BEAM DIAGNOSTICS INSTRUMENTATION FOR THE HIGH ENERGY BEAM TRANSFER LINE OF I.P.H.I.*

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Abstract

I.P.H.I. is a High Intensity Proton Injector under construction at Saclay (C.N.R.S/I.N.2P.3; C.E.A./D.A.P.N.I.A and C.E.R.N. collaboration). An E.C.R. source produces a 100 keV, 100 mA C.W. proton beam 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 (H.E.B.T.) will deliver the beam to a beam stopper and will be equipped with appropriate beam diagnostics to carry intensity, centroïd beam transverse position, transverse beam profiles, beam energy and energy spread measurements for the commissioning of I.P.H.I. These beam diagnostics will operate under both pulsed and C.W. operation. Transverse beam profile measurements will be acquired under low and high duty factor pulsed beam operation using a slow wire scanner and a C.C.D. camera to image the beam-induced fluorescence. The beam instrumentation of the H.E.B.T. is reviewed and preliminary obtained transverse profile measurements at 100 keV are described.

INTRODUCTION

IPHI is a high intensity proton injector (C.N.R.S/I.N.2P.3, C.E.A./D.A.P.N.I.A and C.E.R.N. collaboration) and has been designed to be a possible front end for High Power Proton Accelerator (HPPA) devoted to fundamental and applied research: radioactive beams production, neutron sources, neutrino factories and transmutation. IPHI consists of an E.C.R. proton source SILHI (100 mA, 95 keV), under operation at the present time, followed by a Low Energy Beam Transfer Line (LEBT). A Radio Frequency Quadrupole (length: 6m), operating at 352 MHz will then accelerate the proton beam up to 3 MeV. Finally, the High Energy Beam Transfer line (HEBT) will transfer the beam to a beam stopper. Following the necessary commissioning period, a reliability test (several months) operation of the RFQ will be conducted with the support of EUROTRANS (FP6). In the frame of the SPL (Superconducting Proton Linac) study at CERN, a 3 MeV test stand, designed to become the low energy part of the new linear accelerator “Linac4”, is being built. The beam acceleration will be performed by the RFQ of IPHI which will be moved from CEA/Saclay to CERN for this purpose. Downstream the RFQ, a chopper line will deliver the beam to the Linac 4 with the appropriate time structure.

IPHI is planned to work under C.W. operation but during tests and commissioning periods, pulsed mode operation has to be considered.

BEAM DIAGNOSTICS

General considerations

The general layout of the HEBT is shown in Figure 1. The straight section (dipole “off”) will be 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 in the C.W. mode operation.
- Provide a sufficient characterization of the beam accelerated by the RFQ during the commissioning period and the daily operation.
- Operate under pulsed mode (pulsed mode operation of the ECR source) for machine commissioning or experimental operation, and under the planned CW operation.
- Test and evaluate non intrusive techniques for measuring transverse beam profiles of high average power beams: Due to the large quantity of beam energy deposited in any possible intrusive sensor leading to its destruction and the resulting high activation induced level in the accelerator structure, non interceptive beam diagnostics have to be put on operation in HPPA.

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.

BEAM CURRENT MEASUREMENT

This is probably the most important measurement to achieve. RFQ beam transmission efficiency will be drawn from this measurement:

C.W., Low duty factor pulsed mode operation:

This measurement will be achieved by a DC beam current transformer: a MPCT manufactured by Bergoz Company. It will be housed in a magnetic shielding and placed after the second dipole doublet.

- Resolution reaches 10 µA according to at least a one second integrating signal duration and the bandwidth ranges from 0 to 4 kHz.

Pulsed mode operation:

Under this mode operation, the duration of the beam pulse is expected to be as low as 100 µs and the repetition

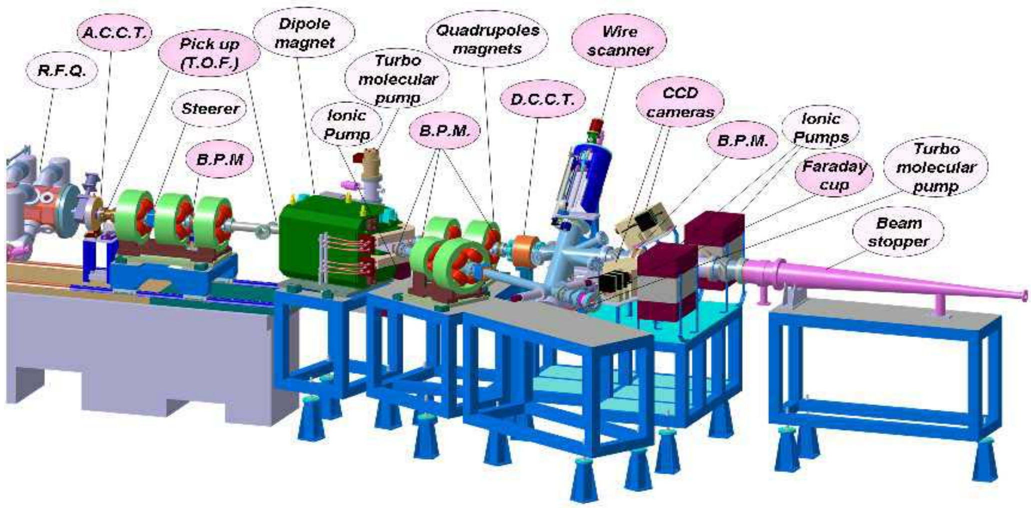

Figure 1: general layout of the high energy beam transfer line of IPHI.

rate 1s. A specific AC beam current transformer has been built and will be located just at the exit of the RFQ.

- The electrical noise is 10 µA rms and the band width ranges from 4 Hz up to 6 MHz.

This beam current transformer is similar to another one which has been put on operation for several years in the LEBT.

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 centroïd position.

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): σ_{wall}rms = $\frac{a}{\gamma\sqrt{2}}$

  with $\gamma = (1-\beta^2)^{\frac{-1}{2}}$
- The current i(t) flowing into the electrode can be expressed versus linear charge distribution λ(z) or current beam and has been computed (table 1). Bench test measurement agrees with the calculated sensitivity: 8.5 mV per mA beam.
- Signals are processed by Log-Ratio Beam Position Monitor electronics module from Bergoz Company.

Error analysis:

- Electrical and mechanical center misalignment lead to offset measurement: 150 µm for the bloc prototype. (mechanical calibration system accuracy : ~ 40 µm)
- The voltage button is obtained by the product of i_{button} by the impedance Zc of the cable seen by the button for low frequencies and by $\frac{Z_c}{1+Z_c C_b \omega}$ for high frequencies.

(C_b : total capacitance electrode / ground: 9,4 pF).

Table 1: Calculated signal amplitude for each B.P.M.

BPM number	$\sqrt{\sigma_{wall}^2 + \sigma_z^2}$	**I (fundamental) beam seen by chamber**	**V button in mV** (50 Ω)
1st	25 mm	16 mA eff	136
2 nd	29 mm	2.7 mA eff	23
3 rd	30 mm	1.3 mA eff	11
Last one	57 mm	~0.6 mA eff	~5

- 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. (L/R card input impedance measured: 110 Ω)
- The position sensitivity: 17 µm/mV decreases as the input voltage decreases. After measurements, -80dbm (i.e. 60 µA beam current on the first electrode) at the input of the electronic module is the lower limit.

BEAM PROFILE MEASUREMENTS

Transverse charge distributions and calculation of the emittance of the beam at the exit of the RFQ will be drawn from the transverse profiles measurements.

Wire scanner

A wire scanner, traditionally used for transverse profiles measurements [4], has been built for IPHI and will be located after the dipole.

- A 30 µm diameter carbon fibber has been selected to be moved through the beam. This fibber can not withstand the CW operation. Results of resolution of the "heat equation" leads to limit the pulse duration to 300 µs, rate repetition 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.
- The transconductance amplifier associated with each signal wire has been designed to exhibit a 1V/mA gain conversion; 1.5 nA rms noise in a 0-76 kHz bandwidth.
- Measurements have been carried on the LEBT.

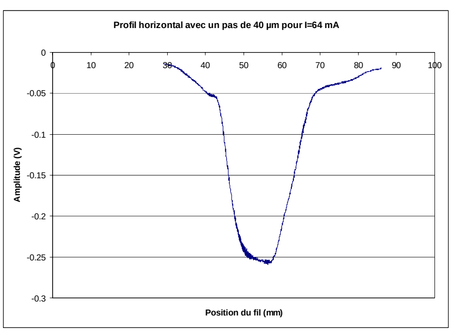

Figure2: LEBT beam profile measurement: Proton beam, 95 keV, 64 mA, pulse 1 ms, repetition 1s, step 40 µm

Fluorescence Beam Profile Measurements

In the L.E.B.T. the moderately relativistic protons interact strongly with the atoms of the residual gas which is mainly hydrogen (pressure: 2.10^{-5} hPa) or additional gaz. A light, visible by the human eye, is emitted by the de-excitation of these atoms. This phenomena looks very attractive and may lead to realisation of non destructive diagnostic for high power beams. This light was studied [3] with an intensified C.C.D. camera working in the 200 nm-820nm range with the aim to measure the transverse beam profiles. Some results have been pointed out:

- The intensity of the emitted light depends on the nature of the gas and increases proportionally to the pressure of the gas.
- Profiles obtained by F.B.P.M. have the same geometrical shape for all gases at the same pressure.

However discrepancies between the width of the profiles obtained by fluorescence and by a grid profiler have been pointed out and further investigations were made. The typical Doppler shift effect of Balmer lines series of hydrogen has been used to sign among the overall light present in the vessel the one produced by the protons accelerated at the nominal energy.
The vacuum vessel of the wire scanner has been equipped with windows to re-conduct these optical experiments at 3 MeV with the aim to compare optical and W.S. profiles.

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 may be called to measure the time a particular bunch takes to travel between two probes separated by a known distance: two electrodes P.U. will be separated by a distance of 1,3855m ± 0.1 mm. The accuracy on the time measurement must be at least 20 ps. Then an accuracy of 10^{-3} may be reached on energy measurement. Pick Up probes have been built (inner ϕ: 66 mm; length: 10 mm; Capacitance: 26 pF). Their signals will be delivered 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.

ACQUISITION AND SUPERVISION

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

CONCLUSION

Beam diagnostics of the HEBT line will allow the characterisation of the beam accelerated by the RFQ. The wire scanner is under operation and will be our profile measurements reference. Developments on fluorescence induced by the beam will be carried at 3 MeV.

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