FINAL DESIGN OF THE IFMIF INJECTOR AT CEA/SACLAY

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Abstract

The IFMIF accelerator dedicated to high neutron flux production for material studies is now entering in a new phase. For this irradiation tool, IRFU institute from CEA/Saclay is in charge of the design, construction and characterization of the Injector. The high intensity deuteron beam is produced by an ECR source located on a 100 kV platform. The 2 m long LEBT, based on 2 solenoids, is ended by a cone installed at the entrance of the RFQ. Specific diagnostics (cameras, Allison type emittance scanner, fiberscope) have been installed for the beam characterization. During the last weeks, after Injector conditioning, more than 100 mA of deuteron beams have been characterized after the RFQ entrance cone in pulsed and continuous mode [1]. The shipment of the Injector towards the Rokkasho site in Japan (where it will be reinstalled) is foreseen at the beginning of 2013. This paper will focus on the final design used during the beam characterization experiments at Saclay.

INTRODUCTION

For several decades numerous projects are based on high intensity beam interaction with different targets, either for industrial applications or research facilities. High intensity light ion beam projects are generally considered as part of the HPPA (High Power Proton Accelerator) family. The IFMIF machine [2] which aims to produce 2 parallel deuteron beams of 125 mA intensity and 40 MeV energy is an HPPA reaching 10 MW beam power. IFMIF is dedicated to the irradiation of materials for future fusion reactors by delivering a high flux of neutrons after interaction of the D^+ beams with a Lithium liquid target.

Having a look at the requested beam characteristics, one could easily consider this machine as the accelerator of all the records: the highest intensity, the highest beam power, the highest space charge and the longest RFQ. Before reaching all these records, the LIPAc (Linac IFMIF Prototype Accelerator) will have to demonstrate the feasibility. The LIPAc is composed of an Injector, a RFQ, an SRF linac, intermediate beam lines (MEBT and HEBT) and a beam dump. Most of the components are presently under construction in Europe before to be installed in Japan. However, the injector has been already built and tested in CEA/Saclay during the last years. It is presently under shipment from France to Japan.

The Injector is composed of the deuteron ion source, the LEBT (Low Energy Beam Line) and the associated diagnostics as well as all needed ancillaries. Table 1 reports the requested beam performance at the RFQ entrance.

Table 1: Summary of the IFMIF injector requested parameters at the RFQ entrance flange.

Requirements	Target value
Particles	D+
Output energy	100 keV
Output D+ current	140 mA
D+ fraction	99 %
Beam current noise	1 % rms
Normalized rms transverse emittance	0.25 π mm mrad
Duty factor	CW
Beam turn-off time	< 10 µs

The final design of the LIPAc Injector is reported in this article where the following section points out on the as built extraction system as well as the fast beam inhibit system. Section 2 reports on LEBT with magnetic elements, diagnostics and chopper.

SOURCE AND EXTRACTION SYSTEM

In such an accelerator, the ion source is the first element on the long accelerator beam line. It has to provide the requested beam with characteristics giving the best conditions to inject the beam into the1st accelerating cavity. Thus, since the beginning, the source has to be designed to minimize the beam emittance. In addition, for safety reasons, the high intensity beam has to be shut down in a very short delay in order to minimize the damages in case of high beam losses or failures.

The source, operating at 2.45 GHz, is based on ECR plasma production with a 2 coil magnetic structure [3]. In order to optimize the beam emittance just at the exit of the source, preliminary simulations pushed to limit the number of electrodes in the extraction system and to increase the diameter of the plasma electrode [4]. In order to keep plasma meniscus tuning, it has initially been decided to build a 4 electrode extraction system.

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As preliminary results demonstrated a quite high spark rate, the addition of a 5th electrode (as grounded electrode between puller and electron repeller) has been decided. Figure 1 presents simulations for the new extraction system.

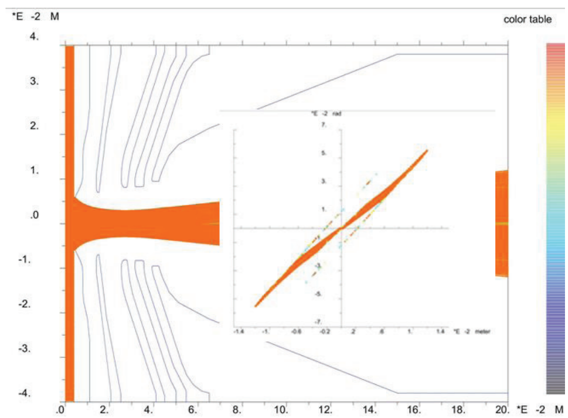
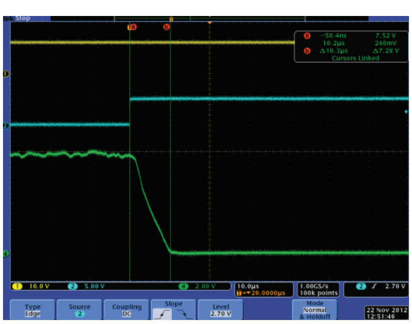


Fig. 1: Simulations of beam trajectories with the new 5 electrode extraction system.

This 5 electrode extraction system has been installed on the IFMIF injector mid of September 2012. After extraction gap conditioning, beam extraction and optimization has been performed with hydrogen beams. Then, deuterium was injected into the plasma chamber and beam characterization has been performed [1] in pulsed mode before switching to continuous mode for a short period (neutron production limitation). A 140 mA high intensity D^+ beam has been characterised at the end of the LEBT, with 10, 30, 50% duty cycles at 100 keV energy. A continuous beam of 140 mA has also been produced. Even if simulations show the electric field in the 5 electrode extraction system does not exceed 10 MV/m, numerous sparks still occur mainly while increasing the high voltage value between the plasma electrode and the puller.



Yellow: Source trigger
Blue: Fast beam inibit trigger
Green: Beam fall time (measured on beam stopper)

Fig. 2: Beam shut-down after fast beam inhibit trigger

For safety fast shut down, a beam off time lower than 10µs has been demanded. To achieve this request, a dedicated rack has been developed by Sairem company © in order to short-circuit the magnetron HV in a short delay. This rack, located on the HV platform is triggered via an optic fiber and directly linked to the magnetron HV power supply. Machine protection system tests have been performed while the source was running in pulsed mode at 10 Hz with 40 % duty cycle. A 10 µs effective beam fall time has been observed.

LEBT AND DIAGNOSTICS

At low energy, along the beam line space charge is partially compensated by the interaction of the beam with the residual gas. Such space charge compensation can be calculated to allow simulating beam trajectories [5].

Fig. 3: Principle of H/V steerers located inside solenoid (left) and picture of steerers coils before assembly (right)

Fig. 4: View of the Injector LEBT before connection of all the water cooling circuits

The LEBT length has been made as short as possible in order to minimize the emittance growth [5]. To match the beam at the RFQ entrance, the LEBT is based on a dedicated accelerator column, 2 solenoids, a diagnostic box (equipped with a 2500 l/s turbomolecular pumping group) and a cone. Two 310 mm long solenoids including the iron shielding have installed with H/V steerers located inside the solenoids (Fig. 3). Each solenoid provides 0.76 T maximum axial field with an integral of $\int B_{z(z=0)}dz = 0.2$ T.m. The H/V steerers can give a 30 mrad angle correction at maximum current of 150A in the air coil windings corresponding to $\int B_{x,y(z)}dz = 1.5$ mT.m. The total LEBT length is finally limited at 2.05 m (Fig 4). For the tests at CEA/Saclay, the RFQ was replaced by a second diagnostic box equipped with the beam stopper.

To characterize and to follow the beam evolution during operation, space for diagnostics is limited. As a

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consequence, only CID cameras, a deported spectrometer (using a radiation resistant fiberscope [6]), an Allison scanner emittancemeter, an ACCT and a movable beam dump are installed in the LEBT.

The Allison scanner has been developed for being able to bear more than 15 kW continuous beam. The entrance slit, made by the thermal screen, is followed by a classical varying electric field which allows analysing the selected beamlet through a second slit. Thermal simulations have been performed to design the thermal screen made of tungsten tiles brazed on a water cooled copper block (fig. 5). This technic has been proposed by CBMT © and Mécadeuil © companies. A 40 l/min water cooling flow is needed in both part of the screen. As the total beam never heats the 2 part at the same time, they have been connected in series. With 2.1 kW/cm^2 beam power density (15 kW over 3 cm diameter), simulations showed that the temperature increase at the surface of the tungsten tiles is in the range of 1200 °C. As a result, beam diameter has to be well controlled at the EMU location before starting an emittance measurement.

Fig. 5: LIPAc injector emittancemeter

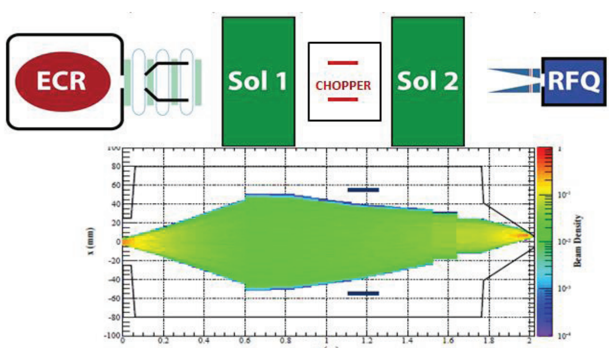

Fig. 6: Simulation of beam deflection onto the cone by using the chopper

Due to the high power beam and too long rise time of the beam extracted from the ion source, a slow chopper will be used to allow interceptive diagnostics after the first accelerating cavities (RFQ and/or SRF linac) for machine commissioning. This chopper has been designed to be used while the machine is operating in pulsed mode. It is foreseen to be installed in the diagnostic box located between both solenoids. Simulations showed < 7 kV/cm applied between 2 plates long of 15 cm will allow deflecting the beam on the RFQ entrance cone (fig. 6). For the chopper, electric behaviour tests have been successfully done at CEA/Saclay. Rise time and fall time of the HV pulses were measured (Fig. 7) with a 8 kV negative pulse of 100 µs. Chopper tests have been performed with pulse duration from 20 µs to 5 ms and repetition rate of 10 Hz. Maximum rise and fall times of 4 µs have been achieved. Tests with beam have not been performed yet.

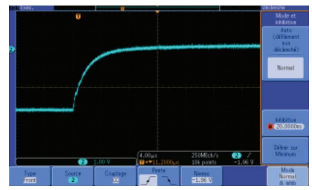

Fig. 7-a: Chopper pulse fall time from - 8 kV to 0 (4 µs/cc)

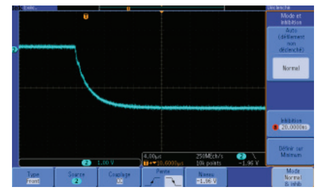

Fig. 7-b: Chopper pulse rise time from 0 to - 8 kV (4 µs/cc)

CONCLUSION

The preliminary tests of the LIPAc injector, performed at CEA/Saclay, demonstrated the great challenge of the 140 mA - 100 kV deuteron beam production. High spark rate pushed to switch from a 4 to 5 electrode extraction system. Additional work will have to be done in order to fully reach the expected reliability.

Anyway, acceptance tests have been performed last November [1] and the Injector is presently travelling between Europe and Japan. The Injector re-installation on the Rokkasho site is expected in summer 2013 [7].

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REFERENCES

[1] N. Chauvin et al., "Linear IFMIF Prototype Accelerator injector beam commissioning: experimental results and simulations", this conference

[2] J. Knaster et al., "The Installation and Start of Commissioning of the 1.1 MW Deuteron Prototype Linac for IFMIF", this conference

[3] R. Gobin et al., Rev. Sci. Instrum. **79,** 02B303 (2008)

[4] O. Delferrière et al., Rev. Sci. Instrum.**79,** 02B723 (2008)

[5] N. Chauvin et al., Rev. Sci. Instrum.. 83, 02B320 (2012)

[6] F. Senée et al., "Beam species fraction measurement using Doppler shift method with FUJIKURA fiberscope for IFMIF-EVEDA Injector", Proceedings of the DIPAC 2011 Conference, Hamburg (Germany)

[7] H. Shidara et al., "Installation of Deuteron Injector of IFMIF Prototype Accelerator in Japan", this conference