ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-THPPP053

CLSI LINAC UPGRADE PROJECT

L.Lin, J. Campbell, S. Carriere, F. Le Pimpec, K. Wyatt
Canadian Light Source Inc., Saskatoon, Canada

Abstract

The Canadian Light Source Inc. (CLSI) is undertaking a significant Linear Accelerator (LINAC) injector Upgrade Project to enhance both the mechanical reliability and operational stability of Canada's primary research synchrotron facility. In late 2018, a critical gun failure led to a seven-month facility downtime. . This incident raised concerns that the original LINAC from 1980 continued to be a high risk to daily facility operations. Furthermore, several other mechanical systems within the facility, including cooling/heating water, HVAC, and certain aspects of the LINAC vacuum systems, have also aged, resulting in decreased reliability. The upgrade to the LINAC and its associated mechanical systems presents an opportunity to significantly improve the operational reliability of the entire facility.

INTRODUCTION

The CLSI's existing LINAC complex is based on a 1960s-era 2856 MHz RF, normal-conducting 250 MeV electron linear accelerator, capable of producing a 40 mA beam current. This accelerator is followed by an Energy Compression System (ECS) and a transfer line, which injects the beam into a Booster Ring, raising its energy to 2.9 GeV before the beam is injected into the Storage Ring. The LINAC operates in a multi-bunch mode at a rate of 1 Hz and can also work in a top-up mode, injecting a bunch train every few minutes. The existing LINAC is powered by a 220 kV DC thermionic electron source with bunching sections that achieve 13 MeV before injection into S-band traveling wave accelerating structures [1].

CLSI now requires a reliable, stable, and serviceable Injector, consisting of an electron source and a LINAC capable of generating a 250 MeV electron beam. This Injector should support a variable repetition rate ranging from 1 to 10 Hz. CLSI has acquired a "turnkey" Injector from Research Instrument GmbH (RI). This Injector will encompass various components, including the electron source, bunching sections, accelerator sections, RF plant, compression system, distribution system, vacuum systems, transport optics, diagnostics, control systems, and associated cooling/heating systems. The new Injector components are currently in the fabrication process, with a planned delivery date at CLSI in March 2024. User operations will resume after a 6-month downtime for installation and commissioning.

REQUIREMENTS

The new Injector, as shown in Fig. 1 [2], must meet the performance parameters outlined in Table 1 [1]. One of the key Injector characteristics is the requirement to remain operational even if one of the modulators feeding the RF structures fails. This feature will ensure continuous operation until the next maintenance period. The maximum repetition rate of the modulators and klystrons is set at 10 Hz.

Figure 1: The new injector.

Table 1: Injector Performance Parameters

Parameters	Values	Units
Accelerator Particles	electrons	n/a
Nominal Beam Energy	250	MeV
Minimum Beam Energy in any RF failure mode	180	MeV
Single Bunch Mode Beam charge in 500 MHz Bunch	1.5	nC
Single Bunch Mode Bunch Length 1 σ	1	ns
Multi Bunch Mode Beam charge per 500 MHz Bunch (adjustable)	>0.08	nC
Multi Bunch Mode Train Length, 5 to 70 bunches at 500 MHz (2 ns RF buckets)	10 to 140	ns
Center energy stability (pulse to pulse)	≤0.1	% (RMS)
Energy Spread	≤0.5	% (RMS)
Normalized Emittance (1s) (X or Y)	≤50	π mm·mrad
Injector Frequency adjustable to	3000.24 ± 0.030	MHz
Booster Synchrotron RF Frequency	500.04 ± 0.005	MHz
Injector Nominal Repetition rate	1	Hz
Modulators and Klystrons Repetition Rate	1 to 10	Hz
Pulse to pulse beam position variation (RMS)	0.2	mm
Pulse to pulse beam angle variation (RMS)	0.05	mrad

SCOPE

Research Instrument GmbH (RI) will provide a complete "turnkey" Injector. The Injector system will interface with several CLSI systems for which CLSI will be responsible, as illustrated in Fig. 2 [1].

As depicted in Fig. 2, there is a shared responsibility between RI and CLSI for both design and procurement. The hands-on installation and commissioning will be carried out by CLSI personnel under the guidance of RI's technical specialists.

PROJECT PLANNING

Project planning has been underway since late 2021. Through detailed schedule development, the project team, in coordination with RI, has established the "Dark Period" duration, set at six and a half months. The "Dark Period" has been divided into four major phases: dismantling of the existing injector, service integrations, installation, and

ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-THPPP053

commissioning of the new injector. Prior to RI's arrival, CLSI will be responsible for dismantling all components and cable trays in the LINAC Hall, the adjacent hall, and modulator room. Additionally, all mechanical service upgrades are part of the Integration Phase. Installation and commissioning will be carried out by CLSI personnel, ranging from technical services to the accelerator physics group, under the leadership of RI specialists.

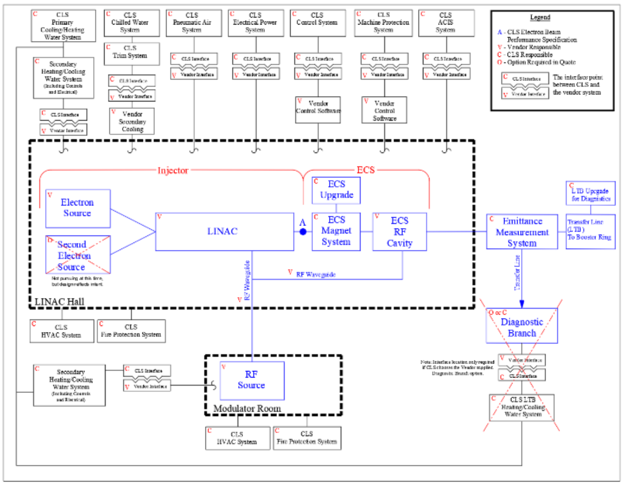

Figure 2: Scope of supply schematic of interfaces between RI and CLSI.

DESIGN

The primary design responsibility lies with RI as part of a "turnkey" project. CLSI's role has been to assist RI in the design of facility services to ensure seamless integration with existing systems and maximize cost-efficiency. A representation of the component and system design is depicted in Fig. 3 [2].

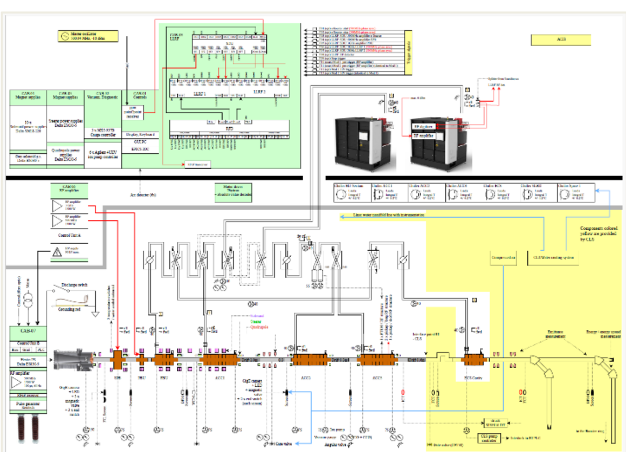

Figure 3: CLSI new injector block diagram.

Systems Designed by RI

RI's design incorporates the beam dynamics and lattice, the RF system in collaboration with CLSI for SLED [3] operation, and various RF structures, including the 3000.24 MHz ECS RF structure. This design also covers the related Mechanical, Electrical, and Control systems. RI has presented various design options in response to CLSI's requirements. One of these options use the SLED Technology. While this design is more intricate in terms of beam dynamics and synchronization for efficient acceleration, it offers the advantage of accommodating a 250 MeV LINAC in a more compact space, it reduces the number of required accelerating structures and RF modules (Klystron and solid-state modulator) to power them. These options alleviate the budgetary constraints and allow for the early procurement of critical spares, as recommended by RI.

RI's design also addresses the RF system. It features two solid-state modulators with klystrons for providing pulsed RF power to the 3 S-band traveling wave cavities. The power is distributed through a waveguide system. Fixed power splitters, adjustable amplitude shifters, and phase shifters are utilized to define the power level at each cavity. The odd frequency is driven by the need to synchronize the RF bucket of the storage ring at 500.04 MHz, which, although non-standard, closely aligns with the European 499.67 MHz (2998 MHz for S-band European).

CLSI Mechanical System Integration

The integration of the mechanical system has required close coordination and communication between CLSI and RI, as many of CLSI's systems are either closely adjacent to or directly interconnected with RI-supplied systems. Both parties have shared the CLSI facility's 3D models and survey coordinate system to facilitate communication and ensure seamless interface integration.

The new modulators will exist in the same room as the original modulators. As the LINAC is two floors below the modulator room level, CLS had to carefully define the envelopes of the floor tunnels between the modulator room and LINAC hall (for waveguide routing). Many of the RI supplied control cabinets will also exist in the modulator room and cable connections will run through these same floor tunnels, to the LINAC level.

Before RI arrives to oversee the installation, CLSI will carry out surveys, alignment, and grouting of accelerator floor stands. All accelerator structures and diagnostic sections are equipped with permanent magnetic survey nests, aiding in the alignment process. RI will provide CLSI with the fiducialization data for each section to ensure that each section is correctly positioned within the CLSI survey coordinate system.

The design of CLSI's mechanical services plays a crucial role in the project's integration. It has faced one of the most significant challenges in meeting the requirements of the New LINAC. RI initially proposed local air-cooled chillers for heating and cooling each RF structure. While this approach is straightforward in terms of design and control, it presented the challenge of requiring external air cooling. The existing Heating, Ventilation, and Air Conditioning (HVAC) system of the LINAC lacks the additional cooling capacity required. Currently, CLSI dose not have the budgetary flexibility to upgrade the HVAC system. The existing water service for the sections operates solely for heating purposes, rendering it unsuitable for reuse. RI initially

ISBN: 978-3-95450-250-9 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2023-THPPP053

considered the chiller option to be the most cost-effective one, aligning with the project's schedule. Comprehensive evaluations were conducted on cooling and heating requirements, taking into account factors such as location, capacity, and the age of current systems. The design focus on maximizing the reuse of the current system to ensure cost efficiency. Given the substantial load that air-cooled systems would impose on the CLSI HVAC, the decision was made to shift to water-cooled chillers. To facilitate the operation of these water-cooled chillers, CLSI will renovate its chilled water system. The design of CLSI's mechanical services has been tailored to accommodate a 10 Hz repetition rate for future operation, requiring minimal modifications to the existing system, which currently operates at 1 Hz. Fig. 4 illustrates the Overall LINAC water system [4].

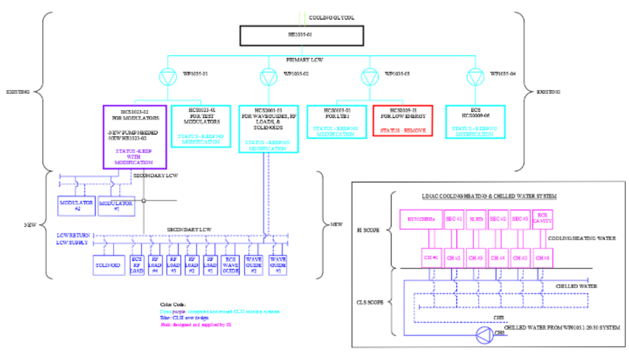

Figure 4: Overall LINAC water system diagram.

OUTCOMES

In December 2022, RI and CLSI reached an agreement on the overall design, and both institutions have either resolved or are finalizing details concerning the beam dynamics, vacuum systems, Low Level RF systems, controls and instrumentation, and machine protection systems. As an optional part of the project, RI is fabricating the ECS RF structure at the appropriate frequency and will supply the RF distribution waveguides. It was decided to retain the existing ECS system, as an insurance to guarantee the energy spread of the bunches for proper capture in the Booster ring. The energy spread, without the ECS, is theoretically expected to meet the specification in Table 1.

The design of mechanical service integration has effectively utilized current systems, including the LINAC primary cooling water system and the secondary cooling water for the modulator/klystron systems, with some necessary modifications. Substantial effort has been invested in the design of a chilled water system for the water-cooled chillers, considering the requirements of variable low flow and high-pressure applications.

The project's progress is proceeding smoothly, and it is adhering to the established timelines. The design is in the advanced stages of completion for both CLSI and RI. Procurements are currently in progress, with offsite fabrication in full swing from the RI side. The majority of the long lead procurements and manufacturing are on track to be completed by the end of 2023, with delivery to CLSI scheduled for early February 2024. Ceramics for the electron source, vacuum windows, and waveguides are critical path items and are expected to be delivered to CLSI in late February 2024.

CLSI successfully completed chilled water tie-in installations during the Fall 2023 outage, which has alleviated resource and schedule constraints during the "Dark Period". CLSI continues to work on the dismantling plan in conjunction with the installation and commissioning plans.

CONCLUSION

RI and the CLSI accelerator groups have reached a consensus on the injector's design, with operations initially planned at 1 Hz to align with operating licenses, with potential operation to 10 Hz later on. The design incorporates additional spacing to accommodate future needs and a second branch fed by a different electron source. These drift spaces could be harnessed in the future for adding more diagnostics to enable automation of operations and potentially extracting the beam for other applications, should the science division at CLSI require the use of electrons at different energies.

The mechanical service integration has efficiently leveraged current systems to achieve the most cost-effective solution. Chilled water system tie-ins were implemented during the Fall 2023 facility outage, saving time during the "Dark Period".

To date, the project remains on schedule and within budget. In the upcoming months, RI and CLSI will closely monitor the manufacturing and delivery of critical path items. The integrated schedule, jointly developed by RI and CLSI, instils confidence in CLSI that the established timelines can be met with the available internal CLSI resources.

ACKNOWLEDGEMENTS

The CLSI is funded by CFI, NSERC, NRC, CIHR, the Province of Saskatchewan, WED, and the University of Saskatchewan. The authors present this paper on behalf of the entire CLSI team encompassing CLSI engineering, Accelerator Operation Department, Control & Instrumentation and the Operation Technical Service. The authors express their appreciation for the exceptional teamwork between CLSI and Research Instruments.

REFERENCES

[1] CLSI, J. Campbell, 2022, "Technical Specification for a Linear Based Accelerator Injector", CLSI document# 1.8.27.1.Rev.4.

[2] RI, P. Biegun, 2022, "CLS LINAC Final Design Report", RI document# 6030-BP-15050-A.

[3] SLAC, Z. D. Farkas, "A Method of Doubling SLAC's Energy", 1973. https://s3.cern.ch/inspire-prod-files-0/068ed22dae5ba0bab8bcf19f9dcac092

[4] CLSI, 2023, "New LINAC Cooling/Heating Water Service Flow Diagram", CLSI drawing# LINAC\0296500.