

ANALYSIS OF POWER DEPOSITION IN JET MKIIGB DIVERTOR BY IR-THERMOGRAPHY

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INTRODUCTION

One of the unsolved problems for a next step fusion device is the handling of the power fluxes into the divertor in particular with respect to the short off-normal heat deposition by Edge Localized Modes (ELMs) [1]. For a next step fusion device as ITER Type-I ELMy H-Mode is the reference discharge and therefore of particular interest here [2]. At JET a thermography system with high time resolution is used capable to resolve temperature evolutions in inter-ELM and ELM periods. In this work results about the distribution of ELM and inter-ELM power deposition on the inner and outer divertor target plates, characteristic temperature rise times and derived maximum heat fluxes taking influences from surface layers on the target tiles into account are presented.

TEMPERATURE MEASUREMENTS AND HEAT FLUX CALCULATION

The 2D IR-system is equipped with a periscope optic for a survey of the (compared to the former MKIIa divertor) relatively closed MKIIGB Gas Box divertor. The IR-Camera is sensitive to photons in the wavelength range from 3-5 μm , which allows the calculation of the divertor surface temperatures assuming Planck's law for black body radiation (and neglecting further radiation for instance by molecules) with a time resolution of up to 21 μs . A set of ELMy H-Mode discharges with an IR-optimised strike zone position have been performed. The transformation procedure developed to interpret the periscope view was used to deduce poloidal profiles of the temperature distribution on the target tiles [3]. Significant differences between the temperature evolution of the target surface in the inner and outer divertor chamber (split by the septum of MKIIGB) were observed in deuterium discharges. The temperature changes step like with heating power at the inner leg. Whereas an increase with the square root of time was found in the outer leg. Such effects, devoted to a change of the surface properties, have been already reported from several machines like ASDEX-Upgrade [4], TEXTOR-94 [5] as well as from JET [6]. Discharges in Helium (~40 discharges have been run between

the observed changes) removes the step like behaviour. A method to calculate the heat flux deposition within defined error bars from the temperature evolution even with these surface layers is the introduction of a heat transmission coefficient in the heat flux calculation as done with the THEODOR code [4]. The deposited energy calculated with this method and derived by thermocouple measurements is in good agreement. The global energy balance of heated, deposited and radiated energy is matched within error bars of 10-20%.

ENERGY DISTRIBUTION IN H-MODE DISCHARGES:

For the distinction between energy deposition during ELMs and in between ELMs the method of a pulse height analysis is used. In figure 1 two H-Mode discharges are shown in that respect (#53764, $P_{\text{NBI}}=9\text{MW}$, $q_{95}=6$ & #53765, $P_{\text{NBI}}=16\text{MW}$, $q_{95}=3$) both with Type-I ELMs. In pulse #53764 the inner and the outer divertor is attached whereas in pulse #53765 the inner divertor is partly detached. An overview for the energy balance of both discharges is given in table 1. The energy deposition due to ELMs in both discharge is fairly balanced, whereas the Inter-ELM energy deposition is governed by the outer divertor (with a large fraction if the inner divertor is highly detached). The balanced energy deposition during ELMs found by thermography and calorimetry (TC) [8] is different from results of other machines. At ASDEX-Upgrade [7] an in/out ratio of 2/1 is found during ELMs [7].

#53764				#53765			
Inner (tile #2)		Outer (tile #7)		Inner (tile #2)		Outer (tile #7)	
21 MJ (TC: 16MJ)		31MJ (TC: 33MJ)		25MJ (TC: 24 MJ)		80MJ (TC: 80 MJ)	
Inter ELM	ELM	Inter ELM	ELM	Inter ELM	ELM	Inter ELM	ELM
12MJ	9MJ	21MJ	10MJ	7MJ	18MJ	55MJ	25MJ

Table 1: Energy distribution for two H-Mode discharges derived by IR-measurements. The derived values by Thermocouples measurements (TC) are presented for comparison.

CHARACTERISTIC ELM RISE-TIME

An important aspect of the mechanism that governs the power release to the target plates and its consequences for a larger fusion device like ITER is the characteristic time of SOL energy transport by ELMs [2]. The time the temperature rises from 10% to 90% of the peak temperature during the ELM serves as a characteristic time for a first analysis. More detailed studies using the derived power deposition by numerical modelling are in progress but need a careful estimation of error bars due to the mentioned influences by surface layers. However, in figure 2 temperature evolution of a coherent averaged ELM (calculated by a software tool for probe data [9]) from 15 Type-I ELMs in a time window of about one second in discharge #53765 is shown. Here, the rise time of the temperature amounts to about 400 μs . This value for Type-I ELM times is in the same range as reported for DIII-D and ASDEX Upgrade [10]. Nevertheless, it is important to note, that in various discharges a span from 100 μs in an RF-heated H-Mode (#51915) up to 800 μs in an H-Mode with a pure Helium plasma (#54158) has

been found covering also ELM temperature rise times reported from JET MKIIa divertor [11]. Note, that the parameters determining these times are not known and that therefore the characterization of the discharges as RF-heated or pure Helium are of arbitrary nature.

MAXIMUM HEAT FLUX WITHIN TYPE-I ELMs

The calculation of the maximum heat flux by THEODOR modelling results for the Type-I ELMs in #53765 to 220MW/m² but must be complemented with error bars to the not fully known properties of the surface layers. Reasonable approximations for upper and lower limits serving as error bars are given next. For an upper limit it is assumed, that the whole energy coming with an ELM arrives balanced within the characteristic time. A peaking factor reflecting a non balanced energy deposition has a linear effect on the derived value. From IR-measurements it is found:

- a) The characteristic Type-I ELM time (in #53765) is $\sim 400 \mu\text{s}$
- b) The profiles do show a broadening in the range of 50% (e-folding length = 37mm)
- c) The energy deposited during the Type-I ELM (in #53765) is about 200kJ

With these values we get a maximum heat flux of, $q_{\text{max}} = 200\text{kJ}/0.6\text{m}^2/400\mu\text{s} = 833\text{MW}/\text{m}^2$ corresponding to $17\text{MJ}/\text{m}^2/\text{s}^{1/2}$. It should be noted, that the derived value for an upper limit can be increased in other discharges due to larger energies or shorter deposition times. A lower limit can be found by assuming that the whole energy arrives within the duration of an ELM, $t_{\text{ELM}} = 2\text{ms}$. The latter time is defined by edge condition method of the THEODOR code. Then a q_{max} of $200\text{kJ}/0.6\text{m}^2/2\text{ms} = 166\text{MW}/\text{m}^2$ is found ($5\text{MJ}/\text{m}^2/\text{s}^{1/2}$). Therefor we get a value of 220MW/m² with large but reasonable errorbars in particular to higher values.

SUMMARY

Using a fast 2D IR system at JET MKIIIGB divertor ELMy H-Mode discharges have been investigated in particular focussing so far on SOL transport by ELMs. Influences of surface layers have been taken into account using the THEODOR code for heat flux calculations. It is found, that the energy deposition on the inner and outer divertor is fairly balanced whereas the Inter-ELM deposition is governed by the outer divertor. A characteristic rise time for Type-I ELMs is given as 400 μs for the analysed ELMy H-Mode discharge, but a wide span of such characteristic times in various discharges have been seen. An upper and lower limit for the maximum heat flux can be derived for particular discharges for single Type-I ELMs and are in the range of $q_{\text{max}} = 166\text{MW}/\text{m}^2$ -833MW/m².

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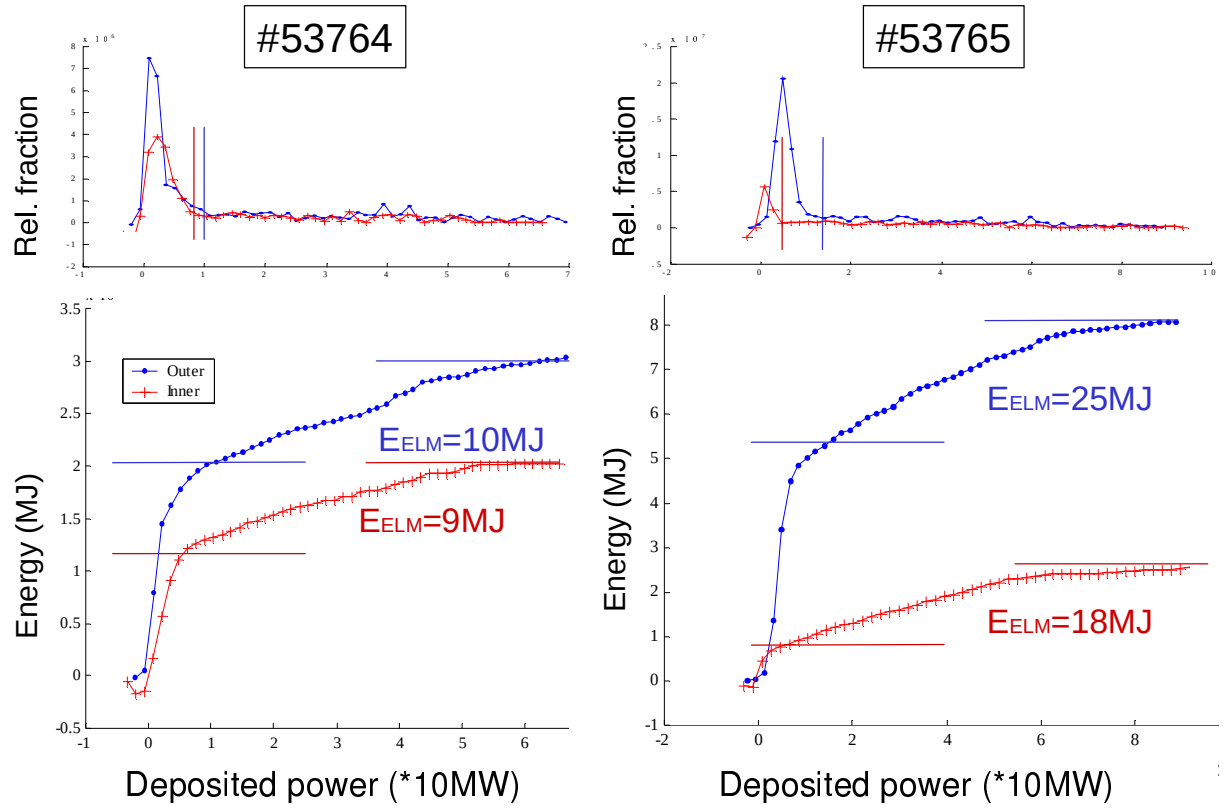


Figure 1: Pulse height analysis of power deposition calculated with THEODOR-code allows a separation of the ELM and inter-ELM fraction. The power deposition due to Type-I ELMs on the Inner and Outer divertor appears to be balanced and favours the Outer (with a factor of 2-3.5) in the Inter-ELM period.

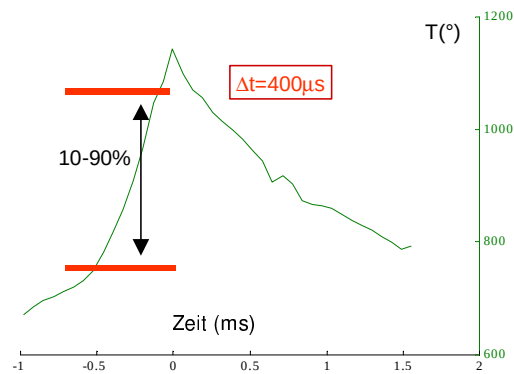


Figure 2: 15 Type-I ELMs in a time window of one second in discharges #53765 are summarized to a coherent averaged Type-I ELM. The characteristic rise time of the temperature amounts to $400\mu s$.