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STAR HIGH-ENERGY LINAC STATUS: COMPLETE INSTALLATION ACCEPTANCE TESTS.

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Abstract

The installation of the STAR High-Energy Linac, the energy upgrade of the Southern European Thomson Back-Scattering Source for Applied Research (STAR) project at the University of Calabria, was conducted by INFN by the end of 2023. This paper presents the testing procedures aimed at confirming the consistency, completeness, and quality of the STAR accelerator upgrade installation (electron beam energy boost from 65 MeV up to 150 MeV). We illustrate the installation and the testing of the electrical, hydraulic and related automation and auxiliary systems. We will discuss the high-power commissioning of the two C-band RF power stations and the testing of the low-level C-band RF system and control system configuration based on EPICS. Finally, we will describe the layout and testing of the vacuum system, the characterization and commissioning of the magnets with related power supplies and the assessment of the installed diagnostics devices. The linac commissioning as well as electron beam measurements are planned for Summer 2024, due to pending radioprotection authorizations.

STAR HIGH-ENERGY LINAC LAY-OUT UPGRADE

The STAR [1-5] high-energy linac layout upgrade is based on two beamlines:

1) The original beamline, known as the low energy line (LE-line or STAR-1), features an S-band RF gun and one S-band accelerating cavity. It operates at a maximum energy of 65 MeV, enabling it to power an ICS source with a maximum photon energy of 70 keV.
2) The new high energy line (HE-line) is an upgrade, increasing its linac acceleration capability from 65 MeV to 150 MeV. This upgrade will be facilitated by the addition of two C-band acceleration cavities. The enhanced HE-line will drive an ICS source capable of producing photons with a maximum energy of 350 keV.

Table 1: STAR-HEL Electron Beam Quality Parameters at the Interaction Point (IP).

	HE-linac	LE-linac
Energy range	40-150 MeV	23-65 MeV
Rep. rate	100 Hz	
Bunch charge range	100 – 500 pC	
Normalized Emittance (x,y)	2.0 μm	
Bunch energy spread	0.5 %	
Bunch length – rms [ps]	≤ 5 ps	
Bunch spot dimensions (x,y) at IP	40 μm	

INSTALLATION OF ALL SUBSYSTEMS

The installation of the STAR-HEL upgrade is completed, and the acceptance tests were carried out in December 2023. A current picture of STAR Linac at Unical with all subsystems installed is shown in Fig. 1.

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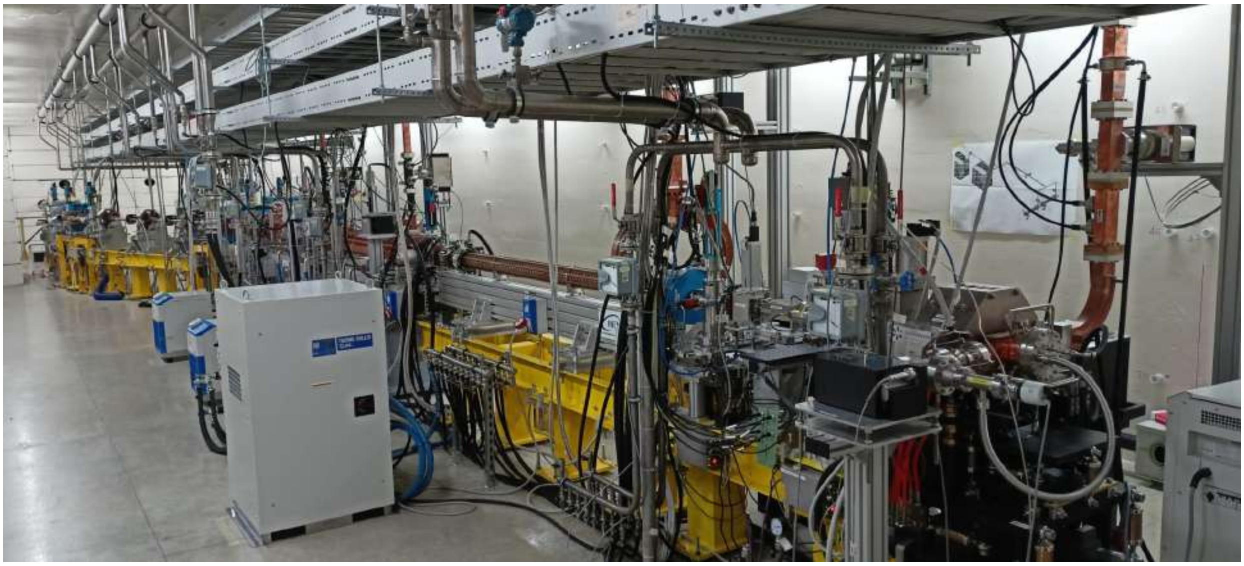

Figure 1: Current picture of STAR Linac at Unical.

RF Waveguide Network and Power Distribution

The schematic layout of the C-band RF system is illustrated in Fig. 2. This system utilizes two C-Band power units operating at 5.712 GHz to generate RF power. Copper waveguides connected with LIL type flanges distribute this power. These waveguides are standard WR187 models designed for C-Band operation. To mitigate arcing resulting from high RF power, the waveguides operate in ultra-high vacuum conditions, below 10^{-8} mbar. Ion pumps are strategically positioned along the network, approximately every 1.5 - 2 m, to maintain this vacuum level. Three ion pumps with pumping units are planned for each C-Band waveguide network, spanning from the klystron output to the linac input. Additionally, an RF window will be installed at each entrance of the accelerating structures. The RF microwave sources consist of high-power klystrons with a nominal rating of 42 MW, each powered by a solid-state pulsed high-voltage modulator (K300 model by ScandiNova, Uppsala). Solid-state amplifiers (SSAs) with an output power exceeding 400W serve as the RF klystron drivers.

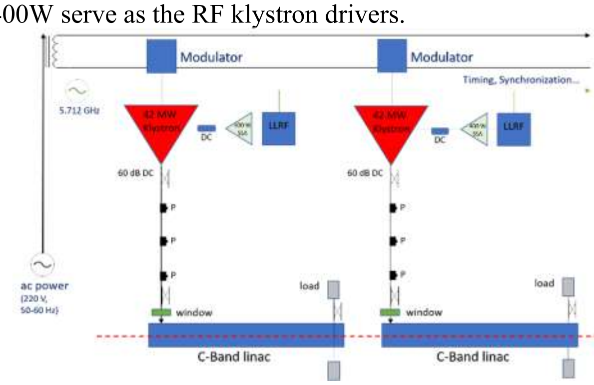

Figure 2: Schematic layout of the C-Band RF system.

The factory acceptance tests (FATs) of the two RF power units, Modulator (K300 by ScandiNova) and Klystron (E37212 model), were conducted in November 2022.

Table 2: Measurements of Main Klystron Parameters

Parameter	Measured Value
RF Frequency	5.712 GHz
Peak RF power	42 MW
RF Average power	4.22 kW
RF gain	> 52.8 dB
Efficiency	> 40.42 %
RF pulse length (flat top)	1µs
Pulse repetition rate (PRF) range	Up to 100 Hz

The site acceptance tests (SATs) of the two RF power units, Modulator (K300 by ScandiNova) and Klystron (E37212 model), were conducted in May 2023. The tests have been successful and therefore meet the specifications, as shown in the table.

Low-Level RF System

The LLRF system for C-band operation in STAR-HE comprises:

- Two Libera LLRF systems (manufactured by Instrumentation Technologies), each comprising analog front-end and digital LLRF components.
- One rack unit for generating and distributing the RF reference at C-band (5.712 GHz), developed at the Frascati National Laboratories of the INFN.

The C-band LLRF systems were installed and configured in their dedicated rack at STAR. The 5.712 GHz RF frequency reference is derived from the 2.856 GHz reference in the STAR-LE RF rack using a calibrated cable. The 5.712 GHz reference generation system provides two outputs of 15.34 dBm and 15.46 dBm, meeting the requirement of the Libera LLRF (> 15 dBm). Additionally, the setup of the trigger conversion system for the Libera LLRF, contained within the reference generation module at 5.712 GHz, was completed.

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Vacuum

The system has been equipped with multiple ion pumps of varying speeds to achieve a vacuum level of approximately 10^{-8} mbar.

Several vacuum valves have been installed to isolate specific sections while keeping others under vacuum for reliability and easy maintenance during operation. A fast valve controlled by a dedicated vacuum gauge has been incorporated to protect the gun, the most critical part of the accelerator.

Diamond windows, 500 microns thick, have been installed at the ends of the high and low energy lines.

Magnets and Power Supplies

We have completed the installation of both the power components and the network connections as well as powered on the entire subsystems, with satisfactory results for several hours. We operated the power supplies using a GUI of the control system and checked the polarity of the magnetic fields and currents with current readouts.

Before installation, electrical coil tests were performed on all magnets, except for the ground insulation test on air-cooled magnets. A 3D field map scanning was conducted for all solenoids, steerers, and dipoles within a field region of ±10 mm from the magnetic axis to evaluate the integrated field quality. The quadrupoles were characterized using a 10.7 mm radius rotating coil at 50% and 100% of the nominal current, with harmonic components referred at a 10 mm radius.

Cooling and Electrical System Upgrade

The expansion works related to the cooling system have included the following interventions, including supply and installation:

- Implementation of the existing hydraulic cooling system network. Specifically, new branches and manifolds were realized to supply all new users, as well as a reorganization to some of equipment already installed in the previous project phase. New pumps with inverters were installed in the cooling plant.
- Installation of thermo-chillers for the thermalization of the S-band and C-band accelerating sections. Connection of the heat exchange unit (skid) for cooling the thermo-chillers;
- Wiring interlocks for magnet protection;
- Installing new I/O modules and relays in PLC panels;
- Integration of new I/O into the monitoring system;
- Installation of UPS for critical power supply;
- Installation of active filters to reduce the total harmonic distortion (THD-I) generated by the two C-band modulators.

Control System

A complete EPICS control system (IOC, process variable server, and OPI graphical console for the operator) has been developed and adapted for the STAR upgrade. The installed hardware components include: vacuum pump and gauge controllers; BPM controllers; Magnet power supplies; Delay generator; Digital Oscilloscope; RF signal generator.

Diagnostics

The following beam diagnostics have been installed along the linac:

- Stripline type beam position monitors (BPM)
- Integrating current transformers (ICT);
- Faraday Cup
- Movable YAG screens coupled with CCD camera.

CONCLUSIONS

We have discussed the layout, installation and description of all sub-systems, such as the RF system (waveguide network, high-power units and LLRF), vacuum, magnets and power supplies, cooling and electrical upgrade, control system and diagnostics for the STAR-High Energy Linac upgrade.

The final acceptance tests were carried out at the STAR facility at Unical in December 2023. All tests were positive, confirming the compliance of the supply with the technical specifications declared by the manufacturers.

The linac commissioning as well as electron beam measurements are planned for Summer 2024, due to pending radioprotection authorizations.

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