured on ICT/FCT3.1 should be a minimum of 90% of the value measured in the straight through operation. Failure to meet this efficiency requires a readjustment of the steering through the ECS.

5.6.2.4 Steering

Oscillate QD3.1 and QF3.1 and eliminate the steering at TRM3.1 using the ST2.1 and ST3.1 steering magnets.

5.6.2.5 Section 7

The RF supplied to section 7 should be adjusted using the attenuation of the RF power to the section. Set the attenuation to the book value (see ref. 10). The phase of the RF must be adjusted to maximize the energy compression and produce the minimum energy spread. This can be done once the ESS is set up. The ESS is described below.

5.7 LINAC MEASUREMENTS

5.7.1 Energy Spectrometer System (ESS)

A more precise determination of the electron beam energy is achieved using the ESS.

To begin, all the “phase space” quadrupoles (QD3.1, QF3.1, QB3.1 and QD3.2) are set to zero. Next the dipoles B3.1, B3.2, and QF3.2 are set to the energy determined from the ECS measurements. (The established cycling procedure is used.) The beam should now be seen on the TRM3.2 directly following B3.2 and should be present on the ESS beam dump (BST3.1).

The beam can be centered on the TR monitor by making a small adjustment to the field values of the dipoles (B3.1 and B3.2). The position of the beam at the TR monitor can be further defined by focusing the beam. QF3.2 is used to create a horizontally focused beam. The ESS slits (CLH3.1) can be used to check the position. With the slits at a value of 4 mm, the dipoles can be adjusted to give the maximum current measured in the ESS dump. The field value of the dipoles that places the beam in the center of the TR monitor and maximizes the dump current gives the beam energy.

When QF3.2 is used to produce a minimum horizontal beam size at the TR monitor the extent of the beam is dominated by the energy spread of the beam. The energy spread is deduced by the beam size and by the theoretical dispersion of the ESS system. The ESS slits will also be useful in this measurement since they can be used to observe beam transmission to the dump for various horizontal apertures.

5.7.2 Emittance Measurement

The emittance measurement procedure is described in detail in reference 8. The measurement utilizes two of the phase space quadrupoles and the viewer at OP1. Since OP1 is downstream from B3.1 on the LTB transfer line, B3.1 must be degaussed to allow straight through passage of the beam.

Emittance measurements should be made for a variety of settings for the emittance slits CLH2.1 and CLV2.1. This will determine the optimum slit settings required to produce small emittance while allowing the maximum current in order to reduce the gun current requirements. This will ensure the lowest levels of radiation produced by the slits.

5.7.3 Commissioning Measurements

The performance of the linac for all combinations of accelerating sections (see 4.6.2) will be evaluated. As mentioned earlier, it is desirable to find the RF requirements for each of the sections from section 2 to section 6 such that using any four of these sections will result in the same beam energy. This can be accomplished by adjusting the modulator high voltage to each klystron. Fine tuning can be accomplished by adjusting the gun current, keeping in mind that the operating current should be near the required value for all set up.

There are five different combinations for operating four of the five sections from 2 to 6. For each one of these combinations, besides finding a common energy, the beam quality will have to be measured. The beam energy spread, and beam emittances will have to be measured, as described above, to ensure the beam quality is suitable for injection into the CLS booster.

Measurements at this time should also ensure that the pulse train duration is not decreased by the acceleration process. As well, the transport efficiencies through each stage of acceleration and transport must be measured to ensure that the efficiencies are as good as or better than the efficiencies assumed in reference 1. These are the most important measurements for determining the radiation levels produced and defining safe conditions for both the machine and personnel.

5.8 LTB TRANSPORT

LTB transport may only proceed if the vertically bending magnet B0004-01 is off. This magnet will be interlocked or disconnected to ensure that the beam is not bent vertically. The magnet will be properly degaussed to allow straight through access to the dump BST0004-01.

Initial commissioning of the beam will include transporting the beam through the first leg of the LTB transfer line to a beam dump located in EA3 (BST0004-01).

Once the beam energy has been determined using the ESS, the LTB magnets can be set for operation at that energy. This should occur after the beam emittance measurements have also been made and B3.1 has been degaussed. The dipole magnets in the switchyard, B3.3 and B3.4, should be set with the established cycling procedure.

Details of the LTB transport are given in references 8 and 11.

5.8.1 LTB Measurements

Transport of the beam through the switchyard magnets B3.3 and B3.4 should confirm the beam energy and energy spread. Transport of a beam with sufficiently small transverse emittances and energy spread should result in 97.5% of the beam reaching the beam dump (BST40004-01). The emittance slits, CLH2.1 and CLV2.1, should be adjusted to increasingly larger apertures to determine the limit of efficient beam transport to the EA3 dump.

The beam at the EA3 dump is near “optical point 2” (OP2) of the LTB transfer line. The beam at OP2 should be properly focused to ensure that the beam is properly set up for future transport to the CLS booster.

Beam diagnostics at OP2 include a current monitor (ICT0004-01), a stripline monitor (SLM004-01) for transverse position measurement and a TR monitor (TRM0004-02) for beam profile measurement.

5.9 COMMISSIONING TIME SCHEDULE

A single setup of the linac should take about 4 to 8 hours. This would include accurately measuring the beam energy, energy spread and beam emittances. Thus, it should take two to four days to establish the conditions necessary to run the five different combinations of sections. This time estimate is based on experience setting up the linac in the past and assumes that the gun and transmitters have already been commissioned. This time estimate also assumes that the beam diagnostics will work as anticipated. The current monitors and TR monitors are untested at low repetition rates. For commissioning purposes the repetition rate can be increased to 3 Hz to increase the signal in the monitors.

The above time schedule also assumes that individual components are operating as required. Final testing of some components requires the electron beam so some time may be required to commission these components. This includes current monitors, position monitors and temperature regulators for the accelerating sections.

The commissioning of the linac will be the first major test for the CLS control system. Time must be allowed for commissioning this system as well.

6.0 MACHINE PROTECTION

To avoid excessive beam spills along the linac, the machine protection system must be enabled before the linac can be operated. The temperature control system, power supply statuses and radiation levels will be continuously monitored.

6.1 VACUUM FAILURE

The vacuum pressure in the waveguides leading from the klystrons to the accelerating sections must be lower than predetermined values before RF power is allowed to propagate through the waveguides. Loss of vacuum quality will result in the RF drive to be disabled. The gun is disabled by any excessive vacuum pressure fluctuations.

The vacuum pressure in the accelerator sections and beam pipe must be lower than predetermined values before beam is allowed to pass through. As noted, loss of vacuum quality automatically causes the gun to be turned off.

6.2 TEMPERATURE CONTROL

Temperature stability of the accelerating sections to within ± 0.1 degree C is important for stable operation of the linac. Temperatures will be monitored and can be checked if beam stability becomes a problem. The linac can be turned off at the operator's discretion, at which time temperature control can be adjusted by a qualified technician.

Large variations in temperature will result in the gun and RF drive both being disabled by the control system. Heat exchanger performance and water flow rates are also monitored for possible indications of problems with the cooling systems.

6.3 POWER SUPPLIES

Power supply failures may result in the mis-steering or defocusing of the beam in the linac or LTB transfer line. Consequently the failure of any magnet power supply will result in the gun being disabled. Similarly, the failure of a modulator will result in the gun being turned off.

6.4 RADIATION MONITORING

Radiation monitors at various locations in the linac vault will indicate possible abnormal levels of radiation. "Normal" levels of radiation will be established as discussed below. Monitoring of radiation levels can indicate problems with the linac that may result in excessive radiation at specific sites. For radiation levels up to thresholds established by the radiation safety officer, disabling the linac will be at the discretion of the machine operator. If radiations levels exceed safe working conditions outside the vault the linac will be automatically disabled. Part of the commissioning process will be to establish the correlation between radiation levels inside the vault with those external to the vault where safe working conditions must be maintained.

As well, components may become radioactive which will make their maintenance more difficult.

7.0 PERSONNEL PROTECTION

Operation of the linac cannot proceed until the personnel protection system is enabled. The primary purpose of the personnel protection system is to ensure that personnel are not exposed to unacceptable levels of radiation. A secondary function is to ensure that personnel are not exposed to conventional hazards such as power supplies and chemical hazards.

For these reasons, the linac is enclosed in a secure area (linac vault). No personal are allowed in the secure area during operation of the linac. This is ensured by a lockup procedure as described in reference 12. Once the lockup is complete the linac can be enabled.

7.1 RADIATION SAFETY

During commissioning and routine operation of the linac, radiation levels both inside and outside the linac vault will be monitored.

Radiation levels outside the vault will be monitored to ensure that radiation levels are in compliance with the guidelines described in reference 13.

Radiation levels inside the linac vault will be monitored to indicate possible errant beam conditions during commissioning or setup and to establish “normal” background levels during routine operation. Re-entry will be permitted once the radiation levels are deemed safe. At re-entry, extra monitors such as personal dosimeters and hand held radiation monitors will be used to monitor doses received and to check the background radiation levels at key locations in the vault. Once radiation levels are established, access times to different areas can be determined and regulated.

7.1.1 Commissioning Considerations

7.1.1.1 Radiation Outside the Linac Vault

Radiation levels outside the linac vault will be measured at each stage of linac commissioning. If levels exceed acceptable levels¹⁴, commissioning will proceed with the gun current reduced to bring the radiation levels to an acceptable level.

Note: radiation levels due to linac operation and beam transport to the beam dump in EA3 are not expected to be a problem. However, special care will be taken to ensure the radiation levels in areas outside the new elevator shaft and the LTB transfer tunnel are not excessive.

7.1.1.2 Radiation Inside the Linac Vault

Each time access to the vault is required after the linac has been in operation, residual radiation levels inside the vault will be surveyed by radiation safety personnel and safe working conditions established. Background radiation levels will be clearly displayed. All personnel entering the vault area are required to wear personal dosimeters.

Short term, restricted, access to the linac vault will be done with a so-called “button access” as described in the lock-up procedure. One person at a single access point will ensure that personnel entering the linac vault will carry radiation monitoring equipment and personal dosimeters. Button access disables the linac.

8.0 REFERENCES

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Appendix A: Diagrams and Drawings

The equipment necessary for the commissioning of the linac and LTB transfer line is identified in the process flow diagrams ACCL/PFD/OPT/0045301(Rev. B) and LTB1/PFD/OPT/0045302(Rev. B) and is shown in drawings ACCL/ME/0005101(Rev. B), ACCL/ME0005102(Rev. B), LTB1/ME/0034601(Rev. B), LTB1/ME/0034602(Rev. F) and LTB1/ME/0034603(Rev. F).