Beam Emission Spectroscopy Measurements on KSTAR

M. Lampert[1,2], M. J. Choi[3], D. Guszejnov[2], I. Kiss[1], Á. Kovácsik[2],
Y. U. Nam[4], H. Park[3], G. I. Pokol[2], G. Veres[1], S. Zoletnik[1]

[1] *Wigner RCP, EURATOM Association HAS, Budapest, Hungary*
[2] *BME INT, EURATOM Association HAS, Hungary*
[3] *Department of Physics, POSTECH, Korea*
[4] *National Fusion Research Institute, Daejeon, Korea*

Beam emission spectroscopy measures electron density from the Doppler-shifted light emission of a heating beam excited by beam-plasma particle collisions [1]. From the measured light intensity one can calculate the electron density after proper calibration. If sufficient light is available, this technique enables us the study of electron density fluctuations and their spatial distribution via two-dimensional detectors. Before the system design, detailed modelling was performed in order to calculate the expected photon flux at the BES port, which resulted at $1 \times 10^{10} - 5 \times 10^{10} \frac{photons}{s}$. According to modelling results for the calculated photon flux and 1MHz bandwidth, the optimal detector type was the avalanche photo diode (APD). A trial BES measurement system was designed and built for validating the modelling and to prove the feasibility of the BES technique on KSTAR.

The trial KSTAR BES system measured the light emission from the 80-90keV heating deuterium neutral beam. The diagnostic was placed inside a port already foreseen for this purpose in the machine design, 45 degrees away from the NBI port (see Fig. 1).

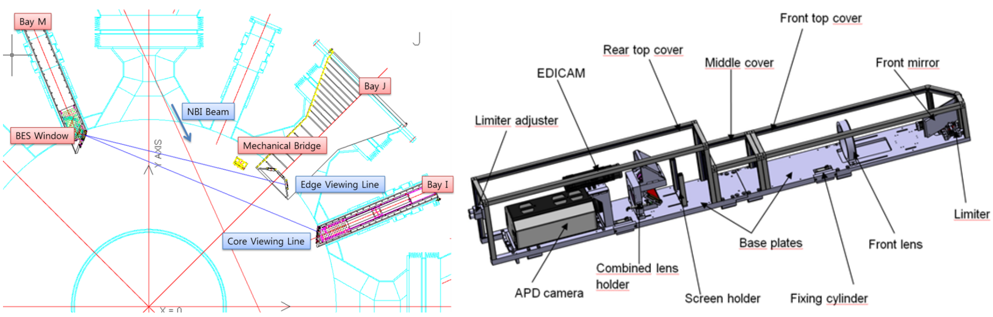

Figure 1: The geometry of the trial KSTAR diagnostic (left) and its schematic image (right)

To save cost and effort in this trial setup the collection optics was designed to be as simple as possible. A couple of lenses imaged an approximately 5x10 cm (poloidal x radial) area of the neutral beam onto a 4x8 pixel APDCAM [1] avalanche photodiode array. A pneumatically operated front mirror was used for selecting edge or core (r/a=0.5) measurement. An interference filter provided selection of the Doppler shifted D_α light. Figure 1 shows the schematic image of the diagnostic. It has to be noted that in this trial optical setup the light collection and filtering efficiency was far from optimum. Nevertheless, in the measurement on KSTAR the typical signal-to noise ratio at 500 kHz analog bandwidth was found to be around 30-50, suitable even for turbulence measurements. The background signal was relatively high, about 10-100%. The actual detected photon flux was calculated from the transmission of the optical system and the gain of the detector and was found to be close to the modelled value. According to the calibration, the spatial resolution matched the design value, which was about 1cm both in the radial and poloidal direction.

Relative calibration of the 32 detector signals was performed in beam-to-gas shots and after disruptions, when the beam was injected for a short time into the residual gas. The BES diagnostic was operated during most of the 2011 KSTAR measurement campaign and collected data with 2 MHz sampling rate on all 32 channel during the whole discharge. In the rest of the paper we show the most interesting results obtained in the analysis: ELM precursors, and correlation of edge plasma turbulence along magnetic field lines over a distance of about 90 degree m toroidal separation.

The maximum available heating power on KSTAR was 1.6MW, only marginally above the H-mode threshold. Nevertheless an L-H transition was routinely achieved. During analysis of D_α and BES signals in H-mode, signatures of ELMs were clearly seen [2]. The ELM type was unclear due to lack of measurement of the heating power - ELM frequency dependence.

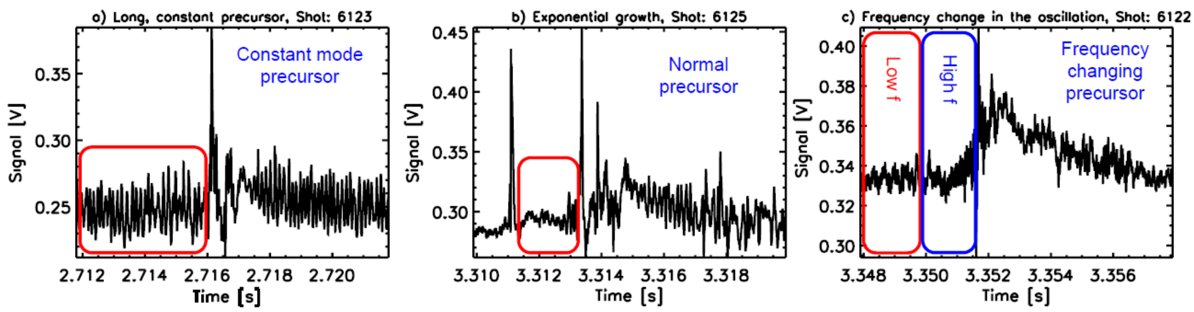

Figure 2: The types of ELM precursors on KSTAR

During analysis of BES signals, clear ELM precursor oscillations were found (see Fig. 2). They were separated into three categories: frequency changing, constant mode and normal precursors. Normal precursors have a growth rate, while constant mode precursors have constant amplitude. These were found on other tokamak devices before [3].

A statistical analysis was done by processing a number of ELMs and determining their frequency spectrum and poloidal flow velocity for two time intervals before the ELM onset: $[t_{ELM} - 1ms, t_{ELM} - 0.5ms]$ and $[t_{ELM} - 0.5ms, t_{ELM}]$, where t_{ELM} is the time of the ELM. The results of the frequency changing precursor analysis can be seen on Fig. 3.

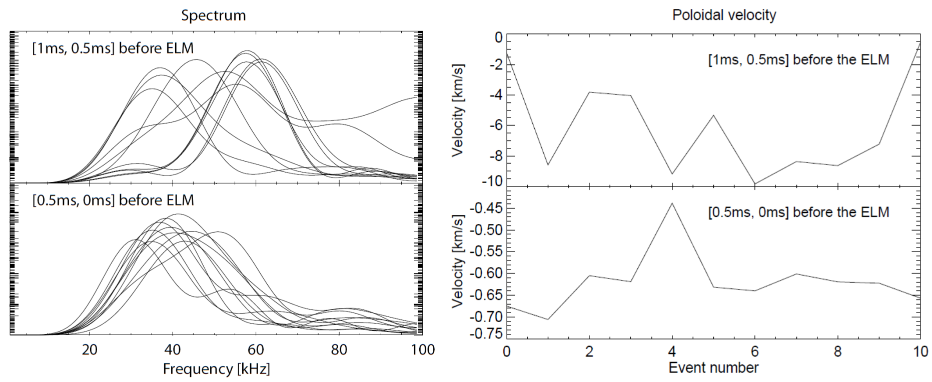

Figure 3: The spectrum (left) and the poloidal velocity (right) of frequency changing precursors

One can see, that while 0.5ms before the ELM, the frequency of the precursor is higher, around 60kHz, while just before almost all analysed ELM events, the frequency drops to 40kHz. 0.5ms before the ELM, the poloidal velocity is in the range of $5\frac{km}{s}$, while just before the ELM, the velocity drops down with one magnitude to around $0.5\frac{km}{s}$. It is presently unclear whether this significant change in poloidal velocity of the mode can be attributed to plasma flow change or a change in mode properties.

In the edge plasma region spectra of BES signals showed signs of turbulent plasma behaviour in the 10-100kHz frequency range. Correlation analysis clearly revealed poloidal propagation with typically 0.5 km/s in the electron diamagnetic direction, while no radial propagation was detected. The relative fluctuation amplitude at the plasma edge was about 2%, while at r/a=0.5 no turbulence signal was detected, most probably due to insufficient statistics. Edge turbulence was analysed in the imaging Electron Cyclotron Emission (ECEi) diagnostic data as well.

ECEi is a novel diagnostic built on KSTAR in 2010 [4] capable of measuring two-dimensional distribution of fluctuations in the electron cyclotron wave emission. This system has two 8x24 (radial x poloidal) arrays of channels movable to various radial locations in the plasma. The ECEi diagnostic is separated toroidally from the BES system by 90 degrees. In the edge plasma region signatures of plasma turbulence were found in the spectra of ECEi signals. After calculating the correlation between BES and all ECEi signals filtered for the 10-100 kHz band, correlation was found between certain channels of the two diagnostics. To analyze this in detail the cross-correlation function was calculated between a selected reference BES signal and all 384 ECEi signals. The maximum for each correlation function was plotted in the case of 4 different BES reference channels as a 2D image on Fig. 4. The contour of the BES channels was mapped along magnetic field lines to the toroidal location of the ECEi diagnostic and over plotted on these images.

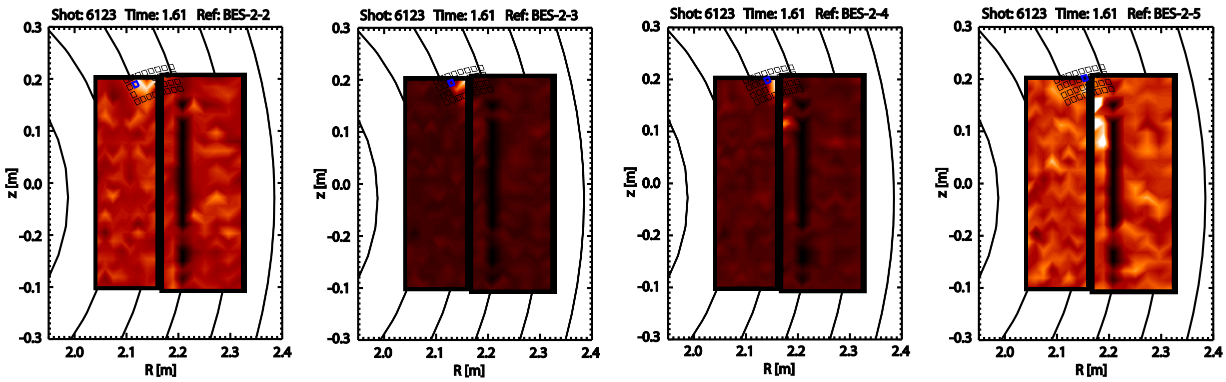

Figure 4: The correlation between BES-2-(2...5) channel and ECEi channels (lighter color indicates higher correlation, blue squares show the position of the reference BES channel)

A clearly localized correlation peak is seen in the images. Moving the reference BES channel radially, the correlation also shifts to other ECEi channels. The results show, that the correlation clearly moves with moving the reference channel, however the relative spatial coordinates of the mapped BES, and ECEi channels do not match. The error can be either in the spatial calibration of the diagnostics or the EFIT reconstruction and will be analysed further in the future. It has to be noted that at the edge plasma the ECEi diagnostic measured a mixture of electron temperature and density, therefore the above results are not directly applicable for the determination of correlation between electron density and temperature fluctuations.

Acknowledgments

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