Toroidal asymmetry of divertor heat deposition during the ELM and 3-D field application in NSTX

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Non-axisymmetric divertor heat and particle depositions often occur in tokamaks for various reasons; these can occur either for steady imposed perturbations or from transient events, and such 3-D asymmetries will make divertor heat flux management more challenging in ITER and next step devices. It is found in NSTX that asymmetries in the toroidal distribution of peak heat flux (q_{peak}) and heat flux width (λ_q) become largest at the peak of ELM heat flux; the higher the peak heat flux, the stronger the degree of asymmetry. This can pose a serious challenge to the tile design and cooling requirement in future machines as they are usually based on a 2-D axisymmetric calculation.

NSTX has investigated divertor heat flux profiles in 2-D plane for the first time, by implementing and improving a 3-D heat conduction solver ("TACO") [1,2]. The 2-D heat flux data calculated by TACO allowed for the evaluation of toroidal arrays of peak heat flux (q_{peak}) and its width (λ_q), with each array representing toroidally distributed data for the corresponding radial location. This was achieved by re-mapping the (x,y) coordinate of the 2-D data to the r and Φ. Then the toroidal asymmetry of q_{peak} and λ_q at each radial location was quantified by taking standard deviation (σ) of q_{peak} and λ_q over data in each toroidal array. In order to compare changes in asymmetries for multiple ELM periods, σ_{qpeak} and $\sigma_{\lambda q}$ were normalized by the mean values of q_{peak} and λ_q. In case of ELMs and 3-D field application, the helical heat deposition naturally produces scatter of data around mean values and the fractional σ_{qpeak} and $\sigma_{\lambda q}$ can be interpreted as the degree of toroidal asymmetry of each quantity.

Figure 1 shows the result for type-I ELMy H-mode, color-coded during the ELM cycle, across several ELMs. It is found that both σ_{qpeak} and $\sigma_{\lambda q}$ become largest at the ELM peak times and fractional σ_{qpeak} can be as high as ~1.4 while

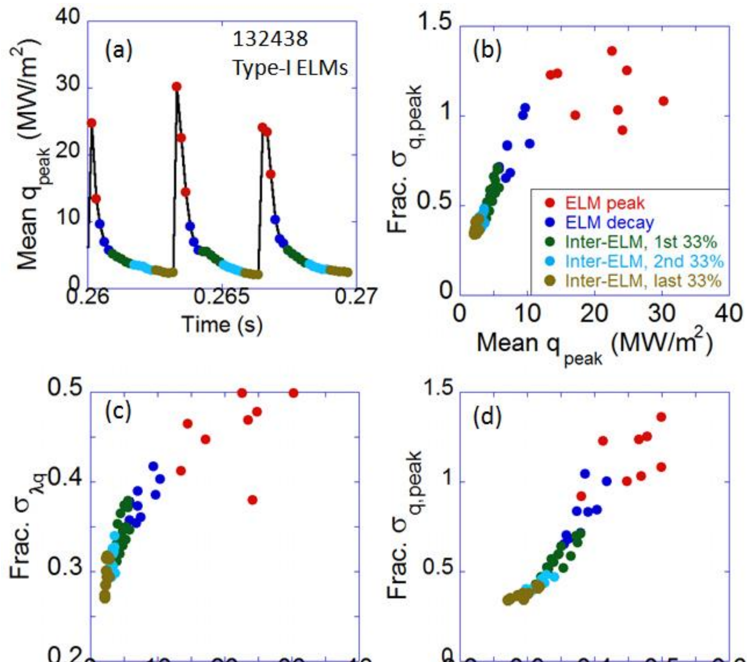

Fig.1 (a) Temporal evolution of measured peak heat flux (q_{peak}) during a type-I ELMy H-mode. (b) Fractional σ_{qpeak} and (c) Fractional $\sigma_{\lambda q}$ as a function of q_{peak}. (d) Relation between toroidal asymmetries of λ_q and q_{peak}. Standard deviation (σ) of λ_q and q_{peak} is divided by mean values of each quantity to make σ a fractional value. The toroidal asymmetry of q_{peak} and λ_q at each radius is quantified as the fractional σ of λ_q and q_{peak} over values at multiple toroidal angles. Data for each of the 1/3 of the ELM cycle have been colored green, sky blue, and gold, respectively.

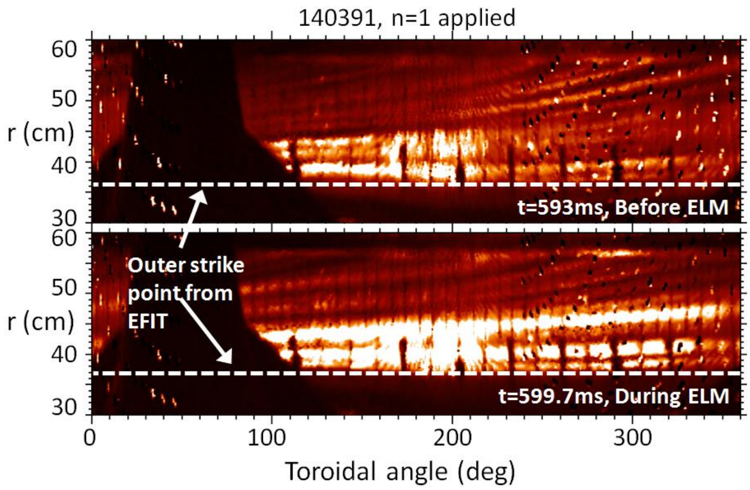

Fig.2 Images of wide angle visible camera for lower divertor plates using a LiI filter (λ=670.9nm) during the n=1 3-D fields application. The upper image is before the ELM and the lower one is during the ELM triggered by n=1 magnetic perturbation. The images are remapped from (x,y) to (r,ϕ) coordinate. The dark portion on the left hand side represents the center column. The light intensity for the ELM case (lower image) was reduced for clearer comparison.

fractional $\sigma_{\lambda q}$ can reach up to ~0.5 for the dataset examined in figure 1. Both fractional σ_{qpeak} and $\sigma_{\lambda q}$ increase with increasing q_{peak} and therefore the degree of asymmetric heat deposition is highest at the ELM peak times, while it becomes lower toward the later stage of the inter-ELM period (see figures 1(b) and 1(c)). This dependence of the degree of asymmetric heat deposition on the ELM cycle is also related to the absolute value of peak heat flux. That is, higher peak heat flux leads to stronger degree of asymmetric q_{peak} and λ_q. It is also found from figure 1(d) that the correlation between fractional σ_{qpeak} and fractional $\sigma_{\lambda q}$ is the strongest at the ELM peak times and becomes weaker later in the ELM cycle.

A wide angle, 2-D fast visible camera with capability of viewing nearly full divertor surface [3] is being used to study the toroidal and radial structure of the divertor flux profile. The immediate application of this new technique is the study of 3-D divertor structure induced by the intrinsic and applied 3-D fields [4,5]. Another application is for the study of ELMs, because they naturally produce helical filaments resulting in non-axisymmetric deposition. The 2-D data is also remapped to the (r,Φ) plane and facilitates the comparison with modeling, *e.g.* from field line tracing and for mode number identification, *etc*. The strike point splitting pattern in the 2-D plane during the n=1 and n=3 field application agrees well with the vacuum field line tracing. The divertor heat flux profile during the ELMs triggered by the applied 3-D fields are found to have the same spatial structure (in both r and Φ directions) as that for the profile during the inter-ELM period in the presence of applied 3-D fields, *i.e.* the ELMs are phase-locked to the imposed field structure. Figure 2 shows that the strike point splitting viewed from the wide angle visible camera during the n=1 3-D field application is very similar for cases before and during the triggered ELM. The toroidal asymmetry of radial heat flux profile is evident from figure 2 and the measured IR heat flux profiles at multiple toroidal locations, which was achieved by toroidally rotating the applied n=1 perturbation relative to the IR camera location, also confirmed this asymmetry.

Data for the intrinsic and applied 3-D fields as well as for the triggered and natural ELM filaments from different ELM types have been obtained, and first results from a 3-D edge transport code, EMC3-Eirene, show that the observed asymmetric divertor flux is qualitatively reproduced [6]. This work was supported by the US Department of Energy, contract numbers DE-AC05-00OR22725, DE-AC02-09CH11466, and DE-AC52-07NA27344.

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