OPTICAL BEAM PROFILER FOR HIGH CURRENT BEAMS

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Abstract

High-power accelerators are being studied for several proposals based on high-flux neutrons driven by protons. An ECR ion source delivers a 80mA H^+ beam at 95keV for a high intensity proton injector prototype (IPHI) developed by a CEA-CNRS collaboration.
The purposes of this proposal include developments of new diagnostics to characterise the H+ beam. Classical interceptive diagnostics cannot be used because of the high current densities. So, it was decided to develop a new type of beam profiler. It is based on the resonant absorption of a laser light by metastable atoms produced by collisions with protons in an injected noble gas (Ar, Kr). The method and preliminary results are described.

1 INTRODUCTION

IPHI (**I**njecteur de **P**rotons à **H**aute **I**ntensité) is foreseen to be the front part of a 1GeV-100mA DC accelerator [1]. It includes a 2.45GHz ECR source, a RFQ and a DTL to provide beam energies up to 10MeV. The Low Energy Beam line between the source and the RFQ is composed of focusing solenoids, pumping systems and diagnostics (a Faraday cup, an emittancemeter and a Wien filter to measure the $H^+/H_2^+/H_3^+$ ratios). Measuring the profile of such an intense beam with an interceptive system is problematic and the study of a new profiler based on light emission / absorption has started.
In a first step, the light due to the residual gas-proton interaction was used to show a direct correlation between the total proton current and the light flux.

In a second step, after injection of a noble gas, metastable atoms produced by the same interaction were optically pumped and a beam profile deduced from absorption measurements. This seems open the way to get a point-to-point information within the beam by using a system involving a thin pump laser beam crossed with a filiform gas jet both perpendicular to the proton beam.

2 THE H^+ SOURCE AND THE LOW ENERGY BEAM (LEB) LINE

This new prototype of diagnostic was tested on the LEB line of SILHI (**S**ource d'**I**ons **L**égers à **H**aute **I**ntensité). This ECR source [2] is able to deliver a pulsed or continuous beam up to 80mA at 95keV. The transport line (Fig. 1) includes two focusing solenoids, two transformers for beam current measurements, a sampling emittance-meter and a diagnostic chamber with viewing ports. At the chamber location the beam diameter is close to 40mm.

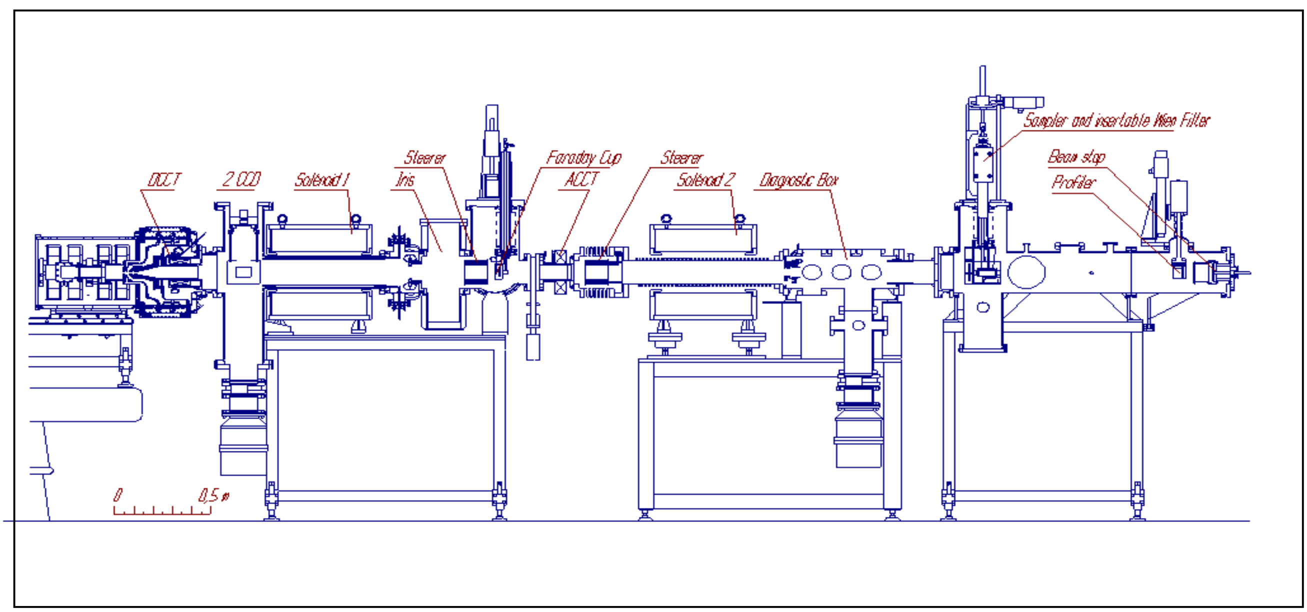

Figure 1: SILHI and the LEB line

2.1 *Beam current-emitted light relation*

The interaction between the proton beam and the residual gas (or an injected one) produces excited and ionised gas atoms. This ionisation produces electrons able to space-charge compensate the beam. A proper analysis of the emitted light makes possible to get informations on the beam size and current.

The mean pressure inside the diagnostic chamber is #2 10^{-3} Pa mainly due to hydrogen. In the visible region, the Balmer lines (Fig. 2) of the atomic hydrogen spectrum (H_α: 656.2nm, H_β: 486.1nm, H_γ: 434nm) are analysed by a monochromator followed by a photomultiplier.

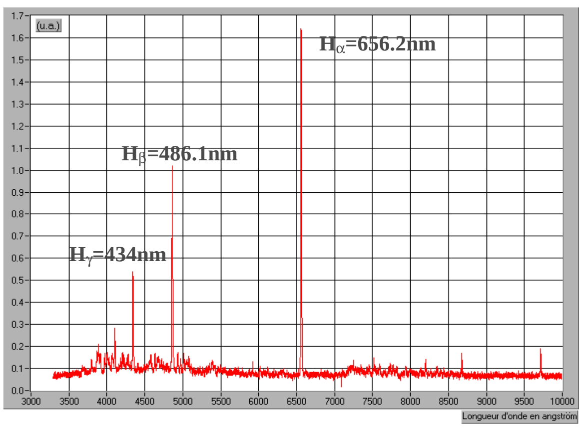

Figure 2: Observed Balmer lines.

The light intensity I_l of a line is proportional to the total current through:

$$I_l \propto I_{beam}\, \sigma\, n_{exc}$$

where I_{beam}, σ and n_{exc} are respectively the beam current, the excitation cross-section and the volume density of the excited atoms. Experiments confirm this linearity with slopes directly connected to the excitation cross-sections (Fig. 3). After calibration, a simple measurement at a given basic pressure of such a Balmer line allows for a direct non-interceptive beam current measurement.

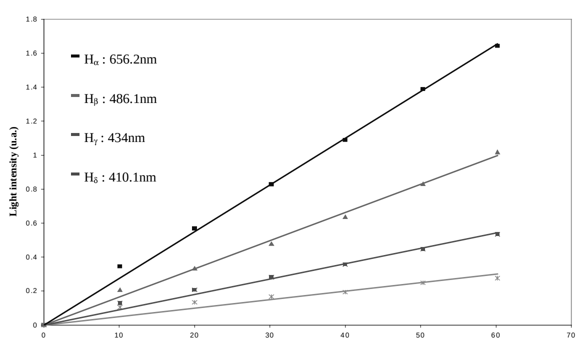

Figure 3: Variation of the light intensity with the total beam current.

This global light emission is not suitable for a point-to-point (pixel) information of the beam profile.

2.2 *Optical pumping and absorption measurements*

If long lived states of a noble gas are produced by the primary protons, case of the metastable states (lifetime close to 10^{-3} s), it is possible to induce a new transition by either a spectral lamp or a laser if they radiate the corresponding wavelength.

Measurements of the absorption rate allows for an estimate of the density n_m of the metastable atoms, itself proportional to the local beam current as previously shown. The transmitted pumping light intensity through the metastable atom medium I_t is given by:

$$I_t = I_0\, e^{-\sigma \cdot n_m \cdot L} = I_0 e^{-K}$$

where I_0 is the incident light intensity, σ the absorption cross-section, L the medium thickness and K the absorption coefficient.

A transverse scanning by a well defined beamlet and an accurate measurement of the absorption may give the proton beam profile after an Abelian conversion if:

-the absorption rate versus the proton current is a known function

-if the chosen transition is highly absorbent for a good precision.

To examine if the first condition is fulfilled, we have measured the absorption rate of a known argon transition [3] at λ=763.5nm. Considering the above equation, for absorptions < 25%, the metastable density obeys:

$$n_m \propto -\mathrm{Ln}\,(I_t/I_0) \approx (I_0-I_t)/I_0 = \text{absorption rate}$$

A linear dependence absorption rate versus the proton current is then suspected and experimentally observed (Fig. 4).

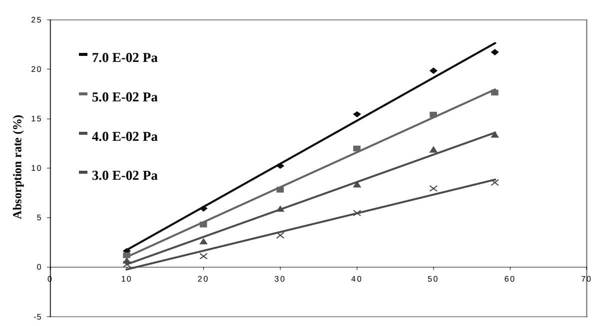

Figure 4: Absorption rate vs. beam current for different injected Ar pressures.

A first test of a transverse scanning has been made with the set-up of Fig. 5. The emitted light from a spectral lamp is collimated as to form a tiny beamlet. With the detection system, it is moved across the 40mm diameter-60mA main beam with a 7 10^{-2} Pa background pressure of krypton.

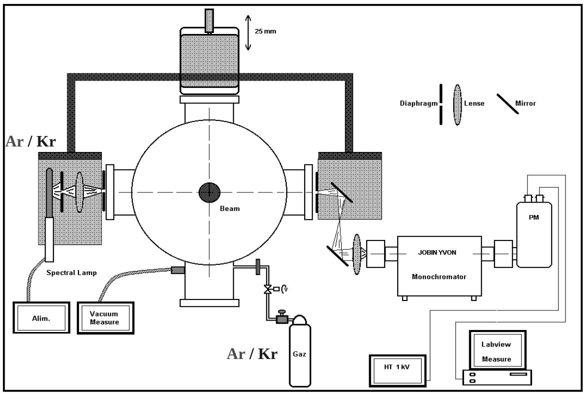

Figure5: Arrangement of the transverse scanning.

A preliminary result is shown on Fig. 6 which seems to prove the feasibility of an operational profiler. The spectral lamp has to be replaced by a laser which wavelength must be chosen to be the more absorbed as possible. λ=811.5nm for argon (~20 %) and λ=811.3nm for krypton (~40 %) have been experimentally found adequate and easily available with a low cost and tunable laser diode. These measurements corroborate the previous studies [4]. To get a spot scanning, a thin jet crossing the main beam and perpendicular to the laser beamlet must replace the rough injection. Experiments are underway to generate such a jet from a 0.2mm diameter capillary. The accuracy of the scanning is directly connected to the dimensions of the jet and beamlet i.e. #1mm.

3 CONCLUSION

A profiler based on absorption by metastable atoms of noble gases seems to be an alternative to interceptive profilers with the possibility to get a point-to-point information of the spatial distribution of a high current proton beam with a good accuracy without scattering.

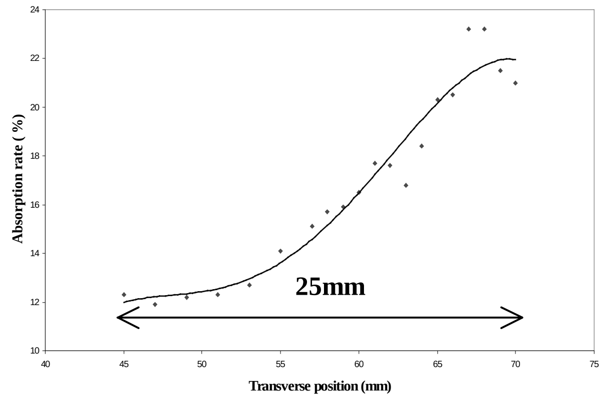

Figure 6: Absorption rate vs. transverse position.

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