

STATUS OF SPES CYCLOTRON AT LABORATORI NAZIONALI OF LEGNARO

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Abstract

The SPES cyclotron at Laboratori Nazionali di Legnaro (LNL) was installed and commissioned in 2017 and the accelerator was operational until March 2021. The shutdown was foreseen in order to permit the completion of the SPES facility, while the resume of activities is expected in 2023. The status of the SPES cyclotron and related high intensity beamlines will be presented as well as the last performance achieved in terms of accelerated current up to 1 MeV. Moreover, the program of upgrade of the ancillary systems shall be discussed.

STATUS OF SPES PROJECT

The SPES project [1] is developing in the international framework of the new facilities producing exotic beams for astrophysics research, fundamental interactions, and applications for society, including in medicine.

The project was divided into four phases aiming to provide a multipurpose facility whose accelerator complex is shown in Fig. 1:

- α -phase: construction of main building and installation and commissioning of the high intensity accelerator delivering the high-power proton beams.
- β -phase: installation and commissioning of Radioactive Ion Beams (RIB) facility. It consists of ISOL targets, low energy beam transport lines, beam cooling device and High-Resolution Mass Separator (HRMS), charge breeding system (ADIGE), new RFQ injector and re-acceleration by actual superconducting Linac ALPI.
- γ -phase: installation and commissioning of equipment and laboratories for production and R&D of radioisotopes for medical applications.
- δ -phase: realization of experimental hall to produce neutron beams by interaction of high intensity protons with heavy and light targets.

Once the alpha-phase was completed in 2017, the SPES project has entered in 2018 in the crucial beta-phase of installation of target and low energy beamlines. Moreover, at the same time, the completion of the related infrastructures is carrying on in order to provide a full power facility plant including the implementation of the HVAC upgrades.

Without a doubt, the emergency due to the Covid-19 pandemic had strongly impacted with the progress of the scheduled works. Moreover, the international situation worsening since beginning of 2022 has further delayed the planning, but nevertheless, very important progresses were done in the last three years.

The ISOL target station was installed in 2021, including the first section of the beam transport line downstream the source: i.e., the Wien filter beam selector and first electrostatic quadrupole. The High Voltage platform providing 40 kV voltage for the ion source is under commissioning. The main electrostatic lenses and the recombination magnets of the first leg of low energy beamline were also installed in 2022.

The beam cooler device which is necessary to improve the quality of beams produced by the plasma source, it was completed from the Laboratoire de Physique Corpusculaire (LPC) of Caen (France) and the beam commissioning is ongoing in the French laboratory. The installation in the SPES facility is foreseen in late 2023.

The final design of the High-Resolution Mass Spectrometer was accomplished out and the tender for the supply of the resistive magnets and the electrostatic lenses was awarded to the Elytt Energy company [2] in 2022. The delivery is expected by the end of 2024.

The charge breeder device is installed and the ion source for stable beams has been commissioned in 2022. The High Voltage platform has been finished while the installation of the Medium Resolution Mass Spectrometer is under completion.

The post acceleration section is progressing very well, as the new resistive RFQ injector is finalizing, and the first module was mounted at LNL. The upgrade of superconducting Linac ALPI has been carried out and the first accelerating beams started in December this year.

During the 2023, the resume of cyclotron operation is expected to allow the commissioning of new high intensity proton beamlines. In 2024, the first exotic beam produced by the small size ISOL target, hit by few hundred watts of primary beam, should be available for the low energy experiments in the dedicated area of SPES facility (see Fig.1).

SPES CYCLOTRON STATUS

The SPES Cyclotron is a four sectors compact cyclotron supplied by Best Theratronics [3], capable to accelerate H⁻ ions up to the maximum energy of 70 MeV. The protons are extracted by the stripping of the H⁻ ions passing thru a thin graphite foil where the two electrons were stopped.

The proton beams are available in the energy range within 30-70 MeV and with an average current varying from few tens of nA up to the nominal value of 750 μ A.

The vacuum system is equipped with four cryogenic pumps CTI-10 of Brooks Company installed into the two valleys, providing a vacuum level of 3×10^{-6} Pa. A scroll pump allows to get the primary vacuum level of 1.5 Pa.

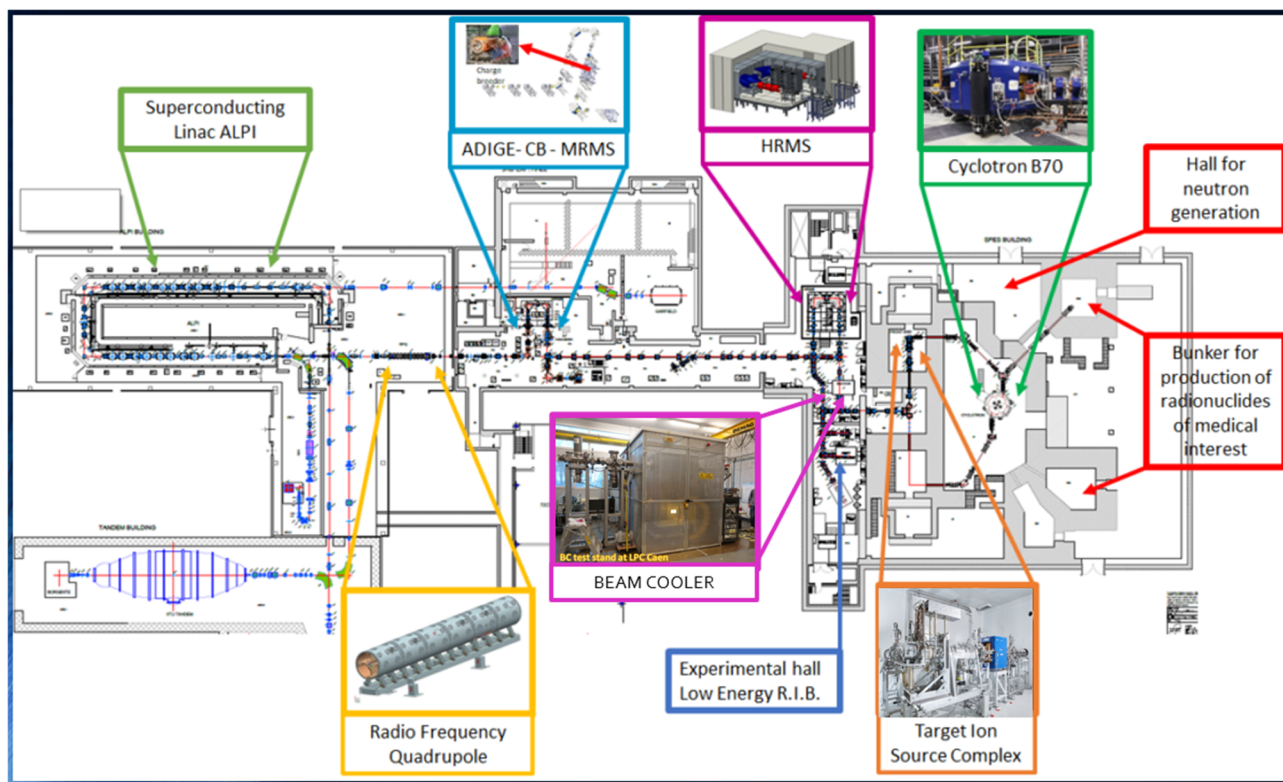


Figure 1: Layout of SPES facility complex at Laboratori Nazionali di Legnaro, Italy.

The RF system consists of 2 delta-type cavities (half-wave) placed in the valleys, providing up to 70 kV of accelerating voltage. The devices operate in 4th harmonic mode at the frequency of 56 MHz. To optimize the performance of the whole system, the cavities are fed by two separated amplifiers (dual stage, tetrode based) able to provide up to 55 kW RF power each.

The injection of the beam is axial and a multicusp H⁻ ion source (IS) is placed underneath the cyclotron in the pit. A beam stop is placed downstream the IS for current measurement. The injection line is composed by two magnetic solenoids for focusing the beam in series with two quadrupoles needed to provide the matching with the inflector entrance.

The central region has been designed in order to maximize the phase acceptance up to the value of 50 RF deg. It allows to have margin for optimizing the injected current. A beam stop is placed into the cyclotron intercepting the accelerated particles once they have made few turns (1 MeV energy). It permits to setup the best conditions of the injected beam before the full acceleration and extraction.

The extraction mechanism allows changing the stripper foil without breaking the vacuum in the main chamber. The device has been designed in order to hold up to 20 stripper foils quickly movables and easy to re-charge entirely.

Two main extraction lines come from the Cyclotron. Each line ends in a switching magnet (10 tons) bending the beam along three potential lines to be used exclusively.

Each beamline is equipped with a cryogenic pump CTI-8 type and with the necessary beam diagnostics device. A fast gate valve is installed along each beamline line arm, in

order to prevent any damage coming from potential vacuum breaks at the target stations. Table 1 summarizes the performance.

Table 1: Cyclotron Parameters

Parameter	Value/Description
Cyclotron type	Compact, resistive magnet
Sectors number	4 straight sectors
Accelerated particle	H ⁺ (protons extracted)
Beam energy range	35÷70 MeV
Beam current range	50 nA÷750 µA
Magnetic field at center	1 tesla
Peak magnetic field	1.6 tesla
Pole radius	135 cm
Weight	~200 tons
RF system	2 delta-type cavities λ/2
RF frequency	56 MHz, harmonic=4
Extraction system	Stripping process
Injection system	Axial from external IS
Ion Source (IS)	Volumetric multi-cusp
Nominal intensity IS	6÷10 mA
Voltage IS	40 KV

During the three-year period 2020-2022, the cyclotron systems have been upgraded. In the following we reported the main interventions we carried out.

Electrical Systems

During the 2021 year, the electrical systems to support the components of the beamlines LARAMED and ISOL2 were completed. The wiring of both DC cables and signals from the power supply room to the magnets and ancillary devices was carried out. The new cabinets were placed in the dedicated room and the power supplies have been mounted inside these. The old main electrical board was replaced with a new one by increasing the number of available slots for future upgrade of the facility (see Fig. 2).



Figure 2: On right side, the picture shows the new main local electrical board dedicated to supply the cyclotron's components. On the right side the new cabinet with the power supplies of LARMAED beamlines magnet.

Water Cooling System

In 2018 it was decided to replace the actual single cooling system supplied by Best Theratronics which provides the water for the cyclotron and related subsystems with a new one. The latter consists into five independent skids and related distribution circuits which supply respectively.

- Cyclotron and injection line systems.
- Beamline devices branching off from exit port 1.
- Beamline devices branching off from exit port 2.
- Activated devices (Faraday cups, collimators, baffles).
- Radio Frequency and vacuum systems: power amplifiers and cryo-compressors.

The new configuration will allow to improve the maintenance activity by separating the management of potential activated components from the 'cold' ones. Moreover, the upgraded system will increase the reliability of the facility during the beam operation.

During the 2021 year the old skid was dismantled, and the new five devices have been positioned in the final destination inside the technological room of SPES building. The design of the ultimate distribution of the water lines connecting the skids to the apparatus was carried out in 2022. In 2023 we expect to dismantle the old system then replace it with the new lines.

New Server for Control System

Due to the obsolescence of the hardware dedicated to the cyclotron control system, two new DELL workstations were setup up and a new DELL server has replaced the original HP machine. A dedicated QNAP NAS quad-core provides comprehensive backup and data storage instead of actual HDD device with limited performances.

The system has been designed to be expandable based on future needs of beamlines deployment and accelerator system upgrades.

Diagnostics

During the commissioning of high intensity beam, we observed the anomalous activation of the beampipe in correspondence of a doublet quadrupole magnets, where in effect we expect the beam size should increase. Evidently, the hot spot was caused by a beam loss due to a wrong setup of magnetic lenses setting. To prevent this kind of problems, we decided to adopt a system of beam loss monitoring able to detect the neutron contribution caused by the interaction of protons with material of the beam pipe.

The detectors will be connected to the cyclotron Machine Protection system to interlock the accelerator once a certain threshold of produced neutrons is exceeded.

Moreover, the devices will be placed in well known points where the beam size reaches the maximum envelope, i.e. in the middle of the two quadrupole magnet lenses.

Preliminary test on commercial devices were carried out at LNL, in particular we employed the system offered by Instrumentation Technologies, Libera [4] which is based on scintillators integrated on a photomultiplier, flash ADC and data acquisition [5].

BEAM OPERATION

Once all the system are restored, we proceeded to run the beam. As first step, we planned to inject the beam and accelerate it up to 1 MeV.

In order to avoid that accelerated particles overcome the 1 MeV energy, the movable diagnostic pop-up probe which is installed inside the cyclotron, has been blocked in the lifted position. In such configuration, the injected beam carries out few turns, then it is stopped on the copper made dump (see Fig. 3).

Several setting in terms of extracted current beam from the ion source have been tested and the efficiency of the injection transmission has been verified to achieve the value of 13%, which corresponds to 47 deg of phase acceptance of the cyclotron central region.

Finally, we accomplished out a test aimed to establish the upper limit of injected current achievable into the cyclotron. The maximum value of current injected up to 1 MeV energy was 956 μA .

Table 2 shows the readback current values of diagnostics along the injection lines during the test.



Figure 3. The picture shows the pop-up probe mechanism installed into the valley of the cyclotron.

Table 2: Current Readback

Parameter	Current [μA]
BS Beamstop	7597.23
IFCOL	45.03
PP Pop-Up	956.20

The *BS Beamstop* is the current extracted from the ion source; the *IFCOL* is the current lost on the collimator placed upstream the inflector entrance; *PP Pop-Up* is the current of beam intercepted by the 1 MeV probe.

The second important test was carried on in order to check the maximum current delivered with a good stability versus time. As shown in the Fig. 4, the ion source set was tuned until a stable current value of 930 μA was measured on the pop-up probe.

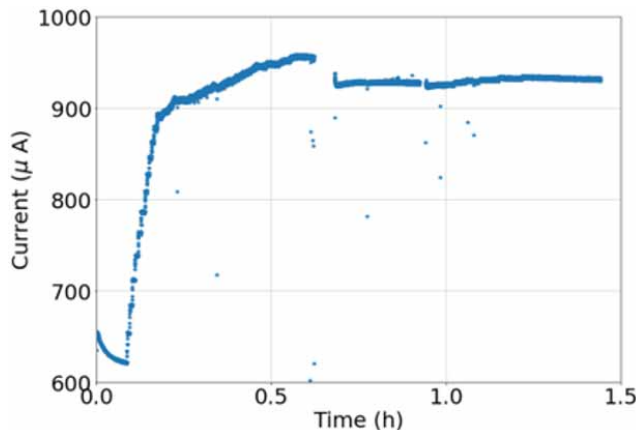


Figure 4. The plot shows the trend of the beam current readback at 1 MeV versus the time.

CONCLUSION

The status of SPES cyclotron and related subsystem was presented. The SPES facility during last three years is growing considerably. Many infrastructures and plants have been accomplished out as well the accelerator systems, i.e., ISOL target station, charge breeder device, etc.

The cyclotron was operational for limited time also due to the Covid-19 pandemic break. Anyway, in June 2020 the beam test demonstrated once again the good performance of the accelerator in terms of high injected current (950 μA) up to 1 MeV energy.

In March 2021, the cyclotron was again turned off to allow the installation of SPES equipment and proceed with the completion of the facility (new safety system, plants upgrading, civil works, compliance with fire brigade directives). Meanwhile the major upgrades of cyclotron systems are still proceeding.

The restart of operations is expected by the end of 2023 with the goal to deliver the first proton beam to ISOL target so that SPES project begins.

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