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PLANNING, INSTALLATION AND TESTING OF THE RF SYSTEM FOR THE UPGRADE OF THE STAR FACILITY

L. Faillace†, D. Alesini, M. Bellaveglia, S. Bini, F. Cardelli, G. Catuscelli, A. Esposito, A. Gallo, A. Ghigo, G. Luminati, L. Pellegrino, L. Piersanti, G. Scarselletta, A. Stella, S. Tocci, A. Vannozzi, S. Vescovi, INFN Laboratori Nazionali di Frascati, Frascati, Italy
A. Bacci, I. Drebot, D. Giannotti, F. Prelz[2], M. Rossetti Conti, M. Ruijter, S. Samsam, L. Serafini, INFN Sezione di Milano e LASA, Milano, Italy
V. Petrillo[1], Università degli Studi di Milano, Milano, Italy
E. Puppin[1], Politecnico di Milano, Milano, Italy
[1]also at INFN Sezione di Milano e LASA, Milano, Italy
[2]also at Università degli Studi di Milano, Milano, Italy

Abstract

In 2021, the Italian Institute for Nuclear Physics (INFN) was awarded the project for installing, testing and commissioning the energy upgrade of the Southern European Thomson back-scattering source for Applied Research (STAR) which is currently installed at the University of Calabria (UniCal). The STAR high-energy Linac, STAR-HEL, consists in a layout comprising RF accelerating structures (linacs), with relative magnetic optics components, in order to boost the electron beam energy from 65 MeV up to 150 MeV. In this paper, we discuss the status of the planning, installation and testing of the RF system (accelerating structures, power, network and LLRF) based on C-band (i.e. 5712 MHz RF frequency) technology. For this purpose, two C-band linacs are installed and are independently powered by two RF power stations, located aside the present S-band RF power station, which will deliver 42 MW (nominal) peak power RF pulses of 1us width and up to 100 Hz repetition rate. Operation in C-band permits acceleration with higher gradients, resulting in a more compact linac footprint.

STAR HIGH-ENERGY LINAC LAY-OUT UPGRADE

The STAR [1-3] high-energy linac lay-out upgrade is based on two beam lines:

- the low energy line (LE-line, i.e. STAR-1): original beam line, with an S-band RF gun and one S-band accelerating cavity, able to work at the maximum energy of 65 MeV to drive an ICS source at maximum photon energy of 70 keV.
- the new high energy line (HE-line): linac acceleration capability will be upgraded from 65 MeV up to 150 MeV, by two additional C-band acceleration cavities. The new HE-line will drive an ICS source at maximum photon energy of 350 keV.

The STAR-HEL electron beam quality parameters at the interaction point (IP) are listed in Table 1.

A short solenoid (8 cm long) is added just before the first S-band cavity, with capability to reach a maximum B_z field peak of ~ 0.2 T that permits a better control of the beam divergence and emittance compensation in a larger range of energy operation. The two additional acceleration cavities, the working points (WPs) have been modified so that now it will be possible to suppress the beam energy spread with a technique that in STAR-1 with only one RF cavity was not feasible. This methodology is valid for both the LE-line and the HE-line for different working energy ranges LE-line: 23-65 MeV and HE-line: 40-150 MeV.

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

The installation of STAR-HEL upgrade is in-progress and will conclude by the end of May 2023. The complete CAD lay-out with the RF power distribution (both S- and C-band) systems and including also other subsystems is shown in Fig. 1.

† luigi.faillace@lnf.infn.it

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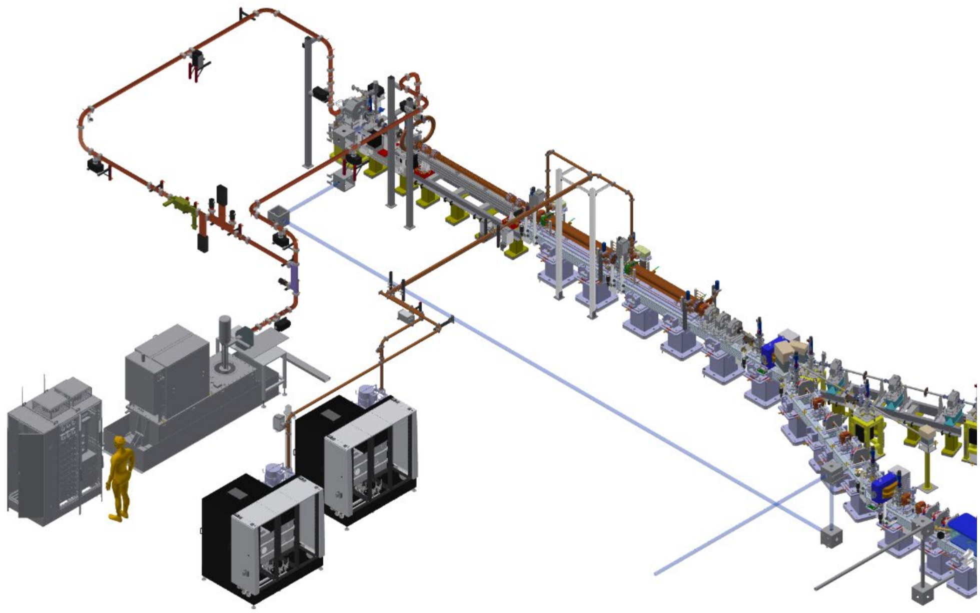

Figure 1: Complete CAD layout of the the STAR-HEL upgrade with the RF power distribution (both S- and C-band) systems.

The construction part includes:

- Civil work
- HE line installation
- RF station installation
- Racks, power supply, electronics installation
- Cooling system upgrade and hoses installations
- Electric plant upgrade and cabling
- Other infrastructural work
- Control system upgrade

RF WAVEGUIDE NETWORK AND POWER DISTRIBUTION

The schematic layout of the C-band RF system is shown in Fig. 2. The RF power is provided by two C-Band power units working at 5.712 GHz. The RF power is distributed through a network of copper waveguides connected with LIL type flanges. The waveguides are the standard WR187 working in C-Band. In order to reduce arcing due to the high RF power, the waveguides will be operated in ultra-high vacuum, below 10^{-8} mbar. Therefore, ion pumps are placed along the network every nearly 1.5 - 2 m. We foresee three ion pumps with pumping units on each C-Band waveguide network from the klystron output to the linac input. An RF window will be located at each entrance of the accelerating structures. The RF microwave sources are high-power klystrons with a nominal value of 42 MW. Each klystron is energized by a solid-state pulsed high-voltage modulator (K300 model by Scandinova). The RF klystron drivers are solid-state amplifiers (SSA's) with an output power > 400W.

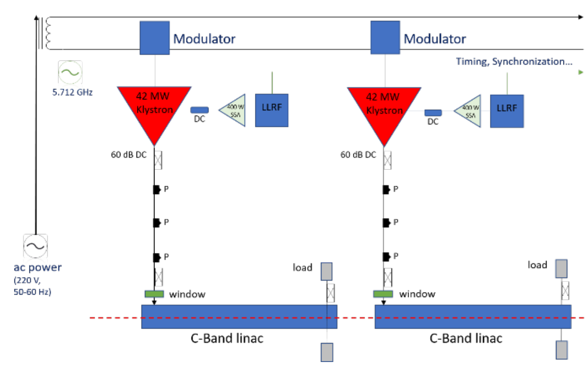

Figure 2: Schematic layout of the C-Band RF system.

Factory Acceptance Test of the C-band Power Units

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	5712 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

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The measurements of the main Klystron parameters fulfilled the STAR specifications and are reported in Table 2. A 4-hour long-run test was carried out at full power (42 MW), RF pulse length of 1 μs and maximum repetition rate (100 Hz). A picture during the FAT is reported in Fig. 3.

Figure 3: FAT of one of the two C-Band klystrons inside the K300 Modulator at Scandinova.

LOW-LEVEL RF SYSTEM

The LLRF for the C-band operation of STAR-HE consists of:

- 2 Libera LLRF systems (made by Instrumentation Technologies), each consisting of analog front-end and digital LLRF;
- 1 rack unit for the generation and distribution of the RF reference in C-band (5.712 GHz), made at the Frascati National Laboratories of the INFN.

The C-band LLRF systems were wired and set up in their dedicated rack at STAR.

The 5.712 GHz RF frequency reference is generated from the 2.856 GHz reference in the STAR-LE RF rack, through a properly calibrated cable. The 5.712 GHz reference generation system provides two outputs of 15.34 dBm and 15.46 dBm, as required by the Libera LLRF (> 15 dBm). Moreover, the setup of the trigger conversion system for the Libera LLRF (contained inside the generation module of the reference to 5.712 GHz) was carried out.

The Libera LLRF system setup consisted in the following steps:

- The LLRF systems were powered on and a test RF pulse was generated to test their functionality. Two measurements were made with a calibrated power meter (one for each system) of the output pulses. Both comply with specifications.
- The two Libera LLRF systems were assigned IP addresses;
- The calibration of each front-end was tested using input signals of known amplitude. Both systems are satisfactorily calibrated.
- The amplitude and phase feedbacks from both systems were successfully tested.

CONCLUSION

We have discussed the layout, installation and testing of the RF system (waveguide network, high-power units and LLRF) for the STAR-HE upgrade.

The factory acceptance tests of the two C-band RF power stations were successfully carried out in November 2022. The power units are now installed at STAR site and we will proceed to their site acceptance test in May 2023.

The LLRF system (Libera LLRF) and the 5.712 GHz reference generation as well as the trigger system for the Libera LLRF were tested on site. All tests were positive, confirming the compliance of the supply with the technical specifications declared by the manufacturer.

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