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INCREASE OF IPHI BEAM POWER AT CEA SACLAY

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Abstract

For the first time, in April 2016, the SILHI source produced a proton beam for IPHI RFQ. Due to several technical difficulties on the RFQ water cooling skid, a short RF power pulse (100 µs at the beginning until few hundred microseconds) is injected into the RFQ accelerates the high intensity proton beam up to 3 MeV. The repetition rate is tuned between 1 and 5 Hz. Under these conditions, the beam power after the RFQ is lower than 100 W. At the end of 2017, the 352 MHz RFQ conditioning has been completed (with the same duty cycle) and the proton beam has been accelerated. The increase of the beam power is expected to continue in 2018 in order to reach several kilowatts by the end of the year. In addition, two Ionization beam Profile Monitors (IPM) developed for ESS have been tested on the deviated beam line with a very low duty cycle. The IPHI facility should demonstrate the possibility to produce neutrons with a flexible compact accelerator in the framework of the SONATE project. This paper presents the status of the IPHI project in April 2018.

INTRODUCTION

During the long shutdown period, it was necessary to upgrade and modify the RFQ water cooling skid in order to be able to dissipate finally the 1 MW of RF power lost in the RFQ cavity in CW mode. After having made functional the RFQ water cooling skid, the 352 MHz RFQ conditioning up to a peak power of 1.2 MW was undertaken again at very low duty cycle. An extended IPHI (Injector of Proton for High Intensity) RFQ proton beam acceleration campaign could be then performed. From December 2017, the second neutron production run started, which consisted of collide the neutron beam onto a Beryllium target. Moreover, two prototypes of ionization profile monitors developed for ESS are being commissioned since the beginning of this year.

IPHI DESIGN

Before its acceleration up to 3 MeV, the proton beam is produced by the SILHI source [1] and transported at the RFQ entrance using a dual solenoid focusing system. Some diagnostics allow the characterization of the 3 MeV proton beam downstream the RFQ [2]. At the end of the main beam line, a 300 kW water cooled beam dump has been installed. The proton beam can also be deviated on a dedicated beam line via a dipole. In this case, the beam power is restricted to a few hundreds of watts due to the limitation of the water cooling system of the Faraday cup. This beam line is designed to be flexible to allow diagnostics developments and tests on collaborators requests. Harps for SARAF project as well as EMIT4D for MYRTE should be soon tested on this deviated beam line.

The RFQ transmission can be easily calculated by measuring the ratio between two ACCT signals located very close to both RFQ end plates. The timing system was tuned to get a RF short pulse (100-400 µs) at the end of the beam pulse delivered by the ion source. The repetition rate was 1 Hz. After the tuning of the solenoids and the steerers of the LEBT, the RFQ transmission reached 92 %, like in 2016 [3], with 75 mA of protons injected into the RFQ.

RFQ WATER COOLING SKID

During the operation, the cavity is water cooled in order to avoid RFQ detuning due to geometric modifications. IPHI cooling is provided by two separated circuits. The first one is cooled through a heat exchanger and is used to protect devices that could potentially activate cooling water (as beam dump or diagnostics). The second circuit, more complex, allows the regulation of the RFQ temperature. The RFQ elements which are cooled are the cavity body, the pumping ports, the tuners and the RF ports which are composed of 268 different pipes. Because of many leaks, all pipes have been modified during 2017. Due to the incompatibility with low duty cycle operation, a bypass of the cold water unit has been done. The water temperature at the entrance of the RFQ is now 30 °C instead of 11 °C, which induces an increase of the RF power dissipation of 60 kW.

The water of the RFQ circuit is now cooled directly by water coming from a cooling tower through a 1300 kW plates heat exchanger. Temperature regulation of about ± 0.1°C is done by three-way valve in order to mix the water heated by the RFQ with the cold water tower. This circuit is divided in four parts in order to feed the different parts of the RFQ (the three segments and the internal cooling channels). Each loop is equipped with a circulation pump and a three-way valve, driven by command control. IPHI cooling skid has been operational and satisfactory since December 2017.

IPHI RFQ TRANSMISSION

The curve representing the RFQ transmission measured as a function of the RF voltage is usually used to characterize a RFQ. The IPHI RFQ transmission curve, obtained in December 2017, is shown in Fig. 1. The experimental results (purple curve) are in close agreement with the Toutatis simulations [4] (green curve) up to a

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relative RF voltage of 0.73 corresponding to 65 % of RFQ transmission. Above this relative RF voltage value, the measured RFQ transmission does not agree with the simulation. The RFQ nominal transmission is reached for a higher relative RF voltage compared to the nominal one: 1.2 instead of 1. Under these conditions, an increase of the duty cycle up to CW seems to be difficult. A comprehensive study of this phenomenon is thus conducted to optimize the RFQ transmission.

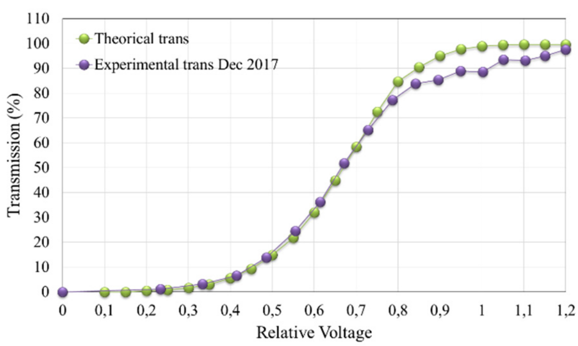

Figure 1: RFQ transmission as a function of the RF voltage.

PRELIMINARY IONIZATION PROFIL MEASUREMENTS

In the framework of the CEA in-kind contribution with the European Spallation Source (ESS), two prototypes of ionization profile monitor (IPM) have been tested on IPHI. As for the IPM developed for LIPAc (Linear IFMIF Prototype Accelerator) [5], the ionization current collected on the conductive strips (32 channels) is used to derive the beam profile. Because of the very low ionisation cross-section at the ESS beam energy (from 90 MeV to 2 GeV), a MCP (MicroChannel Plate) [6] has been added upstream of the stripes in order to intensify single particles (ions/electrons) by the multiplication of electrons via secondary emission. For the second prototype, the stripes have been replaced by an optical system.

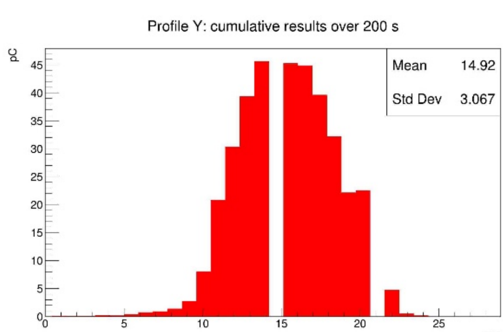

Figure 2: Beam profile obtained with cumulative two hundreds beam pulses.

A CCD camera is focused on the scintillator which is located downstream of the MCP. The scintillator produces photons coming from the particles multiplied by the MCP. The very good spatial resolution of the MCP (10 µm diameter channels) derives the beam profile.

MCP/stripes Readout

The preliminary beam profile obtained with this readout is shown in Fig. 2. The stripe at the centre was not working.

MCP/scintillator Readout

An image of the transverse beam profile obtained with the MCP/scintillator readout is shown in Fig. 3. The beam position fluctuations measured by BPMs (Beam Positon Monitor) located on the IPHI beam line and by the IPM are in very good agreement.

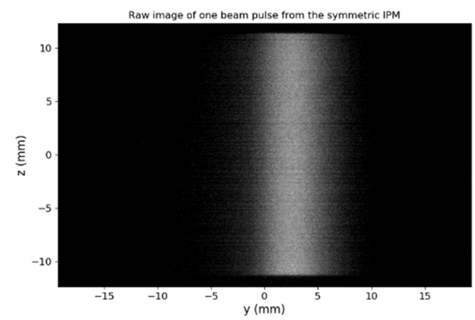

Figure 3: Image of the transverse beam profile.

NEUTRONS PRODUCTION EXPERIMENT

The possibility and the availability of operating with ions current up to 100 mA have been demonstrated, which lead to a strong interest in setting up compact neutron sources based on proton accelerators for neutron science. In this framework, IPHI is entirely suited for the production of neutrons. A thin Beryllium (Be) target with a movable polyethylene moderator has been installed replacing the Faraday cup. An electron repeller and insulation of the Be target allow the precise measurement of the proton beam current at the target and of the proton beam losses on the vacuum chamber. The transmission of the deviated beam line could therefore be optimized to minimize the beam losses up to the target. Several types of detectors were installed to confirm the background measurement and the neutrons energy spectrum, such as a Bonner sphere, a movable ^{3}He detector, gamma chambers, a gamma NaI spectrometer and two types of neutron detectors (slow and fast). These last two detectors, called nBLM (neutron Beam Loss Monitor), and are under development by CEA for ESS and SARAF projects as part of their beam losses measurements/instruments. For the latter project, nBLM are essential to maintain a low level of activation all along the accelerator, to finely tune the beam, to guarantee the accelerator integrity by enabling the shutdown of the beam in a very fast time in case of high beam losses.

From a proton beam energy of 3 MeV, only the neutral particles produce by nuclear reactions due to beam losses (neutrons and photons) can escape from the beam pipe while the other ones are absorbed by it. For this reason,

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CEA is developing two fast neutron detectors having a low efficiency for thermal neutrons, gammas and X-rays (Fig. 4).

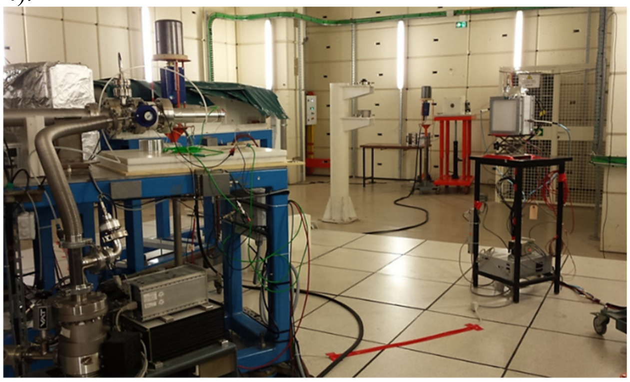

Figure 4: Slow nBLM detector located together with the Beryllium target on the beam axis.

Slow nBLM

After being thermalized by polyethylene (moderator) of 4 cm thickness located all around the detector chamber made of aluminium, the fast neutrons emitted in straight line from the Be target have been measured with a MicroMegas detector (Micro-Mesh gaseous structure) [7] located inside the chamber. The thermal neutrons convertion into alpha particles in the drift cathode made of B_4C. The Micromegas detector detects particles by amplifying the charges that have been created by ionisation in the drift gap. The gas mixture that was used is He (90 %) and CO_2 (10 %). An outer MirroBor thin layer (5 mm) absorbs the thermal neutrons. The time response is shown in Fig. 5 and is about 200 µs. The linear dependency with the beam intensity as well as the angular distribution (4π) was also checked.

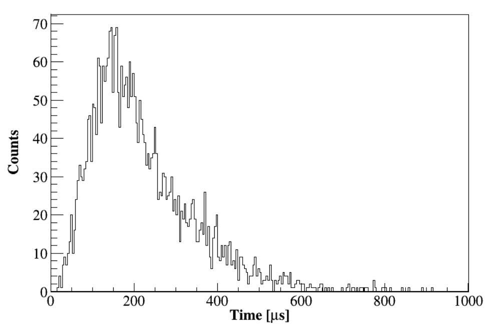

Figure 5: Time response of the slow nBLM detector.

Fast nBLM

The drift cathode in this case is made of Mylar to detect the proton recoils that are created by the elastic scattering of the incoming neutrons. The fast neutrons are thus directly measured, and while the sensitivity is ten to hundred times lower the slow nBLM module. The time response is twenty thousand times faster (0.01 µs), which is suitable with Machine Protection System signal. Figure 6 represents the fast nBLM integrated signal which is perfectly synchronized with the beam current measured on target.

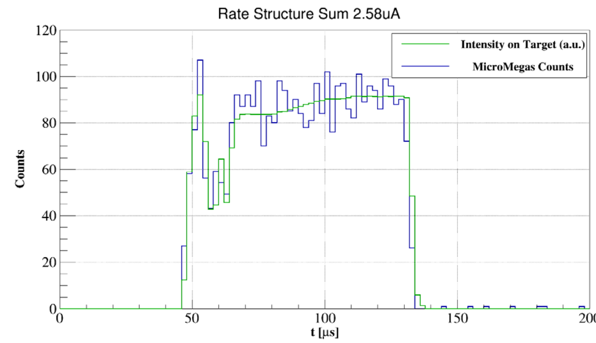

Figure 6: Time response of the fast nBLM detector and beam current on target.

CONCLUSION

With the use of the final RFQ water cooling skid, the SILHI source produced once again a proton beam for the IPHI RFQ. Priority was given to the test of diagnostics prototypes and to the neutrons production before increasing the IPHI beam power. Due to the annual maintenance of the cooling water tower followed by the replacement of the MEBT quadrupoles power supplies, the restarting of IPHI is scheduled for September 2018 in order to reach 7 kW of beam power at the end of this year. In a second phase within SONATE project (2020), the IPHI beam power should be increased up to 50 kW.

ACKNOWLEDGMENT

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