Turbulence measurements with the combined Deuterium and Lithium Beam Emission Spectroscopy diagnostic on KSTAR

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A novel Beam Emission Spectroscopy (BES) observation system was designed, built and installed onto the Korea Superconducting Tokamak Advanced Research (KSTAR) tokamak. The system is designed in a way to be capable of measuring beam emission both from a heating Deuterium and a diagnostic Lithium beam. The system was operating during the 2012 and 2013 KSTAR campaign, which enabled us to gather information about plasma turbulence in different plasma scenarios. Several plasma perturbation techniques are available on KSTAR: Electron cyclotron heating (ECH), supersonic molecular beam injection (SMBI), resonant magnetic and perturbation (RMP). All of these are perturbing the plasma in a way, which modifies the properties of the plasma turbulence, e.g. the wavelength of the turbulent structure or its velocity. These properties were analyzed with cross-correlation and Fourier-transform techniques.

The BES system was installed on the KSTAR M-port in 2012 and it had a minor revision in 2013. The system measures density fluctuations on a 4cm by 8cm region with a 4x8 APD channel array sampled with 2Mhz sampling rate and the camera has 500kHz analogue bandwidth. Its measurement position is continuously adjustable from r/a=0.15 to r/a=1.0, while it can be adjusted vertically by $\pm 20cm$. Being a combined system, it can be switched from measuring the Doppler D_α ($\approx 656.3nm$) to the 2p-2s Lithium line ($\approx 670.8nm$), which provides the measurement of the Lithium beam installed in 2013 [1].

Analysis of turbulence during resonant magnetic perturbation

One of the ELM mitigation/suppression methods is the resonant magnetic perturbation (RMP). This uses several magnetic coils distributed evenly along the whole circumference of the tokamak. By applying difference current schemes on the coils, one can reach a state which is resonant with the magnetic field of the plasma. It was found, that this method can mitigate or even suppress the ELMs entirely [3].

The underlying physics of the perturbation are important, thus it was investigated by analyzing the turbulence properties of a dedicated RMP shot. KSTAR utilizes an RMP system capable of creating n=1 and n=2 perturbations. The chosen shot is $\approx 10s$ long, it has an RMP perturba-

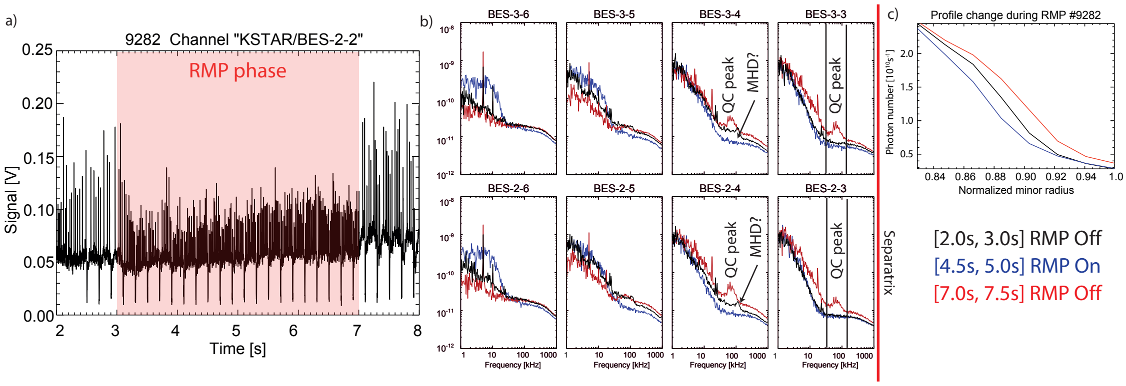

Figure 1: a) Raw signal of 9282 in the range of [2s,8s]. Red area indicated the time of the RMP, b) Calculated spectra for 8 chosen channel at the separatrix. Black shows before RMP, blue is during RMP and red is after RMP. c) BES light profile change due to RMP

tion of n=2 in the time range of $[3.0s, 7.0s]$.The plasma reached H-mode at 2s. The RMP didn't suppress the ELMs, but it increased their frequency and decreased their power (see Fig. 1a).

Three time ranges were chosen for the analysis: $[2.0s, 3.0s]$ (RMP off); $[4.5s, 5.0s]$ (RMP on); $[7.0s, 7.5s]$ (RMP off, after RMP). The analysis started with calculating the spectra for all 32 channels for the three time ranges. The ELM's were left out from the time ranges, because they create an undesired offset on the spectrum. Figure 3 shows the result of the calculation.

If one takes a look at the spectra of BES-2-4, a narrow peak at 150kHz can be seen, which could be a trace of MHD activity. The peak disappears after turning on the RMP. After the RMP turned off again, the MHD like peak does not appear, but a quasi-coherent turbulence peak can be seen. Several other time ranges were also analyzed, but the narrow peak was suppressed during the whole RMP phase. However, it is also interesting to take a look at the low frequency range: the wide range turbulence power is increased in the BES-2-6 and BES-2-7 channels towards the plasma core. One could ask whether this could came from the effect off different plasma shape (see Fig 1c), however by plotting the channels shifted, the wide range turbulence had still higher power. The analysis showed, that RMP ELM mitigation technique has an effect on plasma turbulence. To understand this effect thoroughly, further analysis is needed.

ELM dynamics and precursors

2D BES diagnostic allows high temporal resolution measurements of the structures during ELMs and their movements. Since only 4cm by 8cm of the plasma is measured with the current system, the analysis of such structures are limited. However, the propagation and expansion, contraction or other type of change of the structures are still seen on the BES measurements, eg. precursors and filaments. Two long H-mode shots were chosen for the analysis: 9163, 9421.

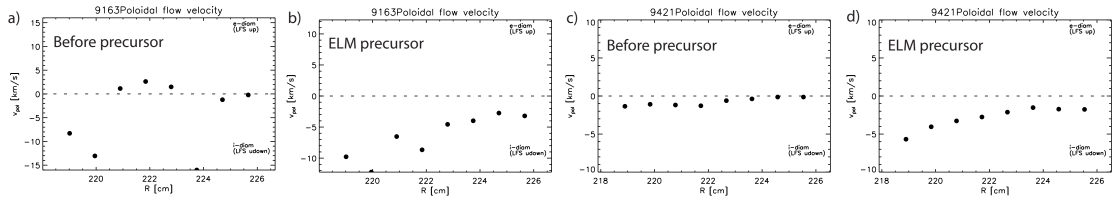

Figure 2: Cross-correlation velocity calculation for two ELMy plasma. a) #9282 before the precursor, b) #9282 during the precursor, c) #9421 before the precursor, d) #9421 during the precursor (the results are averaged over 5-6 ELM events)

Both have same NBI parameters, while 9421 was utilized with electron cyclotron current drive (ECCD). Calculating the poloidal velocity change between the so called inter ELM phase ($> 1-1.5ms$ before the ELM crash) and the precursor phase. Figure 2 depicts the results of the calculation for the two phases and the two shots.

If one takes a look at the figure, it can be seen, that the propagation direction in the scrape off layer (SOL) is in the ion diamagnetic direction, which is the same for the channels around the top of the pedestal. However for shot 9163, the propagation direction before the precursor is reversed, it is going in the electron diamagnetic direction. Several other shots were also investigated, however no trace of electron diamagnetic propagation was found in any of those shots. It can be also seen, that the propagation velocity is increased in the precursor phase inside the confined region close to the SOL.

Structures during ELMs can be depicted by taking a carefully filtered signal (in the range of $[2kHz, 100kHz]$), integrate it over several microseconds time range and take a look at subsequent frames. The movement of such structures can be clearly seen on these images. The aforementioned 9163 shot was analyzed with this technique. Figure 3 depicts six frames for a chosen ELM event.

As one can see the structures during the precursor phase are propagating to the top direction (e^- diam.), as it was seen on the velocity calculation. However at the start of the ELM, a sheared flow can be seen, where $\approx 3cm$ structures are propagating the ion diamagnetic direction outside the separatrix, but next to the separatrix the structures are going in the e^- diamagnetic direction. By plotting other ELM events, one could see filament like structures, which connected the SOL and the pedestal region during the ELM. During the next KSTAR campaign, the 4x16 APD detector array will allow us unfolding these structures in more detail.

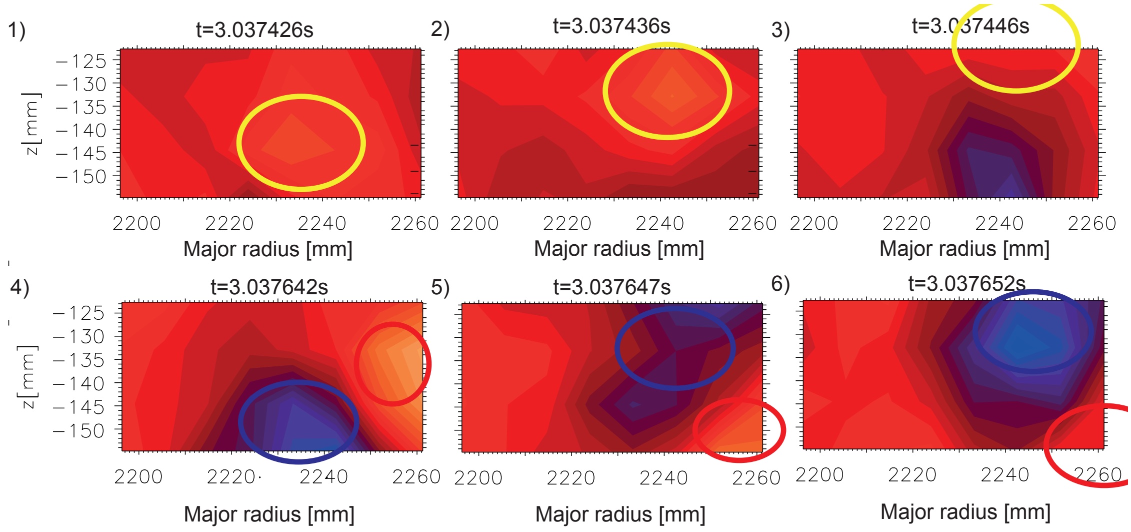

Figure 3: Time frames of one ELM event at #9163 1)-3): ELM precursor phase e^- diam. propagation 4)-6): Sheared flow during ELM phase.

Summary

RMP is a feasible technique for ELM mitigation and suppression. The magnetic perturbation perturbs the plasma in a way, that its turbulence properties are changed. This effect was investigated with the KSTAR BES diagnostic on a dedicated RMP shot. It was found, that RMP does indeed modify the plasma turbulence, which can be seen also on the suppression of the quasi-coherent turbulence in the range of [40kHz,150kHz]. However, the use of RMP results in an increased wide range turbulence below 40kHz. The poloidal flow disappears completely in the RMP range due to the suppression of turbulence, however it reappears after the RMP more intensely then before it. The cause of these effects needs to be investigated thoroughly. Edge localized modes were investigated with BES measurements. Precursors were found 1ms before the ELM events and their movements were analyzed. It was found, that both ion and electron diamagnetic propagation is present, but the latter was only seen in one shot. Interesting filament like structures were found during time trace analysis of the ELMs, which can play a significant role during the ELM phenomena.

References

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