BEAM SPECIES FRACTION MEASUREMENT USING DOPPLER SHIFT METHOD WITH FUJIKURA FIBERSCOPE FOR IFMIF-EVEDA INJECTOR

F. Senée*, G. Adroit, R. Gobin, B. Pottin, O. Tuske, CEA Saclay, IRFU, F-91191 Gif-sur-Yvette, France
A. Olivier-Kaiser, IN2P3, IPNO, F-91400 Orsay, France

Abstract

To characterize high intensity ion beam in low energy beam transport line, diagnostics based on residual gas molecule excitation are commonly used. An example is CCD sensors for beam intensity, beam position and beam profile measurements. At CEA/Saclay with the SILHI injector, beam images transports from viewport to sensor have been performed with a fiberscope. Such technique will be used to transfer the beam images away from the irradiated zone of the IFMIF-EVEDA tunnel which requires using hardened radiation devices. Indeed, the (D,d) reaction, due to interaction of 140 mA-100 keV deuteron beam with vacuum pipes or scrapers, leads to high neutron and gamma ray flux. As a consequence, in addition to CID cameras for online beam positioning and shape measurements, a 20 m long Fujikura fiberscope has been selected to analyze species fraction using the Doppler shift method. Preliminary measurements have been performed with the SILHI beam to characterize the fiberscope. Its spatial resolution and transmission as well as a CCD sensor and fiberscope comparison are presented. Beam species fractions with and without the use of fiberscope are also reported.

INTRODUCTION

The International Fusion Materials Irradiation facility (IFMIF) aims at producing an intense flux of 14 MeV neutrons, in order to characterize materials envisaged for future fusion reactors. Such a facility is based on two high power continuous wave accelerator drivers, each delivering a 125 mA D^+ beam at 40 MeV to a liquid lithium target. In the first phase of the "Broader Approach", the IFMIF-EVEDA (Engineering Validation and Engineering Design Activities) project includes the construction of an accelerator prototype with the same characteristics as IFMIF, except the energy which is limited to 10 MeV instead of 40 MeV. CEA-Saclay is in charge of the design and realization of both the deuteron source and the associated low energy beam transport (LEBT) line. This part, named the IFMIF injector is built and now under test at Saclay before shipment to Japan. The deuteron beam will be extracted from a 2.45 GHz ECR source based on the Saclay SILHI source design [1]. SILHI has been developed to produce cw 100 mA proton beams with 95 keV energy. In the framework of preliminary IFMIF studies, SILHI has been tuned to analyze deuteron beam characteristics [2]. That enabled to demonstrate that the emission spectrum in the visible region of deuterium differs slightly from that of proton due to the influence of hyperfine interactions among others. Therefore, all optical diagnostics developed on SILHI and presented here will be transposable on IFMIF injector. But contrarily to proton beam, the high neutron and gamma rays flux, emitted when deuteron beam interacts with surfaces, pushes to use hardened radiation devices. Radiations hardened camera (CID camera) for online beam positioning and shape measurements has been selected [3] and 20 m long Fujikura fiberscope to analyze species fraction using the Doppler shift method, section 4. This fiberscope has been characterized in spatial resolution and transmission as described in section 2. Once these studies have been done, standard experiment such as beam transverse profile and Beam species fraction measurements were done using the fiberscope and compared with results obtained without fiberscope. Before the conclusion, this article reports a special experiment made with such optical diagnostic where precise wavelength shift between H_α and D_α Balmer lines has been observed.

FUJIKURA FISR-10 CHARACTERIZATION

The fiberscope's parameters depend on the IFMIF beam's size and the IFMIF surrounding. The monochromator used for Doppler shift has to be outside the vault, regarding the size of the vault 20 meters are enough to transport the beam image from the vacuum chamber viewport to the monochromator.

Still, the fiberscope used to transport the beam image has to be able to endure radiations (Radiations attenuation to 650 nm = 0.014 dB/m for 1.10^6 rads/hr to compare with fiberscope attenuation to 650 nm = 0.045 dB/m). A 6 mm focal length C-Mount objective lens would have been more appropriate in order to collect as much light as possible but the beam diameter and the watching distance demand to use broader field of view (20° angle). What's more the selected fiberscope (FISR-10) composed of 10.000 fibers in 1.1 mm diameter, would not have a big enough field of view with a C-Mount objective lens (a FISR-30 which is constituted by 30.000 fibers in 2 mm diameter would have work with C-Mount objective lens but it is too expensive). Thus the use a custom-made Fujikura lens is needed. However, using Fujikura lens involves a loss in the amount of collected light.

The FISR-10 fiberscope spatial resolution has been measured by using a target lighted by a HeNe laser. Because its wavelength is close to the H_α Hydrogen

*franck.senee@cea.fr

Balmer line, the conditions provided by the HeNe laser are akin to the SILHI beam.

Its transmission has been measured by comparing the quantity of the laser light received by a CCD sensor with and without the fiberscope.

Spatial Resolution

The target used for this measurement is a mesh of lines and gaps of varying width. It is viewed by a CCD sensor coupled with the fiberscope observing the target at a distance of 35 cm. It appears that the minimum width to distinguish two lines is 1 millimeter corresponding to the spatial resolution of the fiberscope. It must be noted that spatial resolution decreases as the viewing distance increases.

Transmission

When coupled with the fiberscope, the CCD's shutter time needs to be increased in order to get enough light to get workable image. While using only the CCD sensor, a 1000 µs shutter time looks to be ideal. Such shutter time needs to be increased to 0.8 s when the CCD sensor is coupled with the fiberscope. Of course, with so long shutter time, the image is saturated when viewed with the sole CCD. So to determinate the fiberscope transmission, a corrective factor can be applied to the light quantity received by the same CCD with a shutter time of 1000 µs. Magnification correction has also to be applied on the width axis because of the different field of view with and without fiberscope. Taking into account of both corrections, the FISR-10 20 m long fiberscope transmission is only close to 0.2 %.

BEAM TRANSVERSE PROFILE COMPARISON

Direct fluorescence beam transverse profiles have been measured by a CCD sensor with and without fiberscope, on the SILHI source (88 mA, 90 kV). The viewport is located between the 2 solenoids, at 42 cm from the axis beam. Prior to these measurements the CCD's gain and shutter time influence on the beam profile have been checked: when the gain is doubled the FWHM variation is smaller than 0.1 %. The shutter time needs to vary especially with the use of the fiberscope. Its influence has been checked with the fiberscope: for a shutter time of 2 and 4 s, the FWHM variation is smaller than 1 %.

Knowing this, beam profile comparison with and without the fiberscope could have been made even though the CCD settings had to be adjusted in order to get a workable image in both cases. After adding the magnification correction (0.8) on the FWHM, the FWHM variation is 10 % (Fig. 1). For comparison, the difference between the FWHM of the same beam profile viewed by CID and CCD cameras is 7 % [3].

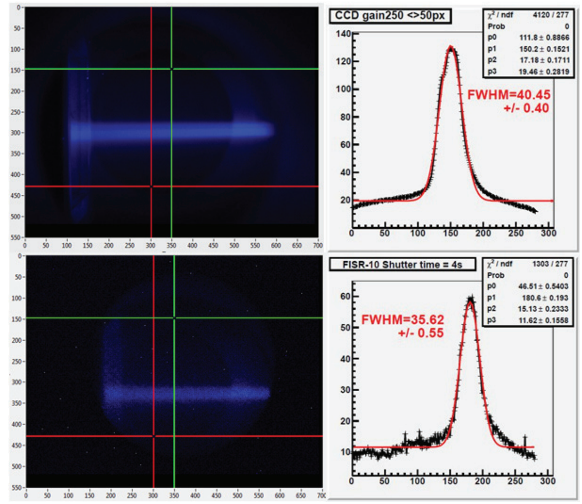

Figure 1: Beam transverse images and profiles obtained with CCD sensor without (above) and with fiberscope (below).

BEAM SPECIES FRACTION WITH DOPPLER SHIFT METHOD COMPARISON

Doppler shift method uses a digital camera installed in the focal plane of a monochromator. Doppler shift observation of the H_α Balmer line allows the isolation of the fluorescence resulting from only proton beam interaction with the residual gas. To minimize damages due to the neutrons and gammas rays, the fiberscope is located between the viewport of the LEBT and the monochromator. For experimental set up calibration, focus is made with and without the fiberscope with help of a mercury vapor lamp illuminating the target. The monochromator is setup to observe the mercury doublet. The focus is made for several distances corresponding to the distance between the monochromator and the beam axis. A linear fit has been used in order to evaluate the magnification value. Indeed, 10 % error on the magnification value leads to 7 % for the FWHM comparison with and without fiberscope.

This allows determining the magnification resulting from the use of the fiberscope whose value is 0.15. Thus, beam profiles measurements with and without the fiberscope can be compared.

The monochromator allows obtaining contains an image of the complete beam at 656.2 nm (H_α) and H^+ beam at 660.2 nm. Preliminary observation showed different profile shapes. Without the fiberscope, the beam has a Gaussian profile. With the fiberscope, the profile is narrower due to more important field of view of the fiberscope objective lens. The background noise also increases and the profile dynamic is far less important: the increase percentage between the baseline and the maximum peak has a value of 42 % without the fiberscope for the complete beam profile. For the H^+ profile this value is lowered to 26 %. When using the fiberscope, for both the complete beam and the H^+ profile, that value decreases to 2 %.

Even when increasing the shutter time while using the fiberscope, the profile dynamic stays low contrary what should be expected. This could be due to a cooling problem on the monochromator digital camera.

With the magnification value obtained with the calibration experiment, the species profiles obtained with and without the fiberscope can be compared. There is a difference of 37 % on the complete beam's FWHM and 44 % on the H^+ profile FWHM (Fig. 2).

The same experiments were carried out with a shorter Fujikura fiberscope (2 meter long and with the same fibers per mm rate). Its field of view is smaller (7.4° angle instead of 20° angle). Thus the magnification varies less, which explains the smaller species fraction difference (17 % on the complete beam's FWHM and 13% on the H^+ profile FWHM).

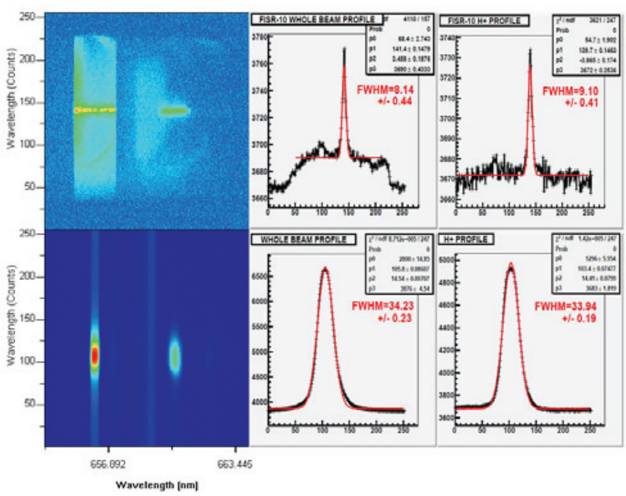

Figure 2: Obtained Doppler shift beam images and species profiles with (above) and without fiberscope (below) for a beam axis-monochromator distance to 44 cm.

D_α AND H_α BALMER LINE OBSERVATION

As already shown, beam interaction with the residual gas or added gas, in the beam line, can give interesting information on beam characteristics. It can also give information on the residual gas itself [4].

To ensure the use of optical diagnostics for IFMIF Injector beam characterization, special experiment has been performed with SILHI installation by mixing hydrogen and deuterium gas in the beam line. As a result, the D_2 Balmer series appeared as well as the H_2 Balmer series while proton beam was interacting with the gas. The D_α line grew, proportionally to D_2 gas flow injected in the LEBT, very close to the H_α line (Fig. 3).

The doublet of the Mercury vapor lamp allowed the calibration of the monochromator (see above). Then a shift of 0.18 nm has been precisely determined between both D_α and H_α Balmer lines.

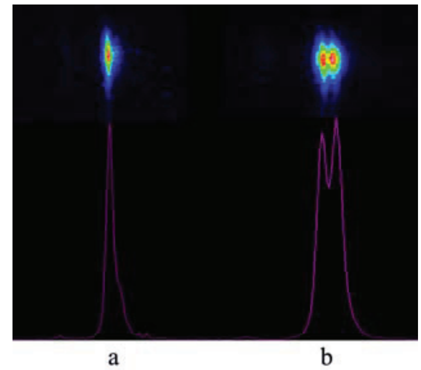

Figure 3: a- H_α Balmer line due to the interaction with H_2; b- D_α and H_α Balmer lines due to beam interaction with $H_2 + D_2$.

CONCLUSIONS AND PERSPECTIVES

Beam observation in the beam line allows beam characterization as well as residual gas analysis. For example, the shift between D_α and H_α Balmer lines has precisely measured. The high neutron and gamma flux due to deuteron beam production, leads us to characterize a 20 m long Fujikura fiberscope. With this equipment, the beam transverse profile results are satisfying, even for shutter time as short as 2 s. Unfortunately, work still remains to get satisfying species fraction measurements. Indeed with monochromator placed 44 cm from the beam axis, experimental conditions are not ideal. On the IFMIF diagnostic chamber, this distance is reduced to 37 cm. It will translate by a general better transmission and spatial resolution. In addition, once the camera cooling troubles will be fixed, the background noise should be reduced and the overall sensitivity of the camera should be increased. Further experiments will be conducted using the monochromator coupled with an objective lens having a similar field of view than the one coupled with the fiberscope. Doing so should increase the magnification closer to 1. As the IFMIF commissioning is now in progress, those experiments will be conducted directly on the IFMIF injector, first with proton beam.

REFERENCES

[1] R. Gobin et al., Rev. Sci. Instrum., 79 (2008) 02B303.
[2] R. Ferdinand et al., "Deuteron Beam Test for IFMIF", EPAC'02, Paris, France, (p. 894-896).
[3] F. Senée et al., "Diagnostics for High Power Ion Beams with Coherent Optic Fiber for Ifmif-Eveda Injector", DIPAC'09, Basel, Swiss (p. 197-199).
[4] B. Pottin et al. "Optical bam profiler for high current beams", EPAC'00, Vienna, Austria (p. 960-962).