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DESIGN OF A NEW S-BAND 250 MeV ELECTRON LINAC WITH RF SLED COMPRESSION FOR THE CLS

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Abstract

RI Research Instruments (RI) in partnership with The Canadian Light Source (CLS) have designed a new 250 MeV electron linac to inject into the 0.25–2.9 GeV booster synchrotron. The RF frequency is 3000.24 MHz, the sixth harmonic of the 500.04 MHz booster and storage ring RF cavity frequency, and the main accelerating sections consists of three 5 m constant gradient accelerating structures. The 3 GHz bunching sections and the first accelerating structure are fed by a 40 MW klystron, while structures two and three are fed by a single 40 MW klystron powered by a solid state modulator (SSM) from Scandinova with a SLED RF compression scheme. The electron source consists of a 90 keV thermionic cathode with a 500 MHz modulated grid and a 500 MHz sub-harmonic pre-buncher to synchronise with the booster ring cavity frequency. A single-bunch mode can be delivered, as well as a multi-bunch with up to 140 ns bunch trains of up to 5.6 nC of charge per shot, both at a 1 Hz repetition rate to match the booster ramp cycle. The project is scheduled to bring the linac into operation for top-up injection into the CLS storage ring by mid-2024. This paper will present the design with a special focus on the implementation of a SLED to deliver a recovery mode of operation using only a single klystron.

INTRODUCTION

The CLS is Canada's national light source and operates over 22 beamlines for scientific users [1]. It was built starting in 1999 by extending the existing Saskatchewan Accelerator Laboratory (SAL) which was established in 1962. SAL operated a 2856 MHz electron linac with a maximum energy of 300 MeV [2] for fixed target nuclear physics experiments. The SAL linac was repurposed to inject 250 MeV electrons into the CLS booster synchrotron [3] which accelerates the beam to 2.9 GeV and injects it into the storage ring at full energy [4].

To improve reliability and upgrade equipment from the 1960s, a new linac is being installed in 2024 with a turnkey system from Research Instruments (RI) [5]. The key requirements for the linac are shown in Table 1.

The design produce by RI was based on previous light source linacs they have delivered, some examples are in References [6–9]. A new aspect to the RI design for the CLS is the inclusion of SLEDs and a recovery mode discussed later. RI have delivered stand alone SLEDs previously [10, 11], which facilities have integrated into their linac systems in-house. The RI design for CLS will reduce the number of structures from six in the present SAL linac to three in the new linac. Using a SLED and higher power klystrons, the new linac will only have two klystrons compared the present number of six used in the SAL linac.

Table 1: Requirements List for the New CLS Linac

Parameter	Value
Maximum Energy	250 MeV
Recovery Energy	180 MeV
Repetition Rate	1 Hz
RF Frequency	3000.24 MHz
Single Bunch Length	1 ns
Multi Bunch Length	10–140 ns
Energy Stability	< 0.1% RMS
Energy Spread	< 0.5% RMS
Normalised Emittance	< 50π mm.mrad

MAIN LINAC COMPONENTS

The main components of the linac are shown in Fig. 1 and described below. The electrons are generated in a 90 keV DC thermionic cathode with a grid that is modulated at 500.04 MHz to match with the RF frequency in the booster ring. After focusing using a solenoid, the beam is then further bunched with a 500.04 MHz Sub-harmonic Pre-Buncher (SPB). This pre-injector part of the linac will ensure beam is delivered only into the accelerating phase of the booster ring and significantly improving the injection compared to the existing SAL linac, which is unsynchronised with the booster at 2856 MHz and prestnly all s-band RF buckets are filled, leading to only around half of the beam being captured by the booster 500 MHz RF.

To prepare the beam for the 3000.24 MHz main accelerating sections, there is a one cell Pre-Bunching Unit (PBU) and a fourteen cell Final Bunching Unit (FBU). The FBU further bunches the beam and increases it from 90 keV to approximately 4 MeV using a $2\pi/3$ accelerating mode. The beam is

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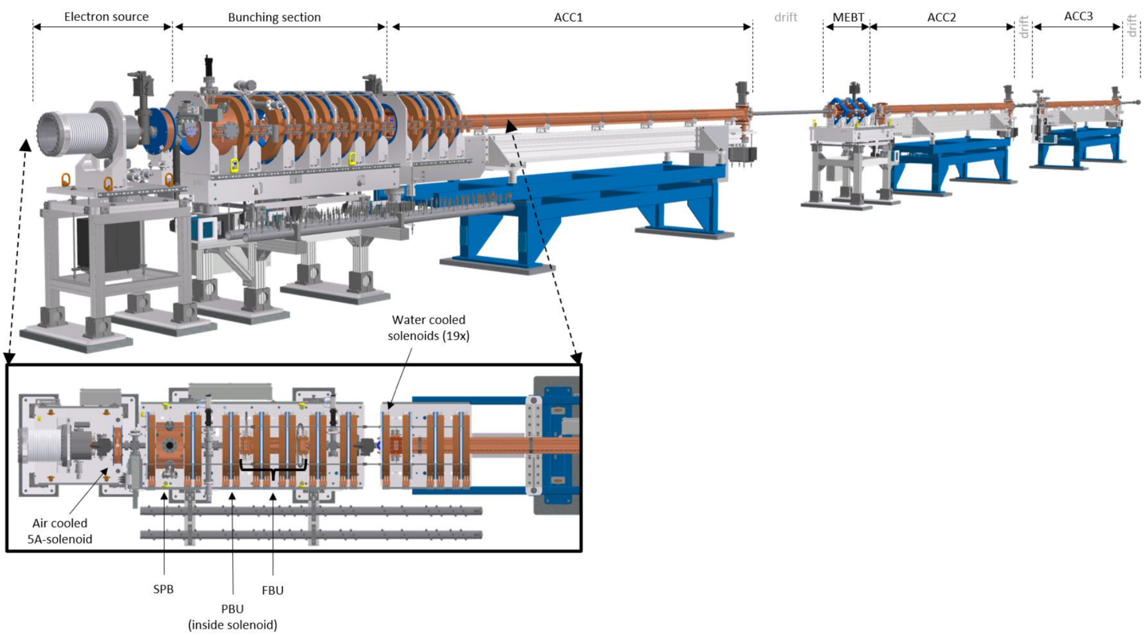

Figure 1: 3D CAD prespective of the RI design for the CLS 250 MeV linac, see text for descriptions and definition of abbreviations. Beam goes left to right.

then injected into the first of three 5.3 m long 3000.24 MHz $2\pi/3$-mode accelerating structures called ACC1, ACC2 and ACC3. The PBU, FBU and the first part of ACC1 are surrounded by solenoids to keep the beam focused.

In between ACC1 and ACC2 there is a quadrupole triplet to further control the focusing of the beam in a section called the Medium Energy Beam Transport (MEBT) line. Some steering magnets and beam diagnostics including a Faraday Cup, Beam Position Monitor, Optical Monitor Screens, Wall Current Monitor and Integrating Current Monitor are placed along the linac to tune the beam path onto the central axis. At the request of CLS, additional space was left between the accelerating sections to allow for future additions of steers and diagnostics if required for tine tuning and on-line automated measurements and optimisation of the beam.

REGULAR MODE

In Regular Mode, the linac will operate in multi-bunch mode with a 140 ns long bunch train at 250 MeV. This will provide an even distribution of beam in the storage ring for present mode of top-up operation [12]. Bunch train length required by the linac is limited to 140 ns by booster period of 342 ns and the rise and fall times of the booster injection and extraction kicker. The RF power levels and the beam energy levels through the linac for Regular Mode are shown in Table 2. Injection into the Booster has been successfully tested in top-up mode for the linac energy range 150–250 MeV, setting the possibility for a recovery mode at lower energy in the event of a klystron failure.

RECOVERY MODE

Operations with the present linac have been demonstrated down to 150 MeV using the present SAL linac, so a recovery mode was requested in the design allowing operations at 180 MeV with only one klystron. The RF waveguides in the RI linac are designed to be able to rout power from klystron station 2 through the SLED and deliver RF to all components at a reduced power level. The power levels and energy elevels along the linac in recovery mode are shown in Table 3. Figure 2 shows a drawing of the layout of the klystron gallery at ground level and the RF waveguide distribution down into the existing underground linac tunnel at CLS. This is the same tunnel the SAL linac is currently located, which will dismantled before the installation and commissioning of the RI linac. The first klystron station delivers power to the PBU, FBU and ACC1, while the second klystron passes through the SLED RF pulse compressor and delivers power to both ACC2 and ACC3. More details of the RF power distribution and the calculations of the SLED operation are presented in Ref. [13] in these proceedings.

CONCLUSION

A new 250 MeV electron linac has been designed by RI for the CLS for top-up operations. It uses SLED RF pulse compression and three accelerating sections to efficiently generate the beam at a harmonic of the booster and storage ring RF frequencies. A recovery mode has been designed in that will allow a 180 MeV beam to be produced with only one klystron, which is sufficient to continue CLS top-up operations. The project is planned to deliver beam by the second half of 2024.

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Table 2: Power Levels in Linac Components for Regular Operation at 250 MeV

	Unit	**Klystron 1**	**Klystron 2**			
Output Power	[MW]	36	36.2			
	Unit	**FBU**	**ACC1**	**ACC2**	**ACC3**	**ECS**
Input Power	[MW]	3.8	23.8	15.7	15.7	3.8
Power at load	[MW]	2.9	6.52	4.12	4.12	
Energy Gain	[MeV]	4.2	66.8	89.9	89.9	
Final Energy	[MeV]	4.2	71.0	160.8	250.7	

Table 3: Power Levels in Linac Components for Recovery Operation at 180 MeV

	Unit	**Klystron 1**	**Klystron 2**			
Output Power	[MW]		39.5			
	Unit	**FBU**	**ACC1**	**ACC2**	**ACC3**	**ECS**
Input Power	[MW]	3.0	8.4	9.5	9.5	3.0
Power at load	[MW]	2.3	1.89	2.29	2.29	
Energy Gain	[MeV]	3.7	38.5	68.6	68.6	
Final Energy	[MeV]	3.7	42.2	110.8	179.4	

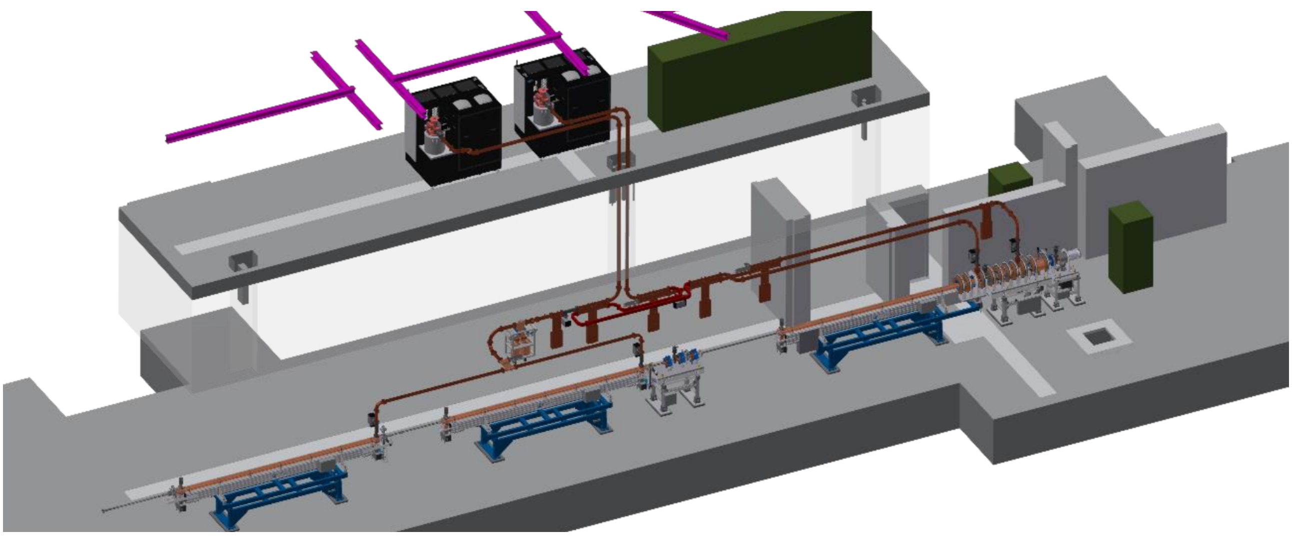

Figure 2: 3D CAD drawing of the placement of the RI linac in the CLS klystron gallery at ground level and the linac tunnel underground. Beam goes right to left.

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