FIRST RESULTS FROM THE IPHI BEAM INSTRUMENTATION

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Abstract

I.P.H.I. is a High Intensity Proton Injector (CNRS/IN2P3; CEA/Irfu and CERN collaboration) located at Saclay and now on operation. An ECR source produces a 100 keV, 100 mA C.W. proton beams which will be accelerated at 3 MeV by a 4 vanes R.F.Q. operating at 352.2 MHz. Finally, a High Energy Beam Transport Line (HEBT) delivers the beam to a beam stopper. The HEBT is equipped with appropriate beam diagnostics to carry beam current, centroid beam transverse position, transverse beam profiles, beam energy and energy spread measurements for the commissioning of IPHI. These beam diagnostics operate under both pulsed and CW operation. However transverse beam profile measurements are acquired under low duty factor pulsed beam operation using a slow wire scanner. The beam instrumentation of the HEBT is reviewed and the first measurements at 3 MeV are described.

INTRODUCTION

Since the front end is the most critical part of a High Power Proton Accelerator (HPPA), it was decided to realize a high power proton injector named IPHI under a CNRS/IN2P3, CEA/Irfu and CERN collaboration. IPHI has been designed to be a possible front end for a HPPA devoted to fundamental and applied research: radioactive beams production, neutron sources and transmutation. The aim of IPHI was also to validate the technical choices, to demonstrate operational reliability and to measure the beam parameters of the accelerated beam by the RFQ. IPHI was also designed in the frame of the SPL (Superconducting Proton Linac) study at CERN as a 3 MeV test stand to become the low energy part of the linear accelerator "Linac4" [1]. IPHI consists of an E.C.R. proton source named SILHI (100 mA, 95 keV) followed by a Low Energy Beam Transfer Line (LEBT). A Radio Frequency Quadrupole (length: 6m), operating at 352.2 MHz performs the acceleration of the proton beam up to 3 MeV. Finally the straight section of the High Energy Beam Transfer line (HEBT) may transfer the total power (300 kW) of the beam to a beam stopper (BS) [2]. The deflected section of the HEBT may transfer only a small fraction of the total beam power (few tens of W) for energy dispersion measurement. IPHI is planned to work under C.W. operation but during tests and commissioning periods pulsed mode operation has to be considered to lower the mean power of the beam in order to prevent the accelerator structure and the interceptive beam diagnostics from excessive heating or even from destruction.

BEAM DIAGNOSTICS

General Considerations

The source ECR source SILHI 100 kV, installed on a high voltage (100 kV) platform produces the required high intensity (100 mA) proton beams either under C.W. or pulsed mode operation according to the selected temporal structure of the radiofrequency signal feeding her magnetron. The LEBT contains the necessary magnetic elements to transport to the RFQ and to centre on the axis of the beam pipe the beam: two solenoids for the focusing of the beam and two pairs (horizontal and vertical) steerers for the beam alignment. An iris controls the beam intensity. The LEBT contains also beam diagnostics for beam current measurements and visualization of the transverse beam profile at the entrance of the cone located on the RFQ.

The general layout of the HEBT is shown in Fig.1. The straight section (dipole "off") is equipped with beam diagnostics in order to:

- Help to the safe transport of the proton beam to a beam stopper able to withstand the full power of the beam: 300 kW under the C.W. mode operation.
- Provide a sufficient characterization of the beam accelerated by the RFQ during the commissioning period and the daily operation: beam current, position, energy, energy dispersion, transverse profile
- Operate under pulsed mode (pulsed mode operation of the ECR source) for machine commissioning or experimental operation and the nominal C.W. mode.
- Test and evaluate non-intrusive techniques for measuring transverse beam profiles of high average power beams. These techniques will have to be brought to operation due to the large quantity of beam energy deposited in any possible intrusive sensor leading to its destruction or to a high activation induced level.

The deflected section (dipole "on") is primarily devoted to energy spread measurements under pulsed mode beam operation (low average beam power operation). For this purpose, an object slit will be located in the straight section before the dipole and an image slit followed by a Faraday cup at the end of the deflected section. The list of the beam diagnostics types in IPHI is given in Table 1.

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ISBN 978-3-95450-177-9

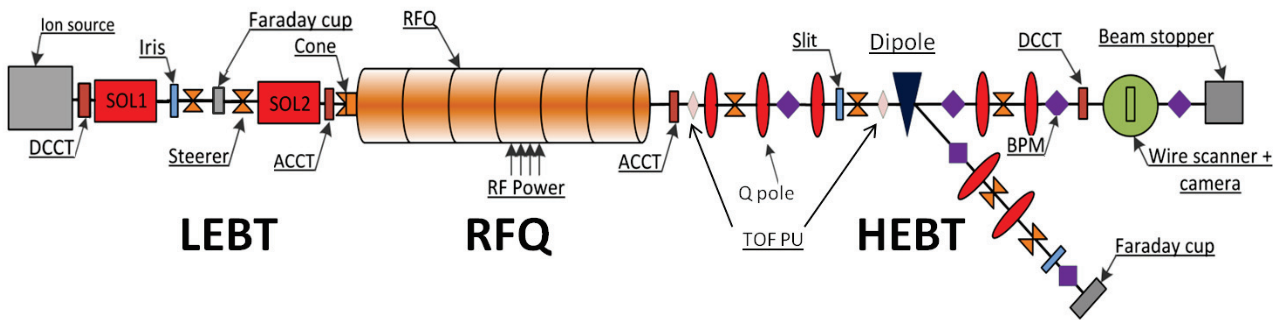

Figure 1: General layout of IPHI.

Table1: List of the Beam Diagnostics Type in IPHI

Measurement	Diagnostic	Location
Current	DCCT – ACCT	LEBT- HEBT
	Faraday cup	LEBT - HEBT
Position	PU - BPM	HEBT
	Lumines-cence	LEBT
Profile	Wire scanner	HEBT
Energy	PU – TOF	HEBT
Energy dispersion	Spectrometry	HEBT

BEAM CURRENT MEASUREMENT

Destructive current measurement in the LEBT is achieved by means of a water cooled Faraday cup located in the LEBT upstream the second solenoid which may acts also as a beam stopper. This Faraday cup and its associated electronics exhibit a sensitivity of 1V/20 mA and the bandwidth (0-50 kHz) allows the observation of the beam pulse under pulsed mode operation.

For non-destructive current measurements, beam current transformers are used throughout IPHI to monitor both average and peak currents. DC beam current transformers are used in the LEBT as well as in the HEBT under CW and very low pulsed duty factor operation. These DC current transformers are MPCT from Bergoz Company. The sensitivity is 1V/20 mA. Two identical ACCT are used, one in the LEBT and one in the HEBT for beam pulse observation and beam current measurement under pulsed mode operation. These ACCT are home-made and built with a VITROVAC 6025F core (outer diameter: 230 mm, inner diameter 130mm, height: 25 mm). Their main characteristics are: Sensitivity: 1V/20 mA; bandwidth: 4 Hz - 6 MHz; resolution: 10 µA. The two ACCT and the two DCCT are housed in a very efficient magnetic shielding.

An example of signal acquisition by the Beam current transformers is given in Fig. 2.

The signals of the Faraday cup of the LEBT, ACCT and DCCT are sent to the acquisition system (LabVIEW) for signal processing: average current, number of charges during the beam pulse or selected integration duration and next to the Command and Control system to calculate the RFQ beam transmission efficiency.

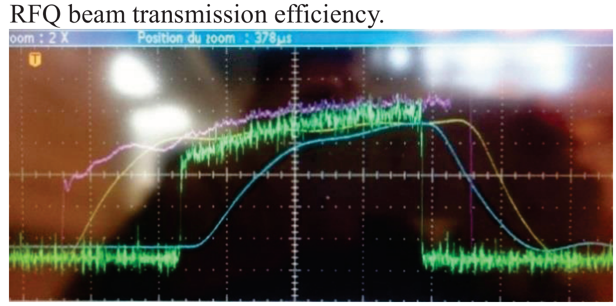

Figure 2: Measurements of the beam current in IPHI. Purple and yellow traces: signals of the ACCT and DCCT upstream the RFQ. Green and blue traces: same measurements with the other couple of ACCT and DCCT downstream the RFQ.

BEAM POSITION MEASUREMENT

Six Beam Position Monitors (BPM) are needed to transport safely the beam: 5 designed for a 33 mm chamber radius (3 in the straight section, 2 in the deflected one) and the last one (before the beam stopper) for a 75 mm radius. Electrostatic Pick Up type has been chosen to measure the transverse beam centroid position (Fig. 3). The core, feed-through and assemblies have been built by the French company PMB. The space between electrode and core is 2 mm with a tolerance of ± 0.05 mm. The four standard Metaceram 50 Ω feedthroughs are terminated by SMA connectors. During the brazing process the four electrodes have been positioned by using a template to insure the axial symmetry of the four electrodes [3].

Electrical Signal Amplitude:

The amplitude of the signal at the terminals of a load connected to the electrode depends on the charge linear distribution seen by this electrode.

- Due to the space force charge and to the energy spread, simulations show (TRACEWIN code) that the linear charge density decreases as the beam propagates to the beam stopper (rms width: σ_z)
- Due to the low value of β (~ 0,08), the image charge distribution is spread longitudinally along the beam pipe wall (radius a) according to:

$$\sigma_{Wall} rms = \frac{a}{\gamma\sqrt{2}} \quad \text{With } \gamma = (1-\beta^2)^{\frac{-1}{2}}$$

ISBN 978-3-95450-177-9

- The current I (t) flowing into the electrode can be expressed versus linear charge distribution λ(z) or current beam and has been computed (see Table 2). Bench test measurement agrees with the calculated sensitivity: 8.5 mV per mA beam.
- Electrodes signals are processed by a Log-Ratio Beam Position Monitor electronics module from Bergoz Company. The expected beam intensity dynamic range measurable is 40 µA – 100 mA.

Figure 3: View of an IPHI BPM.

Errors Signal Analysis:

- Electrical and mechanical centre misalignment leads to an offset measurement of 150 µm for the bloc prototype (Mechanical calibration system accuracy: ~ 40 µm on our test bench)
- The voltage button is obtained by the product of i_{button} by the impedance Zc of the cable seen by the electrode for low frequencies and by $\frac{Z_c}{1+Z_c C_b \omega}$ for high frequencies where C_b is the total capacitance of the electrode versus ground: 9.4 pF. The capacitance dispersion value between the four electrodes is less than ± 0.1pF.
- Discrepancy between the characteristic impedance Zc of the cables leads to offset measurements: 400 µm offset deviation has been measured for 1% dispersion of Zc
- Impedance mismatches between Zc and the input impedance of the Log Ratio module increase the Voltage Standing Wave Ratio and induce error measurements.
- The position sensitivity of ~ 17 µm/mV measured for the BPM associated with its electronics on our laboratory BPM test bench, decreases as the input voltage decreases under input amplitude signal of - 60 dBm. After measurements, -80dbm (corresponding to a ~ 60 µA beam intensity on the first electrode) at the input of the electronic module is the lower limit. (Fig. 4) For current well above 10 µA, the non-linearities are still acceptable in order to centre the beam with a precision of 100 µm by successive iterations.
- The test bench measurement are only valid for β = 1. For the lower value of β = 0.08 corresponding to our beam, the positions measured for a beam travelling in a cylindrical chamber of radius a and at a frequency f must be multiplied by (1+G), according to [4], where G is:

$$G = 0.139.\left(\frac{2.\pi.f.a}{\beta.\gamma.c}\right)^2 - 0.0145\left(\frac{2.\pi.f.a}{\beta.\gamma.c}\right)^3$$

Table 2: Calculated Signal Amplitude for Each B.P.M (straight beam transfer line)

BPM	$\sqrt{\sigma_{wall}^2+\sigma_{im}^2}$	**I_{pp} @ 352 MHz seen by electrode**	**$V_{electrode}$** (mV pp) (50Ω)
1st	25 mm	17 mA	130
2nd	30 mm	8.8 mA	64
3rd	30mm	7.8 mA	58
4th	57 mm	~0.1 mA	~0.1 mV

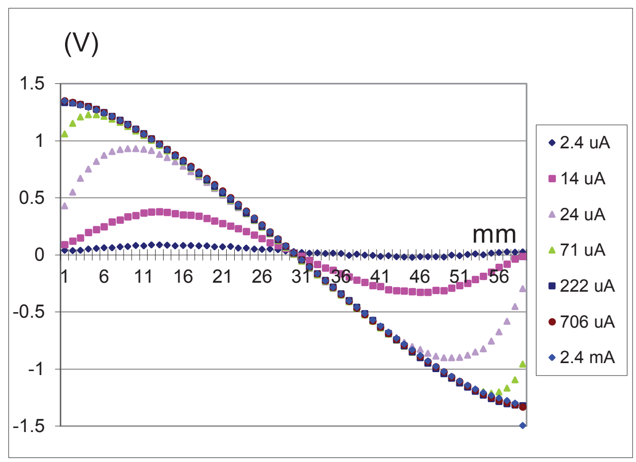

Figure 4: Variation of the output signal of the LR-BPM module with the displacement of the central rod and for different currents in the rod. These measurements have been obtained on our laboratory BPM test bench.

The first measurements were carried on IPHI under a beam intensity of 60 mA on the first BPM. However these measured were smeared by a fraction of the RF signal at 352 MHz propagating in the vacuum chamber. This problem remains to be solved.

BEAM PROFILE MEASUREMENTS

The transverse charge distributions and the transverse emittance of the beam at the exit of the RFQ will be measured and drawn from the transverse profiles measurements according to beam dynamics colleagues' statement. For this purpose a wire scanner (WS), traditionally used for transverse profiles measurements, has been built. It is located in the straight section of the HEBT after the dipole [5].

ISBN 978-3-95450-177-9

- A 30 µm diameter SiC fibber has been selected to be moved through the beam. This fibber cannot withstand the CW operation. The resolution of the "heat equation" leads to limit the beam pulse duration to 300 µs, repetition rate to 1s (100 mA, 3 MeV)
- The two carbon fibbers, (horizontal and vertical measurements) are mounted in a "V" design on an alumina frame moving at 45 ° to the axis of the beam line. Two biasing wires surround the signal wires.
- The maximum size of the beam to be sensed is 10 cm; the total displacement of the frame is 33 cm and is moved by a stepper motor. (Minimum value of the step: 1 µm)

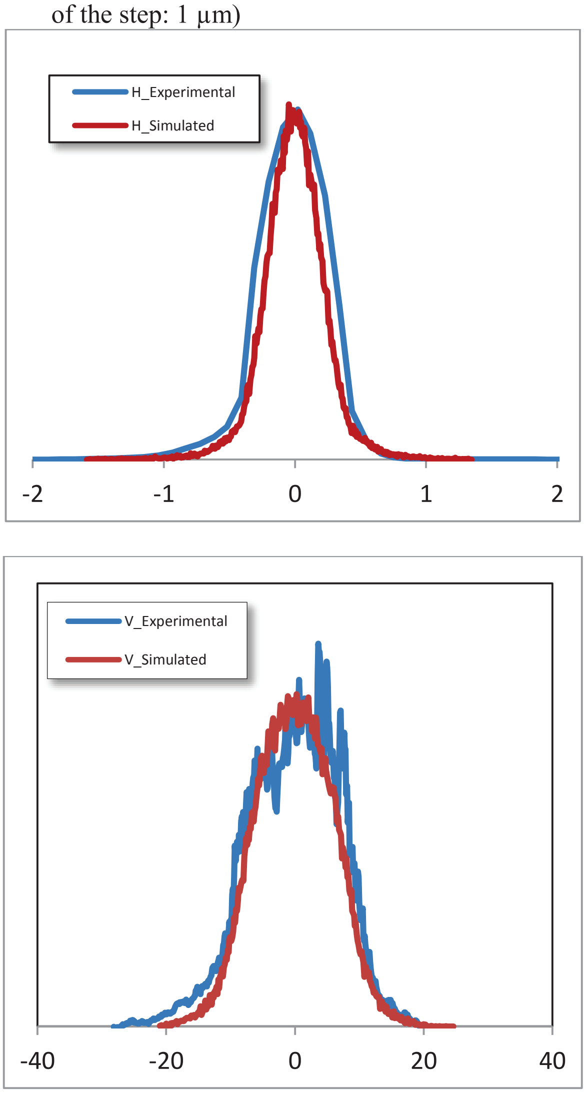

Figure 5: Measurements of the horizontal (up) and vertical (down) transverse beam profiles (mm) with the WS (blue traces) of the accelerated beam (proton 3MeV, 60 mA, pulse duration: 400µs, repetition: 1s). Red traces are simulated beam profiles.

- The transconductance of the amplifier associated with each signal wire has a 1V/ mA gain conversion; 1.5 nA rms noise in a 0-76 kHz bandwidth.

BEAM ENERGY MEASUREMENT

The kinetic energy of the protons is established by the RFQ through which they have passed. As β =0,08, time of flight technique has been called for IPHI to measure the time a particular bunch takes to travel between two electrostatic electrodes P.U. are separated by a distance of 1,3855m ± 0.1 mm. The accuracy on the time measurement must be at least 20 ps to reach a relative accuracy of 10^{-3} on the energy measurement. Pick Up probes have been built (inner diameter: 66 mm; length: 10 mm; Capacitance: 26 pF). Their signals are sent to a phase meter. One degree accuracy is expected. A third P.U. electrode (8 cm from the first one) has been added in order to discriminate uncertainty on energy measurement if needed.

The energy of the accelerated beam was checked by applying the current to the coil of the dipole to produce the nominal magnetic field necessary to send the beam in the deflected section of the HEBT.

ACQUISITION AND SUPERVISION

Four PXI chassis (PCI extended for instrumentation) implemented with LabVIEW software, acquire diagnostics signals and receive their commands from the supervision system EPICS by an Ethernet connection.

CONCLUSION

Beam diagnostics for IPHI will allow the characterisation of the beam accelerated by the RFQ. The beam current, beam transverse profiles and beam position diagnostics are now under operation. The beam energy measurement by the TOF technique remains to be put on operation. However a fraction of the RF signal induces a strong perturbation of the diagnostics signals. This problem has to be cured.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the constant support of the IPHI and SILHI CEA teams, in particular the help of Raphaël Gobin. We want also to thank warmly our colleagues of the "Electronics Group" and of the "mechanical study group" of the Accelerator Division of IPNO for their constant assistance during the IPHI project.

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ISBN 978-3-95450-177-9