

COMMISSIONING OF THE LIPAc MEDIUM ENERGY BEAM TRANSPORT LINE *

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Abstract

LIPAc [1] will be a 9 MeV, 125 mA CW deuteron accelerator which aims to validate the technology to be used as neutron source of the IFMIF facility. Those facilities are essential for future fusion reactors material research. A 175 MHz RFQ will increase the energy up to 5 MeV before a Superconducting RF (SRF) linac with eight 175 MHz Half Wave Resonators brings the particles up to the final energy of 9 MeV. Between both stages, a Medium Energy Beam Transport line (MEBT) [2] aims at transporting and matching the beam between the RFQ and the SRF linac. The transverse focusing of the beam is controlled by five quadrupole magnets with integrated steerers, grouped in one triplet and one doublet. Two buncher cavities handle the longitudinal dynamics. Two movable scraper systems are included to purify the beam coming out the RFQ and avoid losses in the SRF linac. In this contribution, checkout of the beamline and its ancillaries in Japan is reported. Tests carried out on the beamline prior to the MEBT beam commissioning are described, focusing in vacuum tests, magnets powering, buncher conditioning and scrapers movement.

BEAMLINE ASSEMBLY

All the components of the MEBT arrived to the LIPAc assembly already assembled and checked from Europe [2]. However, some of the components of the beamline had to be reinstalled and realigned again on the facility. On a first step, the beamline was placed independently of the other subsystems and the work was focused on a proper alignment of the components (magnets, scrapers, re-buncher cavities and beam position monitors) with respect to the local

frame defined by the global mechanical support. Later on, the beamline was transported to the final destination downstream the RFQ. There the metrology of each component was rechecked and the whole beamline was aligned to the beam coordinate frame using the alignment capabilities of the global mechanical support.

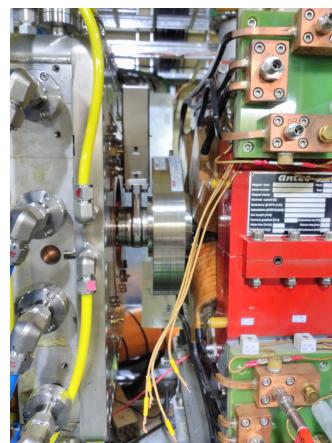


Figure 1: Picture of the assembly of the interface between RFQ and MEBT.

Once the alignment was completed, the mechanical interfaces with the RFQ [3] and the Diagnostics Plate were connected. The interface between the RFQ and the MEBT is quite complex (Fig. 1). At the output of the RFQ there is a valve which closes the vacuum of the RFQ. Connected to the valve, a current transformer which combines an AC and Fast Current measurement is placed. Then, the first vacuum tube of the MEBT which includes a beam position monitor is connected. The vacuum tube has a bellow inside which compensates the mechanical misalignment and the thermal expansion of the RFQ during high power operation.

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Moreover, this chamber is inserted in the middle of the first MEBT magnet. Therefore, the first magnet has to be dismounted to perform the connection to the RFQ. After several attempts and optimization of the procedure, the interface was successfully tighten and the magnets realigned.

Due to the complexity of the beamline the alignment was done in several steps. First, bunchers, scrapers and magnets were placed in the proper position with respect to the local frame defined by the MEBT mechanical support. Then, the beam position monitors were located and aligned inside the magnets. The final metrology survey of the beamline showed that all the components are within the required tolerances. Magnetic centers of the magnets were aligned with an uncertainty below 200 µm and bunchers below 1 mm.

Once the mechanical connections were completed, the electrical cabling and the water cooling distribution system and installation between the cubicles and the beamline was carried out [4]. The RF couplers of the re-buncher cavities were also satisfactory connected to the coaxial lines supplying the 175 MHz from the 16 kW solid state power amplifiers. The result is a very crowded beamline with many interfaces with other subsystems, as can be seen in Fig. 2,

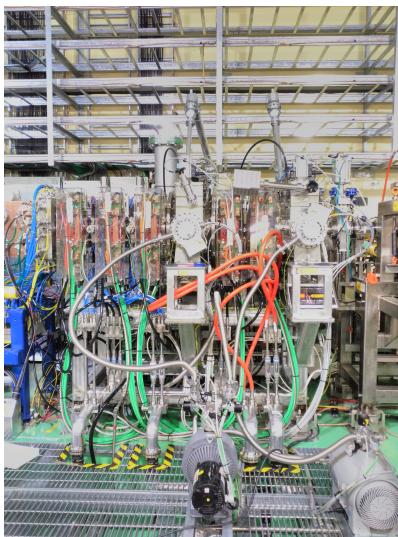


Figure 2: Picture of the MEBT completely assembled in the LIPAc facility.

HARDWARE COMMISSIONING

Vacuum system

The MEBT is pumped down by three turbopumps with a pumping speed of 600 L s^{-1} for D_2 , 550 L s^{-1} for N_2 and 510 L s^{-1} for H_2 . Two of the pumps are placed at vacuum ports in the first buncher and the other one in the second buncher cavity. A combined ionic and titanium sublimation pump is available also at the second buncher cavity. It was tested successfully during the checkout phase. However, since it was foreseen for the operation with the superconducting linac (commissioning phase C [6]), it is left stopped for the moment.

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Figure 3 shows the evolution of the pressure inside the MEBT beamline during a pumping down of the beamline. The high vacuum pressure is monitored at three points : a cold cathode gauge at the first buncher (MVG01) a cold cathode gauge at the second buncher (MVG02), and a hot cathode one at the drift tube between both bunchers. The pressure at the first buncher ($1.5 \times 10^{-9} \text{ mbar}$) is roughly half the one at the second ($3.5 \times 10^{-9} \text{ mbar}$) since as mentioned two of the turbopumps are placed at the first buncher, and one at the second. In the beamline, the pressure rises up to $3 \times 10^{-8} \text{ mbar}$ due to the small conductance of the tube.

Nowadays, the main residual gases in the beamline are: H_2 as major contributor (67 %), water (H_2O) (10 %) and outgassed air (N_2) from the walls (10 %). The measurement with the gauge presented before assumes N_2 as residual gas. The total throughput can be estimated at around $10^{-6} \text{ mbar L s}^{-1}$. This result is in good estimation with the surface outgassing calculated during the design of the beamline.

The present pressure is lower than the required one $5 \times 10^{-8} \text{ mbar}$ and matches very well the simulations taking into account the high uncertainty on the evaluation of the materials outgassing of each component. Nevertheless pressure during operation will increase due to several factors: i) distributed beam losses, ii) beam losses located at the scrapers, iii) change in material thermal outgassing rate during operation. Although they have been estimated for the simulations, they will only be tested during beam commissioning. For example, during the buncher conditioning it has been seen that during bunchers operation at maximum power the vacuum pressure is increased by one order of magnitude.

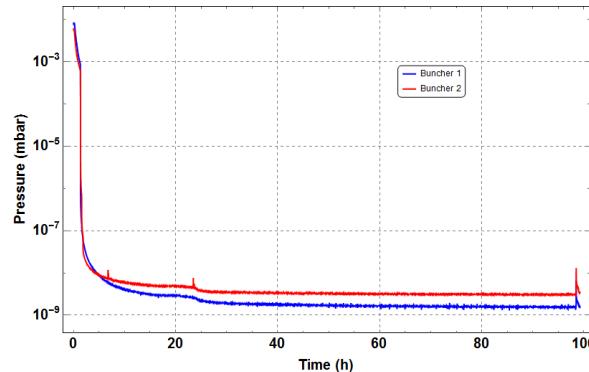


Figure 3: Plot of the evolution of the vacuum pressure at the MEBT during pumping down.

Magnets

A full set of checkouts and commissioning tasks were carried out on the five quadrupole and eight steerer magnets. All of them were tested at full power during a long period while the diagnostics (temperature switches, thermocouples and flow switches) were monitored. No problem was found in any of the magnets or the power supplies. At full power (180 A, 3.3 kW in the quadrupoles), the temperature rises

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up to more than 40 °C. However the maximum temperature reached at the steerer coils is well below the threshold, placed at 60 °C both for quadrupole coils and steerer coils.

Re-buncher Cavities

Both re-buncher cavities were already conditioned up to full power in ALBA-CELLS [7]. However, in the meantime between the first conditioned and the installation at the final location, the cavities underwent the assembly in the beamline, the transport to Japan and the re-assembly of the beamline and the coaxial lines. For this reason, it was decided the two re-buncher cavities were re-conditioned. The on-site reconditioning was successfully finished up to the target level of $E_0 LT$ of 350 kV in CW without problems.

The forward power was ramped up during the first stages of the conditioning, adjusting the slope depending on the pressure level and the state of the cavity. During the ramped up, the effective voltage goes from zero up to the target level, while the buncher cavity passes through several multipacting levels. For some of the peaks the vacuum pressure of the beamline rises up to almost the interlock level (9×10^{-7} mbar) from the baseline vacuum level of 2×10^{-8} mbar, which means almost two orders of magnitude. Once the final effective voltage is reached, the vacuum pressure is stabilized around 9×10^{-8} mbar which is almost one order of magnitude more than without voltage in the cavities. This change comes from the increase in temperature inside the cavity. The outgassing rate of the copper increases with temperature, affecting the vacuum pressure in the beamline.

During the conditioning, the instrumentation of the bunchers was monitored and adjusted, like the temperature interlocks of the different sensors or the vacuum level interlocks. Once the conditioned in CW was over, several tests regarding the operation of the bunchers in pulsed mode or future operation with beam loading were carried out. A more detailed and extensive description of the conditioning are out of the scope of the present paper.

Scrapers

The movement of the four blades of each the two scrapers was checked out and calibrated. The up and down limit switches of each driving stage were checked and used for the on-site calibration of the position movement of each blade with respect to the beam coordinate frame of the accelerator. Using a feedback loop with the stepper motor, the linear potentiometer of each stage and an adapted control software from [8], the position of the scrapers was set with a precision of less than 10 µm, well below the initial requirements.

On the other hand, a test of the influence of the magnetic field of the nearby quadrupole magnets on the potentiometers and the stepper motors was performed. There was not noticeable effect either on the stepper motor or on the linear potentiometer, comparing the position and the movement with the quadrupole off and with the magnetic field at maximum level.

Cooling system

The main components of the beamline (the five quadrupole magnets, the two rebuncher cavities and the two scrapers) are water cooled. The water is supplied from two different skids: i) the HEBT skid, for the room temperature of the five magnets, and ii) the MEBT skid, for the chilled water of the cavities and the scrapers. At the output of each component, a flow switch monitors the water flow passing through the component. The flow switches used are the RVO type from Meister. An interlock signal was calibrated on-site which sends a safety signal to the MEBT LCS if the flow is below a certain threshold (around 80 %).

The total flow for each branch (magnets, scrapers and bunchers) is measured at the skids using a flow meter. Minimum operation setpoints are defined for each branch. If for any reason the flow drops below the threshold, the skid stops and sends a beam interlock signal.

Control system

The full control system was implemented and tested during the last commissioning campaign. The control system is in charge of managing the vacuum system logic, the acquisition and treatment of the MEBT instrumentation in the vault, and the control of the scraper and buncher stepper motors and the magnet power supplies. The core control unit is a Siemens S7-300 PLC connected to all the components. The PLC is then connected by Ethernet port to an industrial computer running CentOS and the s7PLC driver, to integrate the PLC on the EPICS network. A full description of the control system is provided in [9]. During the last commissioning phase, the vacuum system operation was extensively tested from the central control system since it is the component more prone to human operation errors. All the other instrumentation was also tested to be ready for first beam operation.

The interface with the Machine Protection System [10] was also validated. First each signal was tested individually and then the real beam interlock functionality for all of them was tested. In the case of interlock signals from the bunchers the MEBT sends an interlock to the LLRF system of the bunchers in order to stop the RF. This procedure was also successfully performed.

CONCLUSIONS

The LIPAC MEBT and its auxiliaries were successfully installed, tested and commissioned in the accelerator. All the components which passed previously the validation tests in the factories were checked out to ensure a proper operation in the accelerator. After a careful integration and final tests at CIEMAT, the beamline completed the commissioning stage in February 2018 with the re-conditioning of the cavities and the final integration of the local control system. The start of the beam tests with a pulsed 2.5 MeV proton beam from the RFQ is expected during 2018.

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