MANUFACTURING, ASSEMBLY AND TESTS OF THE LIPAC MEDIUM ENERGY BEAM TRANSPORT LINE (MEBT) *

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Abstract

LIPAc [1] is a 9 MeV, 125 mA CW deuteron accelerator which aims to validate the technology that will be used in the future IFMIF-DONES accelerator [2]. The acceleration of the beam will be carried out in two stages. An RFQ will increase the energy up to 5 MeV before a Superconducting RF (SRF) linac made of a chain of eight Half Wave Resonators bring the particles up to the final energy. Between both stages, a Medium Energy Beam Transport line (MEBT) [4] is in charge of transporting and matching the beam between the RFQ and the SRF. 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 surrounding the doublet handle the longitudinal dynamics. Two movable scraper systems are also included to purify the beam optics coming out the RFQ and avoid losses in the SRF. In this contribution, the final integrated design of the beamline will be shown, together with the auxiliaries. The manufacturing of all the components and the integration in the beamline will be depicted. The final tests carried out to the beamline prior to the installation in the accelerator will be also reported.

MANUFACTURING & TESTS

The challenging requirements from beam dynamics [3] due to the high space charge along the MEBT causes a very compact and complex mechanical design [4]. In less than two meters, the MEBT contains five combined magnets, two movable scrapers, two re-buncher cavitities and four beam position monitors, as main components. Moreover, due to the activation, the time required for maintenance of the components should be minimized with easy access to the most delicate pieces.

Magnets

The mechanical design and the manufacturing was performed by the company ANTEC from an electromagnetical design [5]. The main challenges of the design were the limiting longitudinal space, which complicates the design of the coils and the electrical and hydraulical connections. Further information of the manufacturing can be found in [6] (see Fig. 1). Each magnet has followed a complete set of tests in the company: water cooling tests, insulation, coils impedance at several frequencies, metrology. All the magnets passed the tests prior to the magnetic analysis. Later, the magnets were tested in two magnetic test benches in ALBA-CELLS [14]. The analysis showed slightly higher harmonics in some magnets. However, after redoing some beam dynamics analysis it was seen there was no influence in the beam, therefore the magnets were accepted for assembly in the beamline.

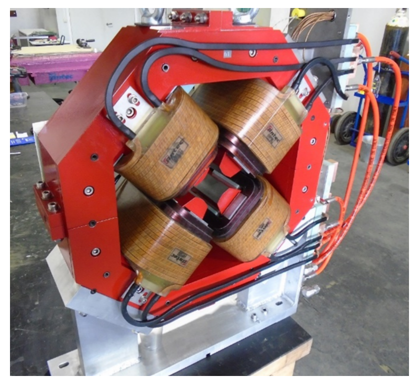

Figure 1: Picture of one of the MEBT combined magnets.

Re-buncher Cavities

Two re-buncher cavities with an E_0LT of 350 kV are necessary to match the beam with the SRF LINAC. The design was really challenging due to the limited space and the high voltage required. It was necessary to search for a special design of 5-gap IH resonant cavity with less than 10 kW dissipation power and low power density in the walls [8]. The re-buncher cavities were manufactured and integrated mainly by the Spanish company DMP (Fig. 2). The two re-buncher cavities have been tested following the same procedure. A complete set of tests (vacuum, water cooling, metrology) was performed in factory after each fabrication step [9]. Later, a smooth RF conditioning up to full power was carried out successfully at ALBA-CELLS RF laboratory [10]. The final Solid State Power Amplifer (SSPA) -developed by bTESA- was used as RF supply [11].

Scrapers

The mechanical design, manufacturing (see Fig. 3) and integration were performed by the company AVS from the thermomechanical and cooling design of the blades [12].

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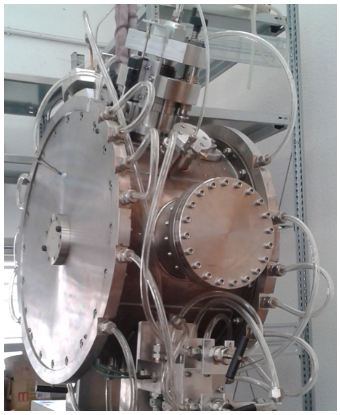

Figure 2: Picture of one of the re-buncher cavities.

Again, the main challenge is the small length available. The design was optimized to use only 80 mm of longitudinal space flange-to-flange.Full checkout tests were performed at the company site. The first was to validate the precision and accuracy of the movement of the collimators with respect to the mechanical axis of the chamber.Afterwards, leak tests of the cooling circuits of the collimators and the vacuum chamber integrated were successfully passed.

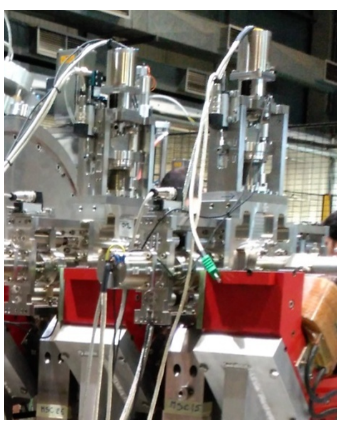

Figure 3: Picture of the scrapers installed in the beamline with the magnets opened.

Vacuum Chambers

Apart from re-buncher cavities and scrapers, the vacuum section of the MEBT is made of four vacuum chambers which pass through the aperture of the magnets. Three of the chambers contain beam position and phase monitors (BPM's): two one of them, and the last one two (Fig. 4). A shielded welded bellow with rotatable flange connects the chambers with other components. The bellows can accept a transverse misalignment of +/- 0.5 mm and a longitudinal one of circa 8 mm. The four vacuum chambers were manufactured by the company Vacuum Projects. Tight tolerances were given to the manufacturer of the BPM's due to the requirement of less than 100 µm accuracy with respect the Global Coordinate System of the accelerator. For this reason metrology was done after the most delicate procedures of fabrication. After following the proper cleaning procedure for UHV use, a vacuum leak test was carried out by the company. Then, RF tests of the BPM's were carried out to validate the behaviour and characterize them.

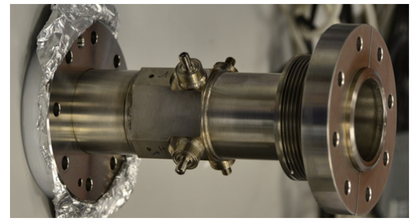

Figure 4: Picture of one of the vacuum chambers including a beam position monitor.

Mechanical Frame

The MEBT is rigidly supported and aligned as a whole with a stainless steel structure with four alignment feet (Fig. 5). The support is designed to be compliant with the seismic requirements of the site [13]. In addition, each main component can be aligned independently to the local coordinate system of the MEBT using individual supports also made of stainless steel. The manufacturing of the elements was carried out mostly by the Spanish company Nortemecánica, with some pieces being manufactured by the CIEMAT workshops.

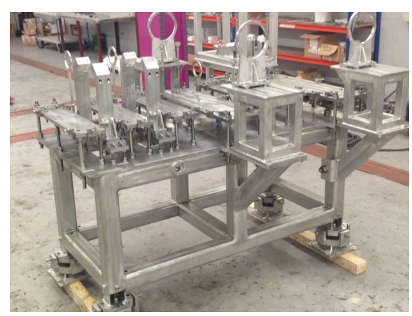

Figure 5: Picture of the mechanical frame for the MEBT with the alignment supports for individual components.

Auxiliaries

Vacuum system One of the important goals of the MEBT is to act as vacuum barrier between the RFQ (5×10^{-7} hPa) and the SRF LINAC (5×10^{-8} hPa). To achieve this goal taking into account the important gas load for 30 W losses in the scrapers, a system including three rad-hard Agilent turbomolecular pumps with drag stages for light gases, and one Gamma Vacuum ionic pump combined with a titanium sublimation one is used. In addition, cold cathode gauges in each buncher and a hot cathode one in the last section of the buncher are included. The rough pump down is controlled by two Scroll pumps backing the turbomolecular pumps. Simulations showed that the required pressure can be achieved at the SRF level.

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Cooling skid The water cooling of the components is supplied by two main circuits. A circuit supplying room temperature water to the magnets, to avoid water condensation and electrical shortcuts in the coils and a chilled water circuit for the re-buncher cavities and the scrapers, which keeps down the temperature of those components lower than 20 °C. Each circuit is driven by independent cooling skids (Fig. 6). Long-term high pressure tests were carried out up to 16 bar in the company.

Figure 6: Picture of the cooling skid supplying chilled water to the re-buncher cavities and the scrapers.

Electrical distribution The secondary distribution board required to channel and control the power from the general transformer to the electrical cubicles. This board, manufactured by ISC Ingenieria, includes all the necessary protections and ligthing warnings in the front pannel. In addition, remote monitoring of the system could be performed if necessary. Four cubicles contain all the necessary power converters and controllers to driven all the components in the MEBT: one for the power supplies of the quadrupole magnets, another one for correctors, and the other two for the control system and the electronics for the vacuum and the scrapers.

Control system The Local Control system of the MEBT is fully integrated in the LIPAc CCS. A S7-300 PLC handles most of the acquisiton and interlock signals from magnets, vacuum system, bunchers and cooling circuits. The movement of scrapers is governed by a Beckhoff IPC with feedback loop which is linked to the master PLC by a Ethercat gateway. The cooling skids are controlled by their own S7-300 PLC. The PLC's are integrated in the central control system in a PC running Linux, via the epics driver S7PLC or running an OPC for old designs. Power supplies are controlled directly from a IOC running over Linux via Modbus/TCP. Direct connections from the power supplies and the PLC's to the machine protection system of the machine ensures a safe protection and operation of the system [14].

BEAMLINE ASSEMBLY

The manufactured components were received at CIEMAT where they were integrated in the beamline. Due to the complex assembly procedure of the MEBT it was necessary the support of metrology survey equipment and team, as further explained in [15]. The alignment supports were dismounted for the metrology survey of the global frame. Then they were reinstalled and the magnets, bunchers and scrapers positioned in the MEBT local coordinate axis one by one. The last step was the positioning of the vacuum chambers with the beam position monitors, which are inserted between the combined magnets poles. The feasibility of the mechanical integration was validated using this procedure prior to the final integration in Japan (see Fig. 7).In parallel, the RF signal integrity from the 16 BPM feedthroughs was checked out prior and after assembly of the magnets. The time domain reflectrometry of each channel was stored so as to compare it later with the same test in Japan.

Figure 7: MEBT assembled at CIEMAT.

CONCLUSIONS

The LIPAC MEBT was successfully manufactured, integrated and tested in CIEMAT. All the components passed individually the validation tests in the factories to ensure a proper operation in the accelerator. After a careful integration and final tests at CIEMAT, the beamline was sent to Japan in February 2016 by ship for the final installation in the accelerator. The final integration in LIPAC is being carried out along 2016 and is expected to be finished in 2017. After the end of the checkout activities of all the components and the beam commissioned of the injector [16], the beamline will be commissioned with proton and deuteron beam.

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