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ELM synchronized Thomson scattering measurements on ASDEX Upgrade

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Introduction

The Thomson scattering (TS) system on ASDEX Upgrade [1] provides fast measurements of electron density n_e and temperature T_e profiles, obtained with high spatial resolution at the low field side of the plasma edge. The measured profiles can be used for analysis of perturbations of the pedestal region near and inside the last closed flux surface (LCFS) caused by type-I edge-localized modes (ELMs) [2]. Still, fast quasi repetitive events like ELMs, appearing approximately every 5 to $20ms$ and causing perturbations of the edge profiles lasting about $1ms$, cannot be easily diagnosed by the $20Hz$ measurements provided by the repetition rate of the Nd:YAG lasers used for Thomson scattering.

In order to provide a larger data basis for analysis of ELM influenced Thomson scattering profiles, an event trigger (ET) which initiates the laser shots and increases the number of measurements during ELMs has been developed.

The event trigger concept

For ELM detection, the plasma light measured by the DC channel of the avalanche photodiodes of the Thomson scattering detection system is used. The major part of the detected light is bremsstrahlung emission.

The signal is processed with a digital signal processor (DSP) loaded with a program which detects ELMs (by an algorithm for peak detection) and sends a trigger signal when an ELM is expected. Direct triggering at ELM onset is insufficient because of a delay between the ET and the measuring time, which corresponds to at least the time distance between the flash lamp trigger of the laser and the Q-switch opening of about $200\mu s$. Therefore the time of the next ELM has to be predicted from several previous ELMs and the ET is sent from the DSP taking the delay into account.

For the prediction of the ELM time the quasi regularity of the ELM events is exploited, assuming that during the periods of the plasma discharge with the constant parameters the ELM frequency does not change significantly. The time of the next ELM onset is calculated by adding the average ELM period to the time of the previous ELM onset: $t_{i+1} = t_i + T$. The average period is calculated from the time distances T_i between consecutive previous ELMs: $T = 1/N \sum_{i=1}^{N} T_i$, as long as the most recent ELM period is within 30% of the average value, $|T_i - T| \leq 0.3 \cdot T$. If the discrepancy is larger than 30% then the average period is set to the most recent ELM period $T = T_i$ and the summing average re-starts.

To test this algorithm for ELM time prediction, the difference between the real ELM time and the calculated time is determined for 30 phases of different plasma discharges lasting from 0.5 to $2s$. In fig. 1 the distribution of those time differences for one phase is shown. In a $\pm 4ms$ interval around calculated value, as presented in fig. 1, there is usually 65 to 90% of all processed ELMs.

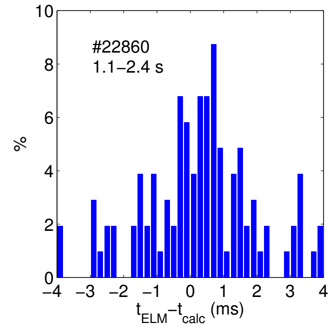

Figure 1: *Typical distribution of differences between measured and predicted ELM times.*

Since the main idea is to measure the n_e and T_e profiles from the very beginning of the ELM cycle ELM time prediction with high precision is needed, and only the narrow central part of distribution in fig. 1 is valuable. In fig. 2 the percentage of all processed ELMs which is within 0.3 and $0.6ms$ of the calculated time for different average ELM periods is shown. The predictability is variable for different parts of the processed discharges, showing no clear dependency upon average ELM period.

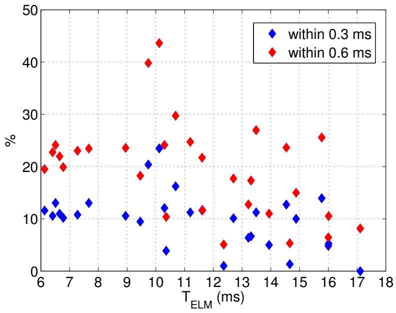

Figure 2: *Percent of ELMs within* $0.3ms$ *or* $0.6ms$ *of the calculated time vs. average ELM period.*

Within $0.6ms$ there is usually $15 - 30\%$ of all ELMs. Within the narrower interval of $0.3ms$ around the calculated time, a smaller number of ELMs is found varying about 10%. This analysis of ELM time predictability proves that the proposed algorithm can be usefully applied as the ET increases the number of measurements in a small interval around ELM onset time.

The laser operation has to be kept stable all the times and since the ET appears with approximately the ELM frequency, reaching up to $200Hz$ in the analyzed cases, it has to be filtered down to a frequency close to the $20Hz$ which is acceptable for applied Nd:YAG lasers. This is performed in the ET module which transmits about 50 to 80% of triggers at calculated times, depending on the ELM frequency, other laser shots are triggered with regular laser trigger.

Results

The results of the ET application are presented in fig.3. The percentage of laser shots during ELMs obtained with the ET operation is compared with the percentage of regular laser shots which would have been during an ELM if the ET had not been used and the lasers were fired with a regular $20Hz$. For the ELM time the interval beginning $0.2ms$ before and ending $0.8ms$ after ELM onset is taken. This is approximately the time where the influence on the edge profiles is observable.

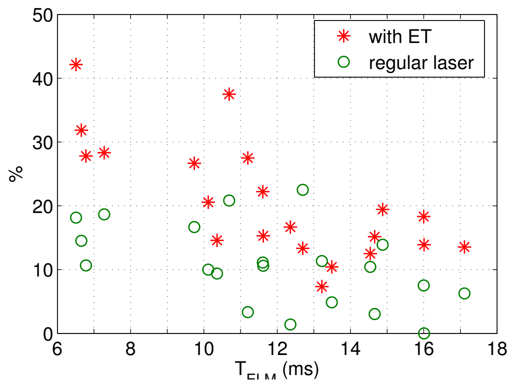

Figure 3: *Percentage of laser shots triggered by ET and percentage of regular laser shots which are during an ELM vs. average ELM period.*

In fig.3 it is obvious that except in two from twenty processed cases the number of measurements during an ELM is increased when ET is applied. The percent of measurements is increased from below 20 to about 30% for smaller ELM periods, where the chance to meet fast ELMs by chance is larger. For longer ELM periods the probability to measure during an ELM with regular laser shots is smaller, about 10%, and it can be increased with ET application to $15-20\%$.

The first application of the improved TS data statistics for ELM measurements is the investigation of possible deviations from the Maxwellian distribution caused by ELMs. As the measure of agreement between electron temperature data obtained with TS and the assumed Maxwellian distribution of electron velocities we can use the χ^2 function which is included in TS data evaluation procedure [3]. This function presents the difference between measured signal intensities and the intensities expected from the theory, where a Maxwellian distribution is included. The values of χ^2 during ELMs are compared with values during quiescent phase in between ELMs and also with theoretically ex-

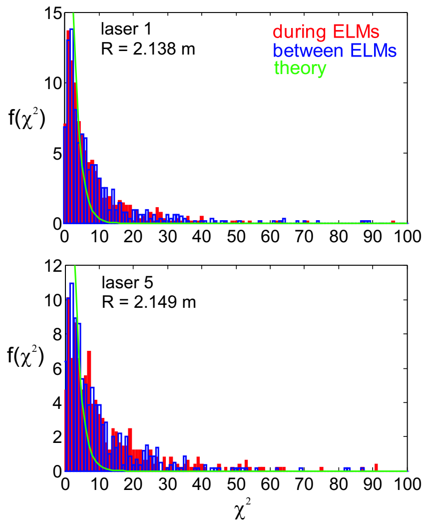

Figure 4: *Distribution of χ^2 values during ELMs - red, in between ELMs - blue and theoretically predicted - green line.*

pected values for χ^2 with two degrees of freedom. It appears that in both cases - ELM and inter ELM, there is large discrepancy from the theoretically predicted distribution (fig.4), the measured distributions are broader with additional outliers.

The reason for the similar behavior during ELM and inter ELM phases is thought to be inter ELM fluctuations which are causing perpendicular particle transport and have been recently investigated also with TS system on ASDEX Upgrade [4]. In any case this large deviation from theoretical distribution will be examined further using residuals of χ^2 function. This analysis should prove if the discrepancies show any tendency in one direction for certain temperature ranges.

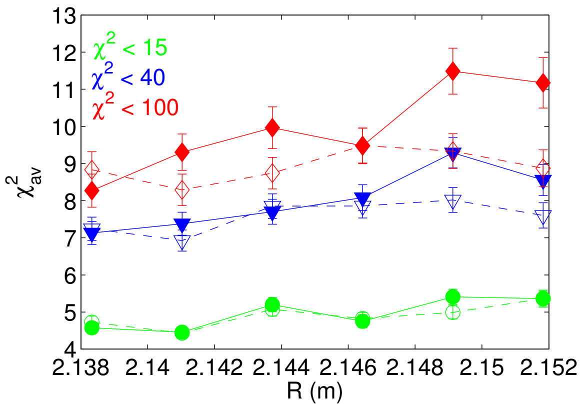

Figure 5: *The moments (average values and their standard deviations) of different parts of χ^2 distributions presented in fig.4 for data obtained with six radially distributed lasers. Full symbols - during ELMs, open symbols - in between ELMs.*

The differences in χ^2 distributions during and in between ELMs are not easily observable. Still, there are some differences for higher χ^2 values (outside the expected distribution) especially with data measured by the two lasers which are measuring the edge plasma in the outermost radial positions fig. 4- 5. This implies that as the next step a detailed spatial analysis of collected data has to be performed.

Conclusions

Although only about $15-30\%$ of ELM times can be predicted from the average ELM period within a useful time interval and only a fraction of the event triggers is applied for laser triggering this scheme still increases the number of TS measurements during ELMs.

The investigation of deviations from the Maxwellian distribution during ELMs is in progress.

References

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