Plasma edge current fluctuation measurements during the ELM cycle with the atomic beam probe at COMPASS

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Introduction

The evolution of the edge plasma current in magnetically confined plasmas is identified as a critical parameter of Edge Localized Mode (ELM) destabilization. While the plasma pressure gradient, the other critical parameter, is routinely measured with high spatial and temporal resolution on fusion experiments, the plasma edge current measurement capabilities are limited. The Atomic Beam Probe (ABP [1][2]) is an extension of the widely used Alkali atomic beam emission spectroscopy diagnostic [3] offering a novel solution for plasma edge current measurement. The atomic beam, which is injected into the plasma, is ionized due to the collisions with the plasma particles. The ions originating from the beam follow a curved path in the magnetic field and might hit the wall of the machine as shown in Figure 1. The toroidal impact location and the number of ions carry information about the toroidal plasma current distribution, the density profile and the electric potential in the plasma. The ABP diagnostic was tested and measurements were carried out at COMPASS tokamak [4]. Along with experimental work, extensive ion orbit modelling efforts have been made in order to interpret the results. This paper presents first experimental results, demonstrating the linear response of the detector to current changes and the ion distribution movement during the ELM cycle, along with parallel fast density and current fluctuation measurements, emphasizing the unique capabilities of the combined BES and ABP diagnostic.

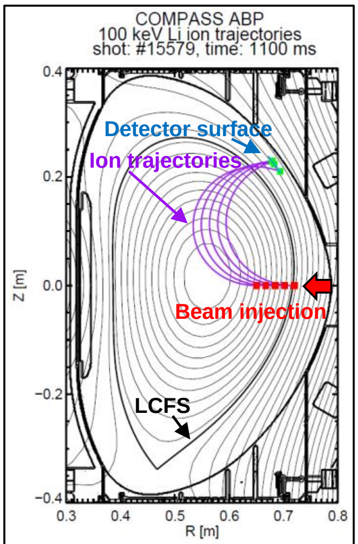

Figure 1: 100 keV Lithium ion beam trajectories (solid purple rectangles), ionization location (red rectangles), detector location (solid blue line), detector plane impact location (green circles).

System characterization at COMPASS

The main aim of the measurement series was to participate in the physics program, namely the ELMy H-mode experiments in order to characterize the effect of the inter ELM current changes. In order to make physically relevant measurements, the operation of the novel diagnostic had to be understood through test measurements. The detector consists of a 5x10 (vertical x toroidal) matrix of 2x5 mm Faraday Cups (FC) [2] as shown in Fig.3. After the successful tests, the diagnostic was operated during plasma discharges, and the signal, background and noise levels in the FCs were characterized. Only 20 channels out of 50 (see Figure 3) were measuring due to the 20 channel amplifier. The typical signal level from the ion beam on one pixel (1.2 mm x 3.6 mm) of the micro FC matrix detector is 1 – 3 μA for full beam width, while it is in the range of 100 nA in case of a 5 mm beam reducer is applied. The background from plasma can be in the μA range, especially due to ELM filaments, thus the background has to be subtracted which is carried out by chopping the beam up to 100 kHz. The signal to electronic noise ratio during a plasma discharge is in the 1-10 range on the 1 MHz bandwidth, thus the effective time resolution is 10-100 μs. Measurements were carried out with 1-2 mA lithium and sodium beam, beam modulation frequency up to 100 kHz, beam size reduction to 5 mm (beam current reduced to 50 μA), with various scenarios (B_T = 1 - 1.38 T, I_p = 150 - 300 kA).

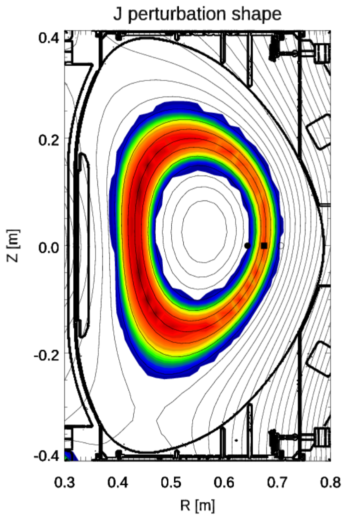

Figure 2: Current perturbation shape in the simulation. The 3 points on the LFS mid-plane show the boundaries of the perturbation.

ABP simulations

A computer simulation code (TAIGA) was applied which calculates the ion trajectories in a given magnetic geometry of the COMPASS discharge. Another code written in IDL runs the ion trajectory calculation by starting sample ions on a 3D mesh along the neutral beam. Using these ion trajectories the code determines the ion distribution at the detector plane as well as the current on each detector segment. Additionally a toroidal current perturbation can be added to the plasma equilibrium which follows flux contours as shown in Figure 2.

To be able to interpret fluctuation data, the modelling and the measurement has to be matched spatially. This is necessary since the beam line position is slightly adjustable, and the beam injection angle is not known precisely. The ion distribution is modelled at the plane of the detector for a whole discharge with 10 ms time resolution, then a virtual detector array is pushed stepwise along all possible positions on the plane. $A_{i,j}(t_k)$ and $B_{i,j}(t_k)$ are the modelled and the measured FC cup currents, respectively, where i,j are the position, k is the time index. The best match between the measured and the modelled distribution is given by the minimization of $L_{p,r} = \frac{\sum_{i,j,k} A_{i+p,j+r}(t_k) B_{i,j}(t_k)}{\sum_{i,j,k} \| A_{i+p,j+r}(t_k) \|}$. The modelled ion beam distribution for shot #17747 can be seen in Figure 3 along with the detector matrix at the best fitting position.

Row 2 of the detectors are highlighted since the measured data in Figure 4 (a) is from that array. Applying different amplitude, 5 cm wide perturbations stepwise on an equilibrium magnetic configuration, taken 1 ms prior to an ELM, knowing the detector position from the previous method the ion distribution on the detector can be calculated. The displacement sensitivity for a current perturbation can be determined from the movement of the distributions peak position and turns out to be 0.08 mm/kA.

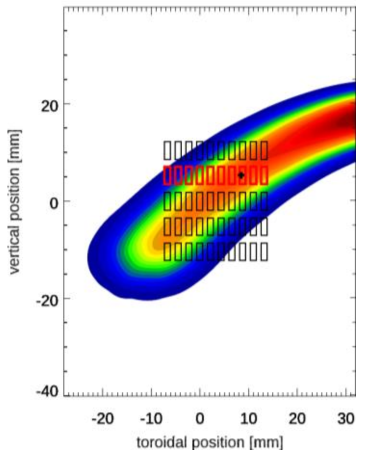

Figure 3: Modelled ion beam distribution at the detector plane with the 5 x 10 channel detector matrix, aligned best to shot #17747 data.

Current perturbation measurement

COMPASS discharge #17747 was a standard H-mode (230 kA, 1.38 T), NBI heated, lower single-null, diverted plasma. The 60 keV sodium beam was not reduced, the beam diameter was 25 mm, and 100 kHz chopping was applied. The background subtracted ABP signal for each detector row and time instance was fitted with a parabola, giving the ion distribution maxima's time evolution as can be seen in Figure 4 (a). The ABP signal response for the plasma current ramp-up can be quantified by fitting the ABP maxima position as a function of the total plasma current, and was found 0.2 mm/kA.

The inter ELM current perturbations are characterized in a conditionally averaged sense, presuming that the beam position movement is proportional to the current changes, as was seen in the simulations. 4 large ELMs were selected as can be seen in Figure 4 (b), with a cycle time of about 5 ms. The beam position offsets were matched in a 1 ms long window before the ELMs since the beam position can have an offset due to changes of the magnetic equilibrium, that is why the average peak position is 0 prior to the ELM. The plasma current perturbation increases until the ELM as can be seen in Figure 5, and the

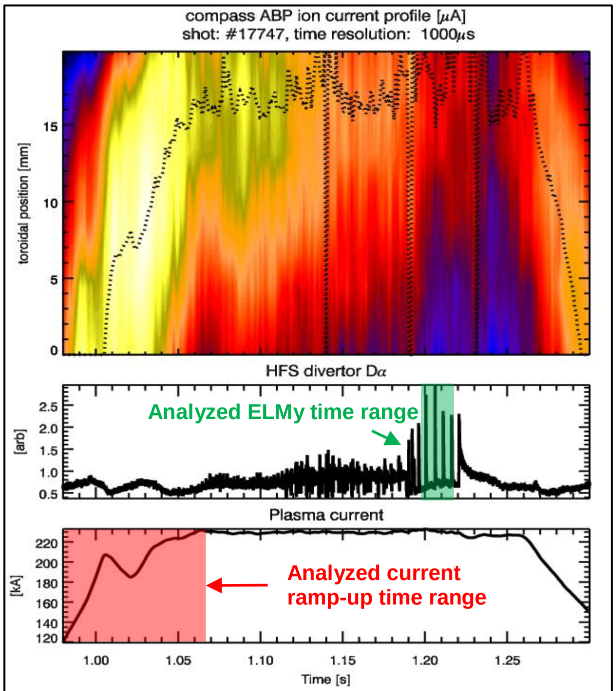

Figure 4: Ion beam distribution on a row of the ABP detector array (a) with the fitted maximum positions (dotted line), HFS divertor D_α (b) and plasma current (c) signals as a reference.

change is about 12.5 kA (1 mm) according to the fluctuation sensitivity from the modelling. The cause of the large position changes during the ELM is being investigated. COMPASS discharge #17178 was an Ohmic heated H-mode (160 kA, 1.04 T), lower single-null, diverted plasma. The 80 keV lithium beam was not reduced, the beam diameter was 25 mm, and 10 kHz chopping was applied. The fast Li-BES system was in operation, thus parallel density and current perturbation measurements were carried out. The density pedestal was fitted with a tangent hyperbolic, providing the time evolution of the pedestal gradient. Figure 6 shows that the current perturbation increases until the ELM, while the density pedestal recovers in 500 µs after the ELM crash, and stays constant at its maxima at least 1 ms prior to the ELM.

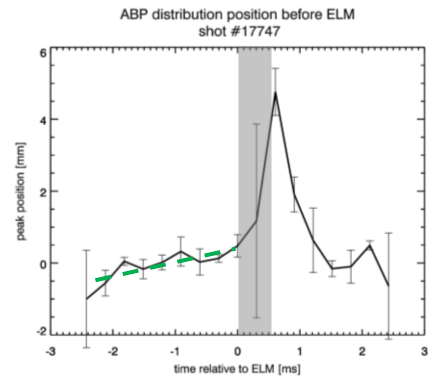

Figure 5: ion beam position as a function of time relative to the ELM. The high background blinds the detector for 0.5 ms (grey rectangle). The current increases until the ELM crash.

Summary and outlook

The ABP diagnostic has been commissioned at COMPASS and measurements have been carried out in standard ELMy H-mode scenarios. The systematic changes in the ion beam position prior to ELMs show the sensitivity of the diagnostic which may be caused by ~10 kA plasma edge current perturbation, however, the plasma potential and other plasma parameter changes cannot be excluded. A 50 channel amplifier is being built which will enable measurements with the full 5x10 channel FC matrix detector.

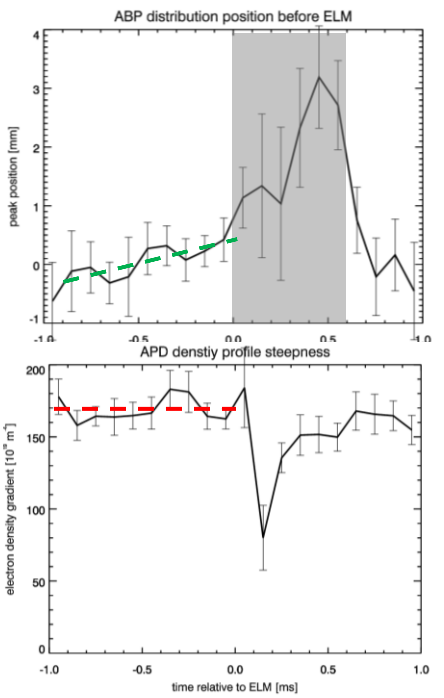

Figure 6: ion beam position and density pedestal gradient as a function of time relative to the ELM. The current increases until the ELM crash, while the density recovers earlier.

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