DIAGNOSTICS FOR HIGH POWER ION BEAMS WITH COHERENT OPTIC FIBER FOR IFMIF-EVEDA INJECTOR

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Abstract

Optical diagnostics based on the excitation of residual gas molecules are routinely used for high intensity beam characterization. Beam intensity, beam position and profile are measured by means of a digital camera. In addition species fraction and profile of each beam are measured using a Doppler shift method. As part of IFMIF-EVEDA project, CEA is in charge of the design and realization of the 140 mA-100 keV cw deuteron source and low energy beam transport line. In the beam line, (D,d) reaction will occur and high neutron flux will be emitted when deuteron beam interacts with surfaces. Moreover gamma ray and activation will also occur. In order to protect diagnostics, coherent optic fibers could be used to transport the beam image outside the irradiated zone. A comparative study of two coherent fibers will be presented (FUJIKURA & SCHOTT), along with the characterization in magnification and transmission of a 610 mm long fiber and its associated optics. To estimate the capability of such fibers to transport beam image, a dedicated experiment has been performed with proton beam produced by the SILHI source. The beam profile has been compared with and without the optic fiber.

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 machine 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 a lower energy of 10 MeV instead of 40 MeV for the incident deuteron energy. CEA-Saclay is in charge of the design and realization of both deuteron source and the associated low energy beam transport (LEBT) line. This part, named the IFMIF injector, will be built and tested at Saclay and then moved to Japan. The deuteron beam will be extracted from a 2.45 GHz ECR source based on the SILHI design [1], the Saclay source. It 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 realized on SILHI and presented in section 2 will be transposable on IFMIF injector. But high neutron flux and gamma rays, emitted when deuteron beam interacts with surfaces, push to use coherent optic fiber to transport the beam image outside the irradiated zone or radiations hardened camera (CID camera). Recent tests of such devices performed on SILHI beam are presented in section 3 and 4.

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OPTICAL BEAM DIAGNOSTICS

The interaction between the proton beam and the residual gas produces excited and ionized gas atoms and molecules. An analysis of the emitted light with different devices allows getting ion beam characteristics.

With Digital Cameras (CCD Camera or CID Cameras)

Direct fluorescence beam profile measurement with digital camera perpendicular to the beam direction allows the following parameter measurement:

- Beam current proportional to fluorescence intensity
- Beam size
- Beam center position
- Beam profile

With Monochromator and CCD Camera

With a digital camera installed in the focal plane of a monochromator with 20° angle. Doppler shift observation of the H_α hydrogen Balmer series allows isolating the fluorescence only resulting from proton beam interaction with the residual gas. As a result, other parameters are achievable:

- Species fraction
- Species fraction beam profile
- Source impurities

With Coherent Optic Fiber, Monochromator and CCD Camera

Adding a coherent optic fiber to transport the beam image outside the irradiated zone and until the device (digital camera or monochromator) seems to be a good solution to prevent these devices from the high neutron flux and gamma ray produced on IFMIF-EVEDA (Fig. 1). All optical diagnostics above should be able to run with this fiber type. That is what we tried to prove with a comparative study made with of two coherent fibers of two manufacturers (FUJIKURA & SCHOTT). Radioprotection simulations show that the radiation level produced by 165 mA deuterons beam at 100 keV should be in the range of 100 mSv/hr around the diagnostic box.

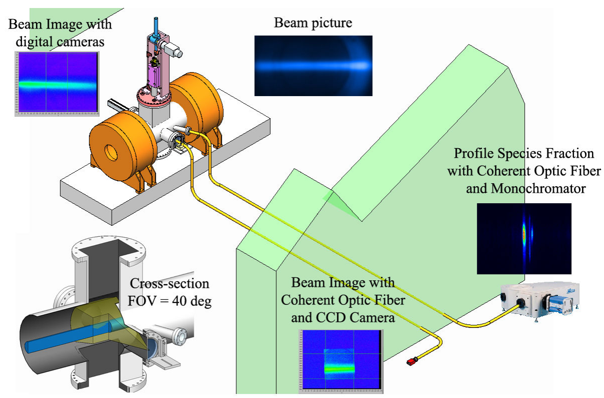

Figure 1: Methods of characterization of the deuteron beam of IFMIF Injector.

FUJIKURA AND SCHOTT COHERENT FIBER SPECIFICATIONS

It seems that only two manufacturers of coherent optic fiber are available: FUJIKURA Japanese Company and SCHOTT USA Company. The main specifications of their coherent optics fiber image transport are presented below (Table 1).

Table 1: Main specifications of two manufacturing coherent optic fiber

Specifications	FUJIKURA	SCHOTT
Model	FISR-30	IG-163
On catalog	No	Yes
Resolution	11200 mm^{-2}	54000 mm^{-2}
Max length	On request	4.575 m
Hardened radiations (650 nm)	Yes (Att=14 dB/km for 1.10^6 rads/hr)	No
Attenuation (650 nm)	0.6 dB/m	1.3 dB/m
Image area	2.7 mm^2	80 mm^2
Image format	Circular	Polygonal
Required magnification	Yes	No
Objective end	Objective lens sleeve (FOV fixed)	C-Mount
Camera end	C-Mount	C-Mount

It appears that the two fibers have got some strengths and weaknesses. Transmission, length and the radiations hardening are the assets of FUJIKURA fibers whereas for the SCHOTT fibers the resolution and the field of view are mutable by changing the objective lens. It would have been interesting to test the two but FUJIKURA fibers are custom-made. Lending it for tests is not possible. So, only one SCHOTT coherent optic fiber of 610 mm long has been characterized with beam profile measurement.

SCHOTT COHERENT OPTIC FIBER CHARACTERIZATION

At first, characterization of the SCHOTT coherent optic fiber was to check its own transmission using a mercury vapor lamp such as light source. The software APILUX will be used to get the transmission of the optical components. After completed the transmission check of the whole optical system with this lamp, the optic fiber transmission with the proton beam has been measured. The optical components used are an objective lens (16 mm), a coherent optic fiber (IG-154, 610 mm, 16 mm^2), a relay lens assembly (IG-1643) and a CCD Camera (Stingray). Finally, the optical system magnification has been determined in order to compare the beam profile obtained with and without the SCHOTT fiber.

Own Fiber Transmission

The obtained ratio between the quantities of light with and without the coherent optic fiber gives the fiber and relay lens assembly transmission. This obtained transmission is 30 %. The relay lens assembly transmission calculated by APILUX is 82 %. One must simply deduce this value to the measured transmission in order to obtain the 610 mm long coherent optic fiber transmission. Therefore, the fiber transmission is 37 %. To compare this result with the spectral transmission given by SCHOTT (Fig. 2), the use of monochromatic light source would have been more suitable. The spectrum of the used mercury vapor lamp has been obtained with monochromator IR550 (Fig. 2). One could note the mercury vapor lamp spectrum is close to the proton beam spectrum (Balmer series).

Transmission of the Whole Optical System for the Proton Beam

To estimate the effective whole transmission system, simulation have been done with APILUX and compared to the experiment results obtained above. The error between the simulation and the experiment is 3 %.

Then the estimated transmission (with APILUX) for whole optical system installed on the proton beam line is 26 ± 3 %. By replacing 610 m long optic fiber by 4.575 m long one, this estimation goes done to 12 ± 3 %. This simulation result doesn't depend on the beam intensity as the light intensity for each Balmer line is directly proportional to the beam intensity [3] (Fig. 2).

Consequently, attenuation will be a decisive parameter in the choice of the coherent optic fiber.

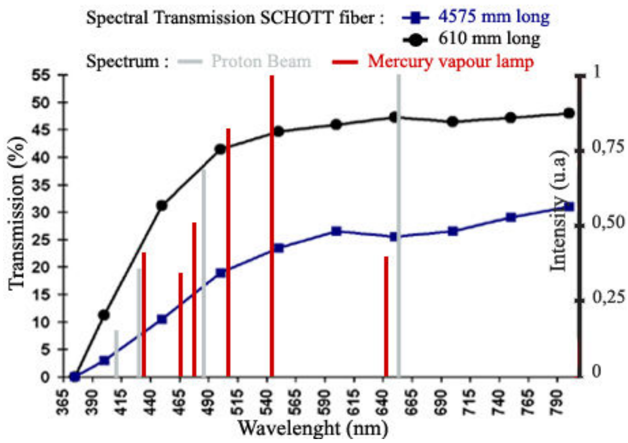

Figure 2: Spectral transmission for a SCHOTT coherent optic fiber of 610 mm and 4575 mm long, mercury vapor lamp and proton beam spectrums.

Optical System Magnification

The magnification is determined by comparing a circular target 20 mm diameter viewed through the optical system with coherent optic fiber and without. The ratio between the two target sizes is 0.64. The field of view with fiber will be thus bigger that without. The Full Width at Half Maximum (FWHM) determined on the beam profile has to be corrected of this value in order to compare the fiber impact on the beam profile.

Beam Profile With and Without SCHOTT Coherent Optic Fiber

The beam profile is deduced from the transverse beam image obtained with the CCD camera (Fig. 3).

This average FWHM difference with and without coherent optic fiber is 10 %. This value is obtained by doing different software corrections on the image such as subtracting the background noise, modifying the Look-Up Table with the pixel maximum luminous intensity. This result could be explained partly by the difference of the field of view: 243 pixels correspond to 69 mm with the optic fiber and 44 mm without. An improved study will be necessary in order to better understand the others involved process but results are promising.

RADIATIONS HARDENED CAMERA IN COMPARISON WITH CCD CAMERA

Radiations hardened cameras operate by Charge Injection Device [4]. One CID8726DX6 designed and manufactured by Thermo CIDTEC (Liverpool, NY) has been tested on the SILHI source with a 25 mm objective lens. Obtained beam profile has been compared with CCD camera results (Fig. 3) for different gains. This CCD camera is the same one used in the above test.

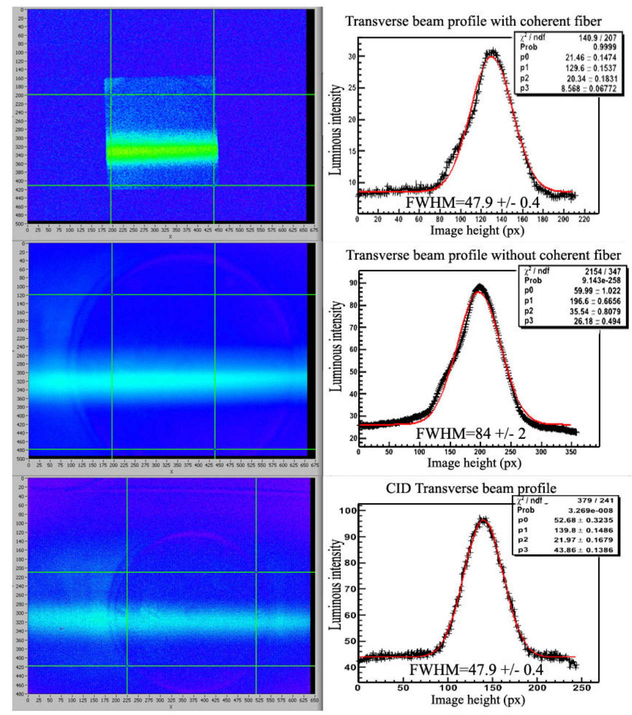

Figure 3: Obtained beam profile from image beam with coherent fiber and without and CID camera.

Taking into account a 0.71 magnification, the obtained difference between CCD FWHM and CID FWHM is 7 %. This result can be explained by the difference between the pixels size (CID pixels are close to 2 times larger than CCD pixels with binning use of 2x2 pixels) but also by the image aliasing. The discrepancy coming from the image aliasing is due to the image format used for the digital acquisition. Further studies are in progress to overcome this trouble. At present time the CID cameras could be used to get the mains characteristics of the beam.

CONCLUSIONS AND PERSPECTIVES

Therefore, it won’t be necessary to used coherent optic fiber to get all characteristics of the beam. CID cameras will be used. The cost saving is about factor 3 for coherent optic fiber 5 m long. Nevertheless an optic fiber will be necessary in front of the monochromator to do the Doppler shift analysis. The use of a FUJIKURA fiber is foreseen.

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