## THE LINEAR IFMIF PROTOTYPE ACCELERATOR (LIPAC) DESIGN DEVELOPMENT UNDER THE EUROPEAN-JAPANESE COLLABORATION

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**Abstract**. The goal of the International Fusion Materials Irradiation Facility (IFMIF) is to provide an acceleratorbased, D-Li neutron source to produce high energy neutrons at sufficient intensity and irradiation volume for DEMO materials qualification. The IFMIF/EVEDA project is part of the Broader Approach (BA) agreement between Japan and Europe. In addition to the evolution of the engineering design, the key technological challenges are to be validated by prototypes. One of them is the 125 mA CW deuteron accelerator up to 9 MeV mainly designed and manufactured in Europe (LIPAc).

The aim of this paper is to give an overview of the LIPAc, which is currently being commissioned in Japan, outlining the engineering design and the development of the key components associated with the experimental program.

#### **INTRODUCTION**

The LIPAc activities are shared among the different institutions as follows (see Figure 1):

- the design, the manufacturing and the test of the accelerator components are provided by European Institutions (CEA, CIEMAT, INFN, SCK-CEN) which procure the Injector, the Radio Frequency Quadrupole (RFQ), the Medium Energy Beam Transport (MEBT), the Superconducting Radio Frequency LINAC (SRF Linac), the High Energy Beam Transport (HEBT), the Beam Dump, the RF Power System, Cryoplant, Local Control Systems and Beam Instrumentation;
- the construction of the building, the supply of the conventional facilities, the control system, the protection and timing systems as well as the RF couplers for the RFQ, are provided by QST.





The coordination of the activities within the EU-HT is managed by F4E which is taking care, among others, of the

#### **04 Hadron Accelerators**

# design integration, interface management, etc. The coordination, integration and commissioning is being led by the Project Team hosted at the Rokkasho site and supported by QST.

#### INSTALLATION AND COMMISSIONING

The component procurement for all accelerator systems is in an advanced stage. During the first installation and commissioning phase targeted at the production of a 140 mA-100 keV deuteron beam (Phase A - see Figure 2), all components were installed at Rokkasho. Current experiments show promising performance (100keV,  $I_{ext}$ :152mA,  $I_{BS}$ :109 mA,  $I_{ACCT}$ : 114 mA, 9.7% d.c.,  $\epsilon_{rms,n}$ :0.233  $\pi$  mm.mrad @  $V_{IE}$ :43kV). The second phase (Phase B - up to 5 MeV) will end by March 2017. The third and fourth phases (C & D) will follow till the end of 2019 with the integrated commissioning of the LIPAc up to 9 MeV in pulsed and continuous wave operation, respectively [1, 2].



Figure 2: Phases with respect to the different stages

## LIPAC COMPONENTS STATUS

## Injector

After acceptance tests were performed at CEA in November 2012, the Injector has been disassembled and shipped to Rokkasho in 2013.



Figure 3. LIPAc Injector at the Rokkasho site

## **A17 High Intensity Accelerators**

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The installation started in March 2014 and the checkout followed in September 2014. The first beam was extracted in November 2014. The proton and deuteron beam commissioning phases which are still in progress [3]. The completion of the beam characterization after the RFQ injection cone is ongoing, expected to finish by the end of May 2016. In the meantime, at low duty cycle, an operating point with protons has been reached and further optimisations are ongoing to meet the RFQ requirements. There is only a slow rise time of the beam (> 1 ms) when the injector is operated at slow repetition rate (1 or few Hz). Therefore, a chopper was installed in the LEBT in order to generate short and sharp edged beam pulses [4].

In order to optimize the project schedule, the phase B was started with the installation of the RFQ, MEBT, Dplate and the RF Power Systems while residual experimental programs from the phase A are still continued to complete the commissioning and full characterization of the Injector by the end of 2016.

## RFQ

The RFQ, composed of 18 modules, provides RF fields which are tailored to transport, bunch and accelerate the beam. The RF tuning of this long cavity (9.81 m) is achieved using static tuners. The heat dissipated in the copper structure including beam losses is extracted by a cooling system which also allows fine tuning of the resonant frequency, driven by the temperature difference between electrodes and the external body of the cavity. The beam losses have also a major effect on the vacuum conditions inside the RFQ; thus the vacuum system based on cryogenic pumps is designed accordingly.



#### Figure 4: RFQ assembly at Rokkasho site

For the EU-HT RF power coupler prototype, high power tests were performed at Legnaro. The final acceptance tests and RF conditioning in travelling wave (TW) mode were successfully completed in June 2015. The series couplers will be delivered fully conditioned in September 2016.

The manufacturing of the RFQ was completed and the high power test on the high end part of the super-module 3 was successful. After the completion of their assembly the 3 super-modules (SM), consisting of 6 modules each, were vacuum tested, packed and shipped to Rokkasho [5]. The installation of the RFQ has started early April and will continue until September with the bead pull measurements and the final tuning. Its conditioning at high power to reach operating field shall start in November 2016.

## MEBT

The main function of the MEBT [6] is to match efficiently the beam profile at the RFQ output to the SRF input,

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transversally and longitudinally. The longitudinal matching is carried out by means of two RF resonant cavities. For these buncher cavities, a 5-gap Interdigital Hmode configuration was selected giving the best compromise in terms of total power dissipation, power density, and space occupied. The radial dimensions of the beam are controlled by focusing magnets forming one quadrupole triplet and one quadrupole doublet; magnetic steerers integrated into the quadrupoles correct its transverse position. In order to cut off the beam edges which determine the beam losses, the unmatched particles coming from the RFQ are collected by two sets of scrapers adjustable on four axes. These scrapers are located between the magnets of the triplet. An adequate pumping system has been design for installation at the bunchers to ensure the vacuum conditions required by the proximity of the RFO and SRF Linac.



Figure 5: MEBT at Rokkasho site

The manufacturing of the main components was completed with the conditioning of the bunchers performed in first half of 2015. After the final assembly in January 2016 [7], the MEBT and its components were shipped to Rokkasho and positioned in the accelerator vault to proceed with the final test and checkout starting July 2016.

#### SRF Linac

The SRF Linac [8,9] accelerates the deuteron beam from 5 MeV to 9 MeV by means of RF fields formed by 8 superconducting HWRs (half-wave resonators). The frequency of each HWR must be precisely adjusted by using a dedicated mechanical tuner. The transport, focussing and trajectory corrections of the beam are performed by 8 sets of solenoids, steerers and beam position monitors, located before each HWR. Cavities and solenoids have their own helium vessel and all the components are placed in a single 6-m long cryostat. Magnetic shielding is used to protect the HWR from the earth's magnetic field.

The design of the cryomodule is now completed [10,11] and all the components containing LHe and/or GHe during LIPAc operation are designed, manufactured and tested according to ASME standard for pressure vessels and piping. The cavity design, in compliance with Japanese High Pressure Gas Safety Law, has been licensed by the Japanese authorities (KHK).

All the cavities are under manufacturing and tests of the naked cavities are expected to be completed by March 2017. Some of the cavities, will undergo specific tests with couplers and frequency tuners in a dedicated test cryostat called "SATHORI". Procurement of all the other

cryomodule components is expected to be completed within May 2017 to start the assembly of the Cryomodule in 2017.

The cryomodule assembly, which is one of the most challenging aspects of the SRF Linac activities, will be performed under the F4E responsibility in a dedicated clean room at Rokkasho. The complete cryomodule will be tested at 4.45 K and under RF power in the LIPAc accelerator building.

## HEBT & Beam Dump

The beam from the SRF Linac will be shaped in a HEBT line and transported into the beam dump, designed to dissipate the 1.125 MW of the deuteron beam. The line includes eight quadrupoles which provide the necessary beam focussing and a dipole that bends the beam to reduce the radiation from the beam dump received by the SRF linac. The beam dump consists of a cartridge surrounded by a modular water and iron shield. The part that stops the beam is a long copper cone whose surface is at a small  $(3.5^{\circ})$  angle with respect to the accelerator axis. During beam shutdown, a mechanical shutter is closed to provide a shield against gamma rays from the activated Beam Dump cartridge. A water-cooling system is used to extract the deposited heat and a vacuum pumping system is implemented to maintain the required vacuum level during operation or for recovery maintenance.

The HEBT and the Beam Dump are well advanced and in the final stage of design and manufacturing. While the HEBT cooling system is already delivered to Rokkasho, the remaining components will arrive till May 2017.

## **Beam Instrumentation**

Beam instrumentation [12] consists of diagnostics aiming at monitoring and controlling all the necessary beam characteristics along the accelerator. These diagnostics will be a key element for the experiments right from the first beam commissioning up to routine operation.

A full set of non-intrusive diagnostics are available: current monitors of various types (AC and DC current transformers, fast current transformer), 20 beam position monitors (8 of them at cryogenic temperature), beam profile monitors (based on ionization and fluorescence of the residual gas), around 20 beam loss monitors (ion chamber Large Hadron Collider type), bunch length monitor (residual gas), Two SEM grids for the measurement of beam emittance an energy dispersion in pulse mode. The analyse of the micro-loss monitors design based on CVD diamond is in progress. For short chopped beams, interceptive devices as secondary emission monitor grids and slits will be used for emittance and energy spread measurement.

## RF Power System

The RF Power System based on 18 RF power chains operating at 175 MHz to feed the RF structures of the RFQ, MEBT and SRF Linac through coaxial lines.

For the RF power chains feeding RFQ and the SRF Linac, the same topology was chosen for standardization and

costs reasons. They are composed of a solid-state predriver and tetrodes for driver and final amplifier which can be individually tuned to provide different RF output powers up to 200 kW. The 200 kW RF power system for the RFQ was delivered. Its installation is currently under finalisation with the commissioning to start in July 2016.



Figure 6: RF Chain 200 kW at Rokkasho site

The 100 kW RF power system for the SRF Linac is expected by end of 2016. The MEBT buncher cavities are fed by a full solid-state amplifier of 16 kW which was delivered and will be installed in July 2016.

## Cryoplant

The production of liquid helium needed for the SRF Linac bath cooling is performed with industrial equipment HELIAL using the well-known Claude refrigeration cycle. The installation including the cryo-piping and reservoirs will be completed by the end of 2016.

## Control System

All accelerator subsystems include a Local Control System (LCS) which can work stand-alone under Experimental Physics and Industrial Control System (EPICS) for monitoring and controlling the different subsystem equipment. During the integration on site, all LCSs will be combined, thanks to the adoption of standard solutions, and will be managed by a Central Control System. In fulfilment of safety aspects, personal and machine protection systems are installed [13].

## Building and Conventional Facilities

The building, constructed in Rokkasho in 2009, consists of an accelerator vault, a nuclear heating, ventilation and air conditioning (HVAC) area, a heat exchange and cooling water area for both radiation-controlled and non-controlled areas, an access room, a control room, and a large hall for power racks, RF systems (HVPS and RF power chains) and the He liquefier. The accelerator vault is surrounded by 1.5 m thick concrete walls and ceiling. The installation of the main auxiliaries is completed, and the remaining components will be provided during the installation of each sub-system.

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#### **04 Hadron Accelerators**

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