CHARACTERIZATION OF RUDI NEUTRAL BEAM PARAMETERS BY OPTICAL DIAGNOSTICS

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Currently a joint experimental program is performed on the RUDI injector at the TEXTOR tokamak in a collaboration between the Budker Institute of Nuclear Physics SB RAS and the Research Center Juelich (Forschungszentrum Juelich GmbH). The diagnostic injector RUDI is used for charge-exchange recombination spectroscopy (CXRS) diagnostic at the tokamak TEXTOR. Since the spatial resolution and CXRS signal level depend on diagnostic beam divergence and beam full-energy component current density, respectively, these beam parameters should be controlled to provide stable CXRS measurements. The beam density distribution, the angular divergence and the species composition, can be measured optically by spectroscopic means. The absence of perturbations to the beam investigated is one of the main advantages of optical diagnostics.

I. RUDI INJECTOR AT THE TEXTOR TOKAMAK

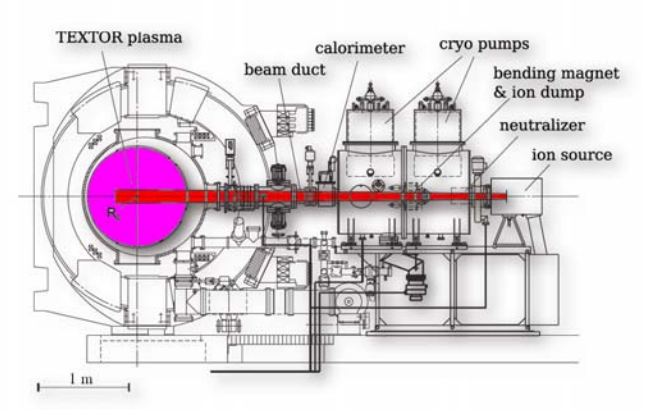

Fig. 1. Scheme of RUDI diagnostic beam setup.

Based on the injection of hydrogen by the diagnostic injector RUDI, charge-exchange recombination spectroscopy (CXRS) diagnostic is utilized at the tokamak TEXTOR for the measurements of the plasma rotation velocity and the radial ion temperature distribution (Ref. 1). The principle of charge-exchange diagnostics is based on the spectral analysis of specific line radiation, emitted by plasma impurities due to interaction with the atoms of the diagnostic beam. The plasma rotation velocity is evaluated from Doppler shift of line peak with respect to the unshifted reference, while the ion temperature measurements are based on Doppler broadening of the line width.

To meet the requirements of the CXRS diagnostic at TEXTOR, the injector was designed to be operated at an energy of 50 keV, and an equivalent atomic beam current (for hydrogen) of up to 1-1.5 A. The diagnostic beam is formed by a multi-aperture four-electrode ion optical system with geometrical focusing.

Since the year 2006 an arc-discharge plasma box with a directly heated cathode is used in the ion source. The cathode element is equipped with a stack of LaB_6 discs alternated by flexible washers made of thermo-extended graphite (Ref. 2). The use of LaB_6 as the emitter material avoids its erosion and provides for a long life-time operation at working temperatures of ~1650 °C, with an arc-discharge current of up to 300 A. The application of an arc-discharge emitter provides a high (~85%) H^+ ion fraction in the source plasma.

To increase the CXRS signal a new slit ion optical system for 3A ion beam current was recently introduced, which provides a beam angular divergence ~0,3° in the direction along the slits (Ref. 3).

II. OPTICAL DIAGNOSTIC SETUP

To control the amount and stability of the main beam parameters during the shot a new optical diagnostic system has been developed consisting of:

- a multichannel spectroscope for beam spectra profiles measurements, and species composition evaluation via $H\alpha$ Doppler shift spectroscopy.
- a beam transverse velocities monitor based on H_α Doppler broadening spectroscopy.
- a CCD camera for the beam optical profile scanning and for an attempt to investigate the high Z beam impurities using narrow-band width filters.

I.A. Multichannel spectroscope for the beam spectra profile measurements

The spectrometer has seven spatial channels covering the whole beam diameter with a separation length of 14 mm. The beam observation angle is 45°. The principle of the diagnostics is based on the Doppler shift of the line radiation from neutralized fast beam atoms in direction of the observation represented by a set of shifted bright H_α lines. Typically, it consists of four shifted peaks (corresponding to full, half, third energy components and water contribution), and one unshifted H_α peak that corresponds to the background gas in the vacuum vessel.

The separation of H_α lines from the beam components provides the beam profile monitoring for each fraction, particularly for the full-energy component, which is responsible for the CXRS signal intensity, and which therefore is important for the correct evaluation of the CXRS measurements.

The device also allows the investigation of the beam species composition (Ref. 4).

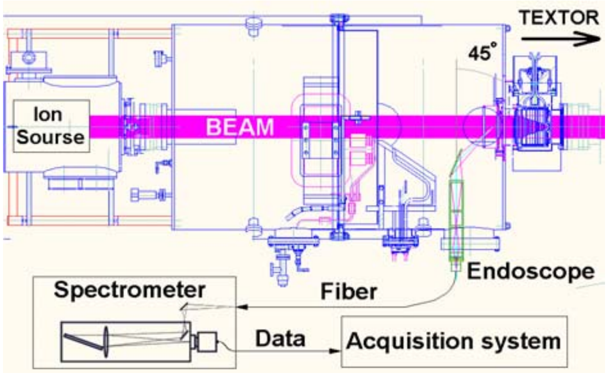

Fig. 2. Spectroscopical diagnostic setup at RUDI.

In order to get the maximum of the beam light intensity the first lens had to be positioned very close to the beam axis. The optics is located inside the vacuum vessel and an endoscope was designed to transport the collected light outside the injector vessel onto a stack of fibers. The other end of the fiber stack is imaged onto the spectrometer slit. An example of beam spectra measurements is presented at Fig. 3.

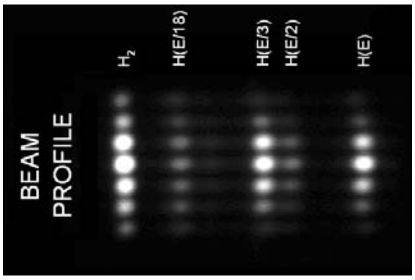

Fig. 3. RUDI beam spectra profile image.

The first tests of spectral profile measurements of the RUDI neutral beam have been performed, and a sufficient difference in divergence for all beam fractions was revealed. The measured divergence for the full energy component is ~0,4°, while the half and third energy components have a divergence value of 0.7° - 0.8° (see Fig. 4).

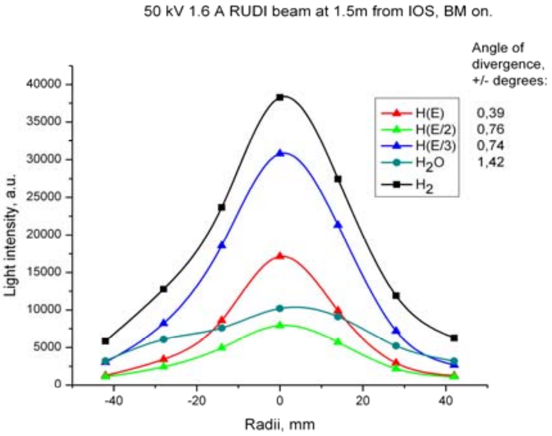

Fig. 4. Beam spectra profile scan (old 2A IOS).

I.B. Evaluation of the beam divergence via spectra lines broadening

Observing the beam in a nearly (~80°-85°) perpendicular direction, the peak of the H_α line has a spread due to Doppler broadening, caused by transverse velocities of the beam particles. This observation angle is sufficient to distinguish the shifted H_α peaks of the different beam components but additionally resolve the spread, defined by transverse particles velocities of the respective beam components. Further deviation of angle is not reasonable because of the longitudinal broadening effect rise, due to particles energy dispersion caused by the accelerating voltage instability.

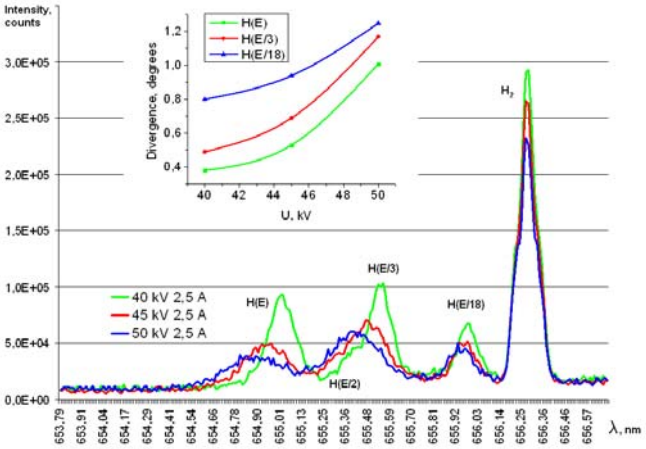

Fig. 5. Beam H_α lines broadening during voltage scans (spectral resolution 30 pm/pixel).

The measurements of the beam transverse velocity distribution via H_α line broadening require high (~10-30 pm/pixel) spectral resolution of the diagnostic setup.

The results obtained at the RUDI beam at voltage of 40, 45 and 50 kV, with 2,5 A beam current, are shown at Fig. 5.

It is necessary to note, that the results presented here are the first measurements of the beam formation with the new slit ion optical system in the direction across the slits.

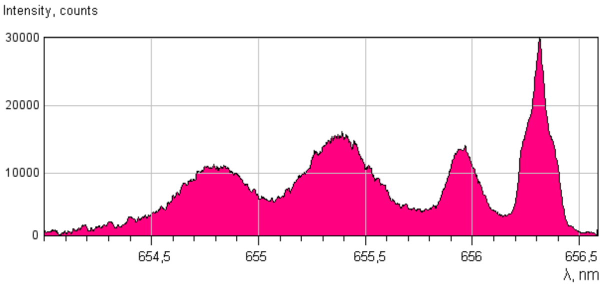

Fig. 6. Spectral lines broadening measured with 10 pm/pixel resolution for a 50kV 2,6A beam.

To reduce the noise level and to improve the spectral resolution, a more powerful spectrometer with the resolution 10 pm/pixel has been introduced (the spectrum of 50 keV, 2,6 A beam has shown at Fig. 6). It is necessary to note that the unshifted peak has a width of a foundation of ~2 Å. More detailed data are presented in the Table. I.

TABLE I. Beam divergence parameters measured with 10 pm/pixel resolution. (H_2 peak half-width = 0,06nm).

Beam component	H(E) (50keV)	H(E/3)	H(E/18)
Spectral half-width, nm	0.17	0.15	0.1
Half-width broadening, nm	0.11	0.09	0.04
v_b, km/s	50	41	18
v_f, km/s	3100	1790	730
$Energy_b$, eV	13	8.7	1.7
Angular Divergence, deg.	0.92	1.31	1.43

I.C. CCD camera for optical scanning of the beam and high Z impurities monitoring

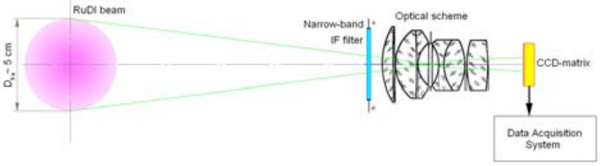

Fig. 7. CCD beam scanner scheme.

In addition to spectral diagnostics a CCD camera was implemented for high-resolution beam profile scanning (Fig. 7). Equipped with high-aperture optics the system allows to achieve the beam images in the visible spectral range. This gives the ability to monitor heavy impurities (like Mo, O, C) in the beam by using narrow-band width filters of the respective bright spectral lines. The importance of such a monitoring is connected with the necessity to control the erosion increase of the ion source elements and to avoid of the impurities accumulation in the main plasma. Currently the beam spectra investigation has been performed by a wide-range (350-700 nm) high resolution spectrometer, but no heavy impurities have been revealed so far. Next attempt will be done with 10 s beam duration.

III. CONCLUSIONS

The introduction of new diagnostic tools for neutral beams investigation is one of the key tasks for beams physics in fusion research. Optical diagnostic setup for RUDI beam investigation has developed along with present RUDI parameters enhancement. The experimental results of neutral beam measurements prove that the injector RUDI provides the steady measurements of TEXTOR plasma parameters.

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