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Feasibility study on the JT-60SA tokamak beam emission spectroscopy diagnostics

O. Asztalos[a,*], G. I. Pokol[a], D. Dunai[b], G. Boguszlavszkij[a], A. Kovacsik[a], M. v.Hellermann[c], K. Kamiya[d], T. Suzuki[d], A. Kojima[d]

[a] *Institute of Nuclear Techniques, Budapest University of Technology and Economics, Budapest, Hungary*
[b] *Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary*
[c] *Dutch-Institute for Fundamental Energy Research, Association EURATOM-FOM, BE Nieuwegein, The Netherlands*
[d] *National Institutes for Quantum and Radiological Science and Technology (QST), Naka, Ibaraki-ken 311-0193, Japan*

Abstract

The JT-60SA superconducting tokamak is proposed to be equipped with a Lithium Beam Emission Spectroscopy (LiBES) and Deuterium Beam Emission Spectroscopy (DBES) diagnostic systems. The purpose of the LiBES system is scrape-off layer (SOL) and plasma edge density profile measurements and density fluctuation measurements in the SOL and outer edge regions, whereas the DBES system on the heating beams would have the capacity of density fluctuation measurements in the edge and the core regions, as well. Considerations for an optimal LiBES system require sufficient plasma penetration beyond the separatrix and reasonable SOL emission with regard to total emission, while an optimal DBES system requires mostly adequate spatial resolution and a sufficient Doppler shift to enable discrimination of beam emission from emission of the background plasma. Various concepts and geometries of the LiBES system for JT-60SA are analysed in detail as well as a potential DBES observation geometry.

Keywords: JT-60SA, BES, spatial resolution

1. Introduction

Beam **E**mission **S**pectroscopy(BES) is an active plasma diagnostic employed for density profile and density fluctuation measurements, by introducing a high energy neutral beam of alkali metals or of hydrogenous species. The spontaneous emission, resulted through collisional processes with plasma particles, is observed. Based on the proportionality between the electron population of the

*Corresponding author
Email address: `asztalos@reak.bme.hu` (O. Asztalos)

observed atomic level and the corresponding light emission profile along the beam, plasma density is reconstructed [1]. BES systems are used for fluctuation measurements, where the spatial resolution is the limiting factor in the dimensions of the detectable turbulent structures. Spatial resolution is influenced by three major components: the area of detector projection in the focal plane, the smearing caused by the atomic physics processes through the finite lifetime of excited levels and the alignment of the lines of sight (LOS) with the magnetic field lines along which most fluctuating structures are elongated [2].

JT-60SA is a fully superconducting tokamak being build in Naka, Japan. Current paper explores the feasibility of potential LiBES and DBES diagnostic systems to be installed on JT-60SA. Both diagnostic systems have been modelled with the RENATE synthetic diagnostic, which is based on the collisional radiative model and calculates the expected light profile and spatial resolution among others for any BES concept [3]. Studies were performed on plasma scenario 2, which is a full inductive single null scenario and plasma scenario 5, which is a high β full current driven single null scenario [4]. Plasma profiles were augmented beyond the last closed flux surface to accommodate a scrape-off layer(SOL) in the range of 1 to 1.2 normalized minor radius, see Figure 1.

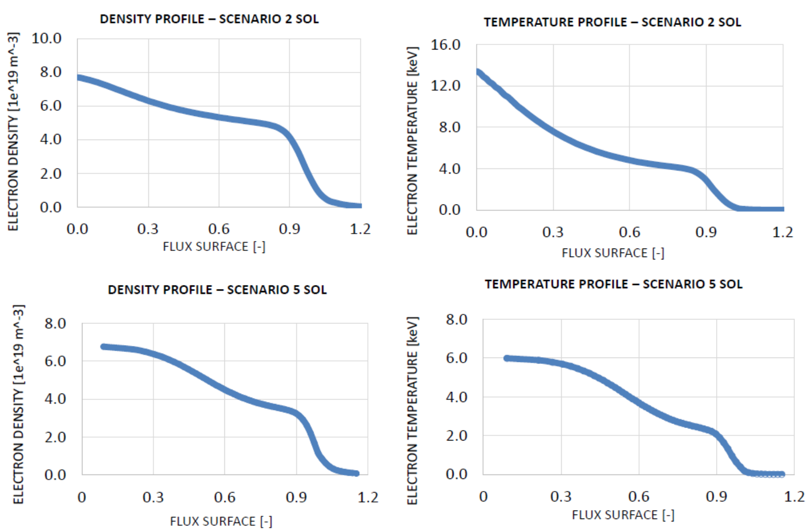

Figure 1: *Plasma density and temperature profiles with SOL extension for high density SOL scenario.*

2. JT-60SA LiBES system

Lithium BES systems have a considerably shorter penetration depth with respect to heating beams (NBI), granting the possibility for plasma edge and scrape-off layer observation. The article discusses the feasibility of two LiBES configurations proposed for JT-60SA, complemented by a configuration suggested by the authors (see Figure 2) [5].

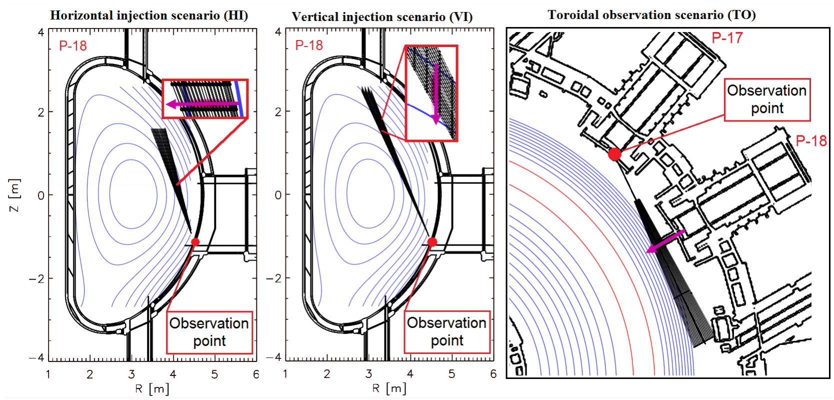

Figure 2: *Left: Horizontal injection scenario. Center: Vertical injection scenario. Right: Toroidal observation scenario.*

The beam was modelled at various beam energies in the 10 to 60 keV range, beam current of 1 mA and a $FWHM$ of 2 cm. The observation system modelled comprised of a 4×16 APDCam detector array [6]. Both proposed diagnostic set-ups are co-planar, located on port P-18. The horizontal injection scenario (HI) presents the neutral beam shot radially into the plasma with the observation on the same horizontal segment of port P-18 (see Figure. 2 left). The vertical injection scenario (VI) features the same observation system, with the beam shot vertically into the plasma from the upper segment of port P-18 (see Figure. 2 center). The co-planar nature of both geometries infer the LOS of the observation system not parallel with the magnetic field lines, excluding the possibility of 2D measurements.

Plasma penetration depth is considered to be the distance between the last closed flux surface and the emission peak along the beam. The comparison of the two plasma scenarios on the HI BES geometry indicates deeper plasma penetration and more observed light in case of scenario 5, due to lower plasma density and a milder gradient along the beam (see Figure. 3 upper). Plasma penetration increases with the beam energy, however the amount of detected light decreases due to photon deposition being stretched on a wider range, inferring a clear trade-off between plasma penetration and light detection. Simulations indicate 30 % of light emission occurring in the SOL region for lower beam energies, the fraction drops to 20 % for higher beam energies. Performance comparison of HI and VI scenarios indicate the beam barely penetrating the plasma for the VI scenario, $55 - 45$ % of the emission occurs in the SOL region (see Figure. 3 lower). The magnetic geometry for BES scenario VI causes the SOL region to increase by 9 cm posing serious beam stoppage. The amount of light collected is considerably lower, the beam is located much further from the observation point.

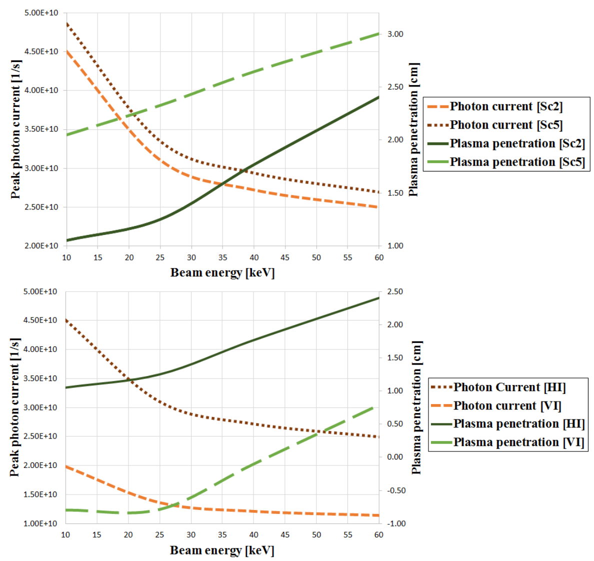

Figure 3: *Upper: Simulation results for HI scenario on plasma scenarios 2 and 5. Lower: Simulation results regarding HI and VI scenarios on plasma scenario 2.*

The here suggested toroidal observation scenario (TO) features a neutral beam set-up as for the HI scenario on port P-18, however the observation system is placed on port P-17 in the same horizontal plane as the beam (see Figure. 2 right). The observation point located at a similar distance from the beam as in scenario HI yielding similar performances with regard to plasma penetration and light detection. The TO scenario ensures however the LOS to be close to parallel to the magnetic field lines reducing the contribution of the magnetic geometry to the spatial resolution, therefore allowing for 2D fluctuation measurements [7].

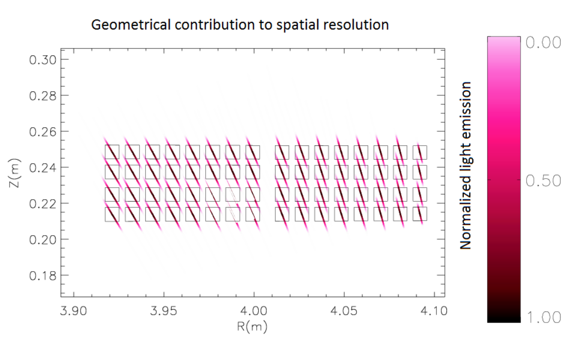

Figure 4: *Point spread functions for all detectors resulted from the misalignment of the LOS with the magnetic field lines.*

Point spread functions for all detector pixels (Figure 4) show the measure by which the emission is smeared poloidally and radially by the magnetic geometry. The set-up ensures a radial resolution of $1.5 - 2$ cm for both plasma scenarios, while a poloidal resolution of 2.5 and 2 cm for plasma scenarios 2 and 5, respectively. Figure 4 also indicates a slight degradation of the spatial resolution towards the plasma core, making the observation of turbulent structures of $1.5 - 2$ cm in the SOL and pedestal regions a realistic possibility.

3. Potential DBES observation system

The proposed BES system on NBI beams for JT-60SA could operate in conjunction with the MSE diagnostic [8]. The possibility of one such set-up was studied from a likely position of the MSE observation, located in the center of port P-17, observing tangential heating beam $8B$ (Figure 5).

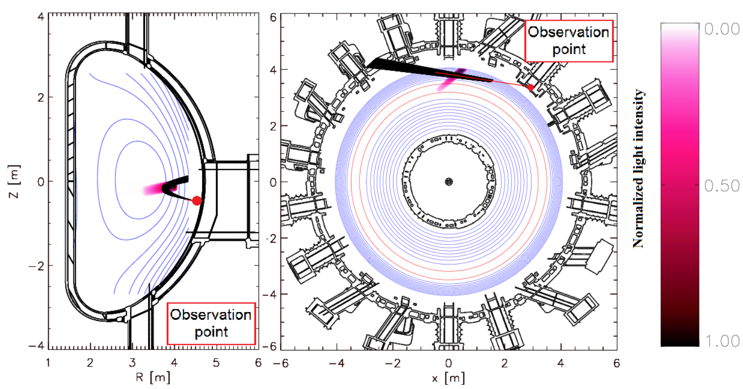

Figure 5: *Poloidal(left) and toroidal(right) view of plasma core observation for potential DBES system on tangential heating beam 8B.*

Plasma edge and core observation scenarios were studied with regard to the contribution of the magnetic geometry to spatial resolution as well as the amount of detected light. The peak detected photon current was in range of 5×10^{10} $1/s$ and 1.5×10^{10} $1/s$ for plasma edge and core observations, respectively, showing a reasonable photon count for a sampling frequency of 1 MHz. Both observation scenarios are red Doppler shifted, in the range of $5 - 6$ nm for edge and core observations, respectively (simulations performed with Simulation of Spectra code), distinguishing the BES spectrum from D_α background and the C_{II} multiplet. Simulations concerning the spatial resolution predict a radial resolution in range of $3-5$ cm and poloidal in range of $6-10$ cm, resulting from the misalignment of the magnetic field lines with the LOS, however it is possible to locate more suitable periscope positions for DBES diagnostics.

4. Conclusions

A feasibility study was conducted on potential Li- and DBES diagnostic systems for the JT-60SA tokamak employing the RENATE synthetic BES diagnostic.

Simulations performed on the proposed LiBES set-ups indicate the horizontal injection scenario to have sufficient penetration and detected light for SOL and plasma edge observation.The co-planar nature of the LiBES set-up infers 1D profile and fluctuation measurement. A toroidal observation scenario was put forward presenting the same performance qualities as the horizontal injection scenario for SOL and plasma edge measurements, providing the possibility of a 2D, more detailed observation for turbulence tracking. The vertical injection scenario presents a wider SOL region to be observed with considerably less light detected and diminished plasma penetration.

A potential DBES diagnostic in conjunction with an MSE observation was found to have a sufficient photon count for edge and core observations likewise, however the spatial resolution clearly indicates a less than favourable observation point. Further detailed study is required with regard to optimal observation positions for a viable DBES system on JT-60SA.

Acknowledgements

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