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DELIVERY STATUS OF THE MAGNET SYSTEM FOR THE STAR HIGH ENERGY LINAC

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Abstract

The Southern European Thomson back-scattering source for Applied Research (STAR) Project [1], based on a collaboration among University of Calabria (UniCal), CNISM, INFN and Sincrotrone Trieste, has the goal to install and test at UniCal a short linear accelerator for high brightness electron beams that will drive a unique advanced X-ray Thomson source [2]. In 2021 INFN was committed to install, test and commission an upgrade of the STAR Linac (STAR High Energy Linac) [3] aiming to increase the X-ray beams energy from 30 keV up to 140 KeV. The new layout foreseen an increase of the electron beam energy from 65 MeV up to 150 MeV by the installation of two additional C-band acceleration cavities and an additional transfer-line where the high energy beam could be delivered to a second interaction point with the laser.

The whole machine layout foresees 43 warm electromagnets (solenoids, dipoles, quadrupoles and steerers) powered by 59 DC power supplies that will cover a wide power range from 90W up to 15kW. In this paper, an overview of the magnet system is given together with the performed tests, the status of the deliveries and the future steps needed to finalize the complete machine installation.

INTRODUCTION

According to Figure 1 the machine layout is composed by three branches: the LINAC, the Low Energy Line (LEL) where the beam is directed when the only S-band cavity is operating and the electron beam could reach a maximum energy of 65 MeV and the High Energy Line (HEL) where the beam is directed when all the accelerating cavities are ON and the maximum electron beam energy is 150 MeV. The beam could be bent towards LEL or HEL line thanks to a DC electromagnetic dipole, varying its current set.

The following paragraphs deal with a general description of the magnet and power supplies (PSs) apparatus, with the test performed and finally it is given an overview on the current machine status and the future steps needed to finalize the machine installation.

STAR MAGNET LAYOUT

The STAR magnet system layout foresees 43 warm electromagnets that operate in DC. In Table 1 all the magnets typologies are listed. Except for the Steerers B all the magnets have an iron yoke. Starting from the electron gun, the first magnet is the gun solenoid, Sol A type, devoted to the emittance mitigation in the first acceleration stage up to about 6 MeV beam energy. Downstream there are two Steerers C, where the first one (CORGUN01) has the additional task of the energy spectrometer. Then there is the second solenoid of the machine (SOLLIN01), Sol B type, that focus the beam and compensates the emittance growing immediately before the S-Band accelerating structure. From the end of the accelerating structure up to the end of the LINAC there are several steerers and a Quad B triplets (named QUATRL 01,02 and 03 in Figure 1) and finally there is a the DPHHEL01 dipole Dip A devoted to a beam bending of ±20 degrees in the LEL or in the HEL.

Immediately downstream the DPHHEL01, in the LEL there is a triplet of quadrupoles Quad B (QUADGL01, 02 and 03) interspersed by two Steerers (CORDGL01 and 02), after there is a 20 degrees bending Dip C, named DPHDGL02 that realign the beam parallel to the linac trajectory towards a Quad B triplet (QUAIPL01, 02 and 03) and two Steerers C (CORIPL 01 and 02) for the beam

focusing and routing towards the interaction point with the laser in the vacuum chamber INTIPL01. Downwards there is the LEL dump line composed by a 20 degrees vertical dump dipole Dip C, named DPVDUM01 and a Quad B, named QUADUM01.

The HEL layout is very similar to the LEL one except for the magnet typologies due to the higher beam energy.

The line started with a Quad A triplet (QUAHEL01, 02 and 03) interspersed by two Steerers A (CORHEL 01 and 02).

After there is a dipole Dip A, named DPHHEL02 who bends the beam of 20 degrees, another Quad A triplet (QUAHEL04, 05 and 06) with two Steerers A and one Steerer C (respectively CORHEL03, 04 and 05).

All these elements focus and steer beam towards the second interaction point

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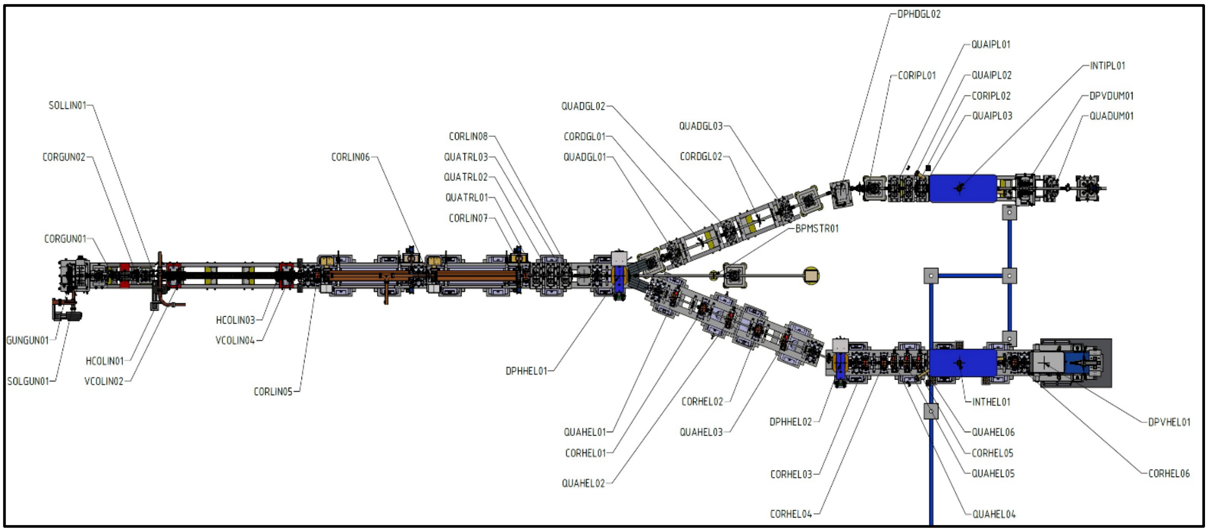

Figure 1 - STAR-HEL Layout with All the Magnets Name Labelled

with the laser in the vacuum chamber INTHEL01.

Downwards the HEL dump line is composed by a Steerers A (CORHEL06) and a 90 degrees vertical dipole Dip B, named DPVHEL01, that leads the beam towards the HEL dump.

Table 1 - STAR-HEL Magnets Typologies

Mag type	Field/Grad	Nominal Current	Cooling*	QTY
Sol A	3000 G	144 A	WC	1
Sol B	1800 G	110 A	WC	1
Dip A	0.8 T	87 A	WC	2
Dip B	0.87 T	90 A	WC	1
Dip C	0.65 T	336 A	WC	2
Quad A	18 T/m	47 A	WC	6
Quad B	9 T/m	9 A	AC	10
Steerer A	70 G	1.3 A	AC	7
Steerer B	45 G	30 A	AC	4
Steerer C	38 G	3 A	AC	9

*WC and AC stands for water and air cooled respectively

STAR POWER SUPPLIES

All the STAR electromagnets are powered by 59 DC switching, air-cooled power converter. Table 2 shows all the typologies and main features of the PS.

Except for the EASY-DRIVER, FAST-PS and the iTest types that could deliver a bipolar current, all the other ones are unipolar PS. Aiming to guarantee the current polarity inversion, several polarity switch modules have been installed, serving START 2, START 11 and NGPS power converters. Concerning the controls, all the PS are based on Ethernet-Modbus protocol and the Control System will be EPICS based. The temperature interlock will be managed directly by the PSs with a dry normal close contact connected to the magnets thermoswitches, while the flowmeters interlock will be managed by means PLC.

All the power supplies are hosted in 6 racks as showed in Figure 2.

Table 2 – STAR-HEL Power Supplies

PS model	Company	Magnets powered	Nominal I/V	QTY
PS8000	Elektro-Automatik	Sol A	200A 15V	1
START11	SigmaPhi	Dip A Dip B	200 A 55V	3
NGPS	Caenels-OCEM	Dip C	400A 50V	2
START 2	SigmaPhi	Quad A Sol B	135A 15V	7
Easy-Driver	Caenels	Steerer A Steerer C	10A 20V	24
Fast PS	Caenels	Steerer B	30 A 20V	4
BE-2811	iTest	Steerer A	5 A 18V	7

TEST ON MAGNETS AND POWER SUPPLIES

Magnets

All the magnets have been tested with properly Factory Acceptance Tests (FAT) at the companies' premises. For dipoles, steerers and solenoids field integral and integrated field quality have been evaluated with Hall probe 3D field maps and also an excitation curve (magnetic field vs current) have been defined. The required integrated field quality is 5E-4 in a good field region of ±10 mm defined as the maximum deviation between the field integral on a generic path with respect to the on axis field integral. For quadrupoles, in addition to the excitation curve, it has been per-

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formed a harmonic analysis with a rotating coil at a reference radius of 10 mm. All the normalized integrated multiple components shall be within 5E-4 p.u.

Figure 2 – PSs Racks Front View

For all the water cooled magnets, a turn-turn and coil to ground insulation tests have been performed together with a water-leakage. Finally, the electrical parameters as resistance and inductance have been defined.

All the magnets showed a very good agreement with the specifications and passed the tests.

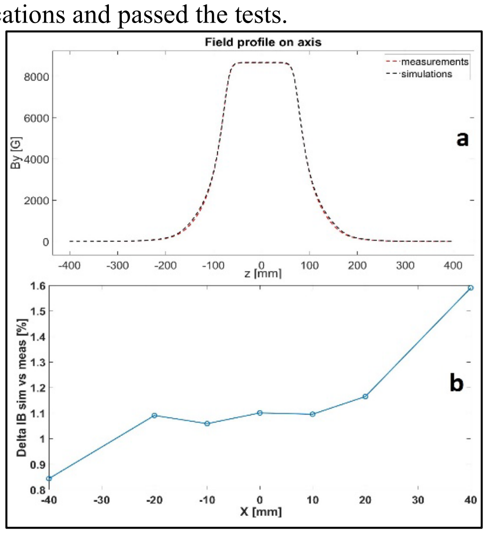

Figure 3 – Comparison DPHHEL01 between longitudinal on axis field profile simulated (a) and the integrated field deviation between simulations and measurement (b).

Additional tests have been performed on the DPHHEL01 dipole that was designed originally for another transfer line where it had to bent for 17.18 degrees an electron beam with a maximum energy of 280 MeV in a good field region of ±10 mm with respect to the magnetic axis. Therefore, in advance of its installation, a first beam dynamics evaluation has been done modelling an as-built 3D model in Opera 3D [4], calculating the field maps in a wide region with respect to the magnetic axis of the dipole of ±40 mm aiming to insert a wide field map in ASTRA particle tracking code. After that, several magnetic measurements have been performed aiming to evaluate if its performances in a new STAR facility configuration. After that several longitudinal scan with a Hall probe, have been done aiming to compare the simulated and measured integrated field.

Figure 3 show the longitudinal on-axis field profile of the measurements and simulations and the difference in percentage between the simulated and measured integrated field. The maximum difference between the simulations and measurements is about 1.6% and all these maps have given acceptable results with ASTRA simulations.

Power Supplies

The power supply test foresees a first FAT phase at the companies' premises and further test at LNF facility in the racks assembly phase before the shipping to UniCal. In the FAT the parameters in Table 3 have been measured and it was verified the compliance with the corresponding requested value.

Table 3 – PS Measured Parameters and Values Requested

Parameter	**Value requested**
Stability test 8 hour	±150 p.p.m.
Reproducibility	±200 p.p.m.
Current ripple	±200 p.p.m.
Resolution	±120 p.p.m.
Power factor	0.92

Concerning the tests at LNF facility, their goal was to ensure the good performances of some PSs on the real loads during the rack assembly phase. For these tests only current ripple and stability test have been done on the STAR 11, STAR 2 and iTest power supplies that came from a supply previous to STAR project.

All the required parameters listed in Table 3 have been fulfilled and guaranteed by all the PSs.

STAR MAGNET SYSTEM PROCURMENT CURRENT STATUS

All the procurement, test and installation phases have been completed. All the racks full equipped have been installed as well as all the magnets in LINAC, LEL and HEL.

Except for the LEL, the DC cabling from PSs to magnets have been completed while all the AC cabling from the busbars to the switchboard of the racks has been done. A preliminary low power test have been performed for all the PSs switching them ON to 10% and 100% of the nominal current, for water cooled and air cooled magnets respectively. The magnet of LEL have been powered with provisory cables. It was still not possible to test the water-cooled magnets at full power because the water pipes installation is ongoing and a future test is foreseen within the end of June 2023.

CONCLUSIONS AND FUTURE STEPS

In this proceeding an overview of the magnetic system of STAR-HEL has been given including an overview on the performed tests on the magnets and power supplies and the current status of the machine. The future steps needed to finalize the whole machine installation are a full power test as soon the water cooling plant will be completed, together with a complete external interlock test. Finally, a complete commissioning has to be done testing all the power supply with the control system who has to be still finalized.

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