HIGH INTENSITY BEAM PRODUCTION AT CEA/SACLAY FOR THE IPHI PROJECT

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Abstract

CEA/Saclay is involved in high power proton accelerators for many years. This activity started in the 90's, with the development of the SILHI source which routinely produces tens mA of proton beam. Several industrial difficulties led to a very long IPHI RFQ construction process. The 352 MHz RFQ conditioning is presently in progress. Before the completion of the conditioning in CW mode, tests with pulsed proton beam have been performed.

As a consequence, the SILHI source recently produced very short H+ beam pulses in order to allow the first IPHI beam acceleration. Such very short pulses, in the range of few hundred microseconds, allowed analyzing the beam loading of the RFQ cavity as well as conditioning the middle energy diagnostic. This article reports the source parameters and beam characteristics in the low energy beam line leading to the best RFQ transmission as well as several results concerning the accelerated beam at 3 MeV.

INTRODUCTION

In the middle of 90's, CEA and CNRS which are 2 important national research organizations, decided to start a collaboration in the development of high power proton accelerator. It was then decided to concentrate the activities on 3 items: (i) the injector of proton for high intensity (IPHI) which is a prototype of linac front end able to accelerate up to 100 mA cw H+ beam, (ii) construction and test of $\beta<1$ superconducting cavities and (iii) development and improvement of the codes for accurate beam dynamics calculations.

The development and construction of the High Intensity Light Ion Source (SILHI) with its associated low energy beam line were the first steps of the IPHI program. To fulfil the IPHI requests (high intensity cw beam), a 2.45 GHz ECR source has been chosen for the SILHI source producing the H^+ particles.

Then the design and construction of the RFQ and a dedicated diagnostic beam line was decided. In a 1st step, the goal of IPHI was to accelerate the proton beam from 100 keV to 5 MeV with an RFQ and up to 11 MeV with a DTL. For different reasons (mainly economical and strategic ones), the final energy has been reduced from 11 to 3 MeV [1]; as a consequence, the DTL was not needed any more.

In parallel to the long IPHI RFQ construction, the SILHI source was producing high intensity beam. The obtained performance allowed us developing and constructing new injectors for Spiral 2, FAIR and IFMIF. The production of such high intensity beams also permitted the development and improvement of innovative diagnostics.

In the past years, the IPHI project faced industrial (company closure), administrative (end of collaboration) and technical difficulties (RFQ brazing troubles for example); and the completion of the RFQ assembly ended few months ago. Then the 352 MHz RFQ conditioning has been undertaken at very low duty cycle; it is still in progress by increasing the duty cycle. Once the conditioning reached a high enough RF field into the cavity, it has been decided to inject the SILHI beam into the RFQ. And the acceleration of the first proton beam up to 3 MeV has been recently achieved in pulsed mode.

This article briefly recalls the IPHI general design as well as the SILHI and LEBT components. The following section presents the SILHI parameters with very low duty cycle and before to conclude, the last section reports the preliminary 3 MeV H^+ beam results.

IPHI AND SILHI DESIGN

The 4 vane type RFQ of the IPHI project [1, 2] is made of 6 modules (Fig. 1). Each module is 1 meter long and is built in 4 parts brazed together. Large copper pieces with very tight tolerances after machining (10 µm over 1 meter long) and precise brazing pushed to use unconventional technics. The whole RFQ is assembled in 3 segments (made of 2 coupled modules) linked with 2 coupling plates. The 352 MHz RF power, generated by 2 klystrons, is injected in the 4th module via 4 ridges and 4 windows. During the operation, to avoid RFQ detuning due to geometry modifications, the cavity is water cooled by means of 268 different circuits and its temperature is precisely adjusted (0.1° C) by regulating the temperature of several circuits.

The RFQ is followed by a dedicated diagnostic beam line designed to fully characterize the 3 MeV beam. At the end of the beam line, a 300 kW water cooled beam dump has been installed. The beam dump conical shape allows minimizing the beam power density and the inner cone made of nickel allows minimizing the activation.

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Figure 1: General view of the 6 meter long IPHI RFQ.

Before the acceleration, the proton beam is produced by the SILHI source [3] and transported at the RFQ entrance by a 2 solenoid LEBT. The SILHI ECR source operates at 2.45 GHz; the RF power is injected into the plasma chamber via a quartz window and a 3 step ridged waveguide. The beam is extracted from the plasma chamber through a 5 electrode extraction system. Then the beam is transported and matched into the LEBT thanks to 2 solenoids, steerers, an iris and a cone. The water cooled cone, located between the second solenoid and the RFQ, allows collecting the unwanted particles (H_2^+ and H_3^+). In the LEBT, the high intensity beam interacts with the residual gas; as a result the space charge compensation (due to electron trapping) helps in minimizing the space charge forces. In order to reach the 95 keV energy at the RFQ entrance, the source and its ancillaries are positioned onto a HV platform.

LOW DUTY CYCLE SILHI BEAM

In 1996 the SILHI source produced its 1st high intensity beam. Several months have been needed to reach high performance with routine operation (beam intensity > 100 mA, energy 95 keV, H^+ fraction between 75 and 80 %). Then, in parallel to other projects (Spiral 2 injector with its permanent magnet source, IFMIF injector), the SILHI beam has been used for dedicated experiments like innovative diagnostic developments or material sample irradiation. But the beam has never been fully characterized after the RFQ entrance cone. So, in order to prepare the IPHI commissioning, this characterization has been recently done by measuring the intensity and emittance versus both solenoid scans after the cone. These measurements have been performed in pulsed mode. After the first data analysis, misalignment of the source has been corrected, both boron nitride discs (located at both ends of the plasma chamber) have been changed. Then, new measurements showed the LEBT transmission increased up to 90 %, in close agreement with the simulations. The 0.36 π.mm.mrad measured emittance is higher than the emittance used in the RFQ design simulations. Despite this high emittance value, it has been decided to install the RFQ in its final position with no additional opportunity to analyse the 95 keV beam after the cone. Then the RFQ radiofrequency conditioning has been done in pulsed mode, starting with very low duty cycle (few 10 µs at few Hz).

In parallel, the SILHI source was tuned to produce very short beam pulses and to inject into the IPHI RFQ. Figure 2 shows a 200 µs pulse crossing the DCCT (at the exit of the accelerator column) and collected on the Faraday cup (located in between the 2 solenoids). It is clear that the low bandwidth of the DCCT (yellow curve) does not allow measuring such beam pulses. The Faraday cup signal (which combines H^+, H_2^+ and H_3^+ pulses on the blue curve) showed a small jitter (between 5 and 10 µs) compare to the magnetron RF control signal (curve magenta). The species fraction measurements were done with the Wien filter. With the 200 µs pulse, H^+ beam fraction was as low as 20% and with a 5 ms pulse, by measuring the species fraction on the plateau (Fig. 3), the H^+ fraction reached 75 %.

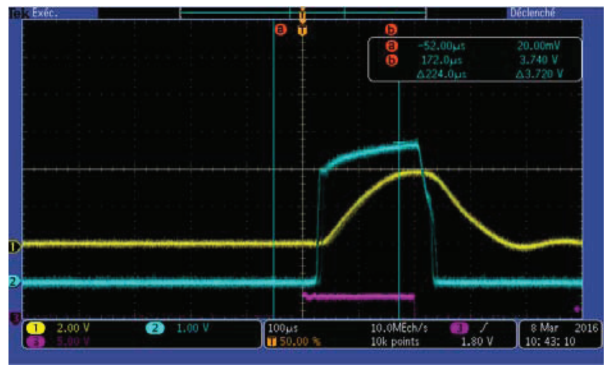

Figure 2: 200 µs beam pulse produced by the SILHI source.

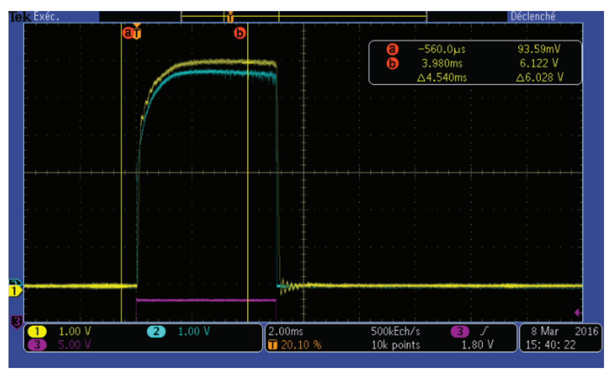

Figure 3: 5 ms beam pulse produced by the SILHI source.

As the beam is injected into the RFQ through the cone which is designed to catch the H_2^+ and H_3^+ particles, the H^+ rise time can be observed on the ACCT signal as the measurement is done between the cone and the RFQ entrance plate.

H^+ ACCELERATION WITH THE IPHI RFQ

Figure 4 presents a schematic view of the whole IPHI installation with the respective position of the different diagnostics [4]. It can be noted the RFQ transmission can

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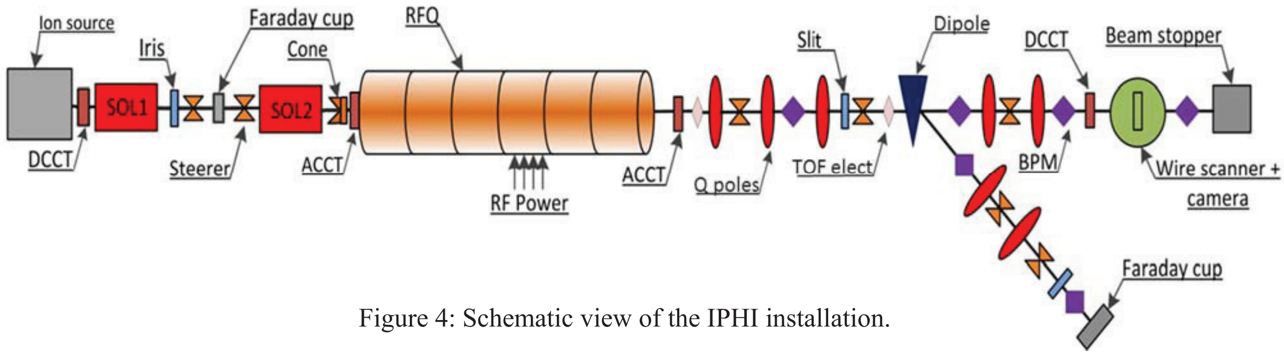

Figure 4: Schematic view of the IPHI installation.

be easily calculated by measuring the ratio between 2 ACCT located very close to both RFQ end plates.

When the nominal RFQ electromagnetic field has been obtained with a 200 µs power pulse, the LEBT gate valve and the Faraday cup have been removed from the beam trajectories. The timing system was tuned to get the same beam and RF pulse fall time.

Figure 5: First accelerated H^+ beam by IPHI RFQ.

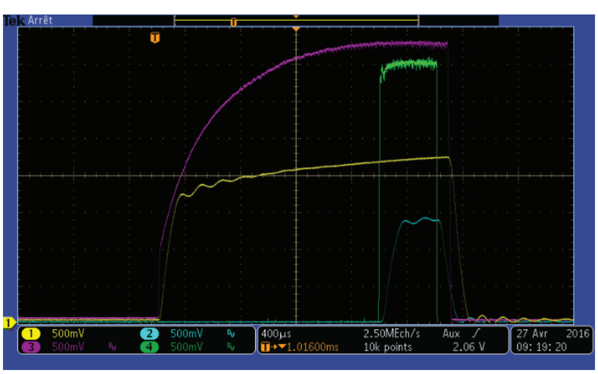

Figure 6: IPHI RFQ transmission reached 92 %.

The beam at the RFQ exit was observed on the ACCT located just at the RFQ exit. Figure 5 presents the signals of different current measurement diagnostics (i) the source DCCT signal with very low bandwidth (yellow curve), (ii) the RFQ entrance ACCT (magenta curve), (iii) the RFQ exit ACCT (blue curve). These signals have been observed after LEBT solenoid and steerer tuning.

In order to overcome the long rise time of the H^+ fraction, the source beam pulse has been enlarged up to 2 ms by keeping a 400 µs short RF pulse located at the end of the beam pulse (Fig. 6). In these conditions, the total current extracted from the source was 100 mA (yellow curve), the RFQ entrance ACCT signal was 82 mA (magenta curve), the RFQ exit ACCT signal was 75 mA (green curve) and the high energy DCCT signal was 64 mA (blue curve). The magenta curve indicates the H^+ fraction rise time is at least equal to 1 ms.

CONCLUSION

For the 1st time, in April 2016, the SILHI source produced a proton beam for IPHI RFQ acceleration. At the beginning of the RFQ conditioning, once the accelerating field map was close to nominal one into the RFQ, very short pulses (of 100 µs at the beginning) have been injected. Such low beam pulses helped us for debugging the high energy diagnostics. Then the short RF power pulse injected into the RFQ has been positioned at the end of a 2 ms source pulse. In these conditions, the RFQ transmission has been estimated around 92 % and the nominal 3 MeV energy has been confirmed by deflecting the short pulse with the dipole.

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