Power Deposition on the Lithium Limiter During the Major Disruption and Locked Mode in T-11M Tokamak

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Introduction

It is generally accepted now, that the divertor plates of a future tokamak-reactor will be subjected to multiple (up to 10^6 cycles) severe pulse heat loadings (up to 0.2…1 MJ/m^2 with 1…10 kHz cycle rate) during the development of plasma ELM activity. Therefore the technical realization of a proper heat sink system faces a number of certain difficulties. The Li-filled capillary porous assembly seems to be one of the most promising solutions [1]. The lithium rail limiter of the T-11M tokamak [2] could be regarded as a first prototype of such a divertor, since its heat loading during disruptions (0.1…0.2 MJ/m^2) approaches the level corresponding to an ELM-induced one. The study of Li limiter behavior during the disruptions initiated by the development of a locked mode (LM) was the primary purpose of current work.

Experimental

Experiments were performed on the tokamak T-11M [3,4] with R=0.7m, a=0.2m, B_T =1T, Ip=70…100 kA. Multichannel radiation losses measuring system (MRLMS) with 15 (5x3 cm^2) channels - Fig.1 [5]. An absolute extreme UV (AXUV) photodetectors used in this system could be regarded as electromagnetic radiation bolometers in 1…5000 eV photon energy range, with high temporal resolution (~ 2 μs). The tangential direction (touching toroidal axis) of the detector field-of-view (FOV) with vertical orientation of FOV plane have been chosen, contrary to traditional poloidal directions of view chords. It provides an opportunity to watch the vertical diameter chord of poloidal plane, in the vicinity of Li limiter installed at the bottom of the vessel, being the main source of impurities during the disruptions. This view geometry eliminates the necessity of Abel inversion procedure, being the main source of errors in the absence of cylinder symmetry of UV-radiation. The variations of power deposition were monitored by the liquid nitrogen cooled Ge:Au IR photodetector watching the Li limiter surface (Fig.1). To study MHD fluctuations, 2 circular B_θ - magnetic probe arrays were installed in two poloidal cross-sections. They were used to recover the details of helical structure of MHD perturbations in the vicinity of Li limiter.

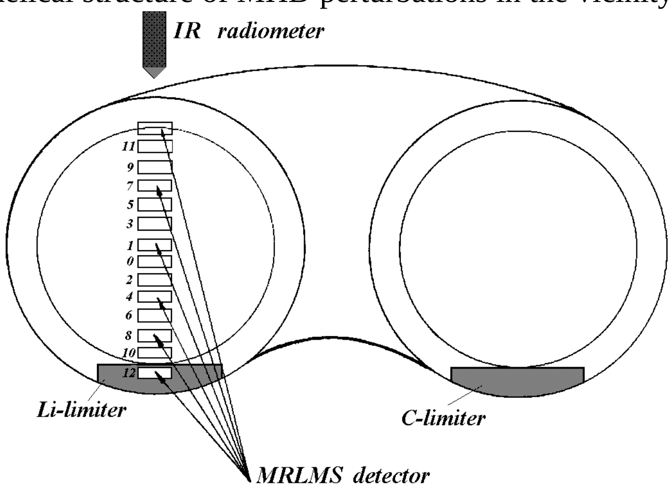

Fig. 1. FOV geometry of MRLMS detector and IR radiometer. Li or C – limiters.

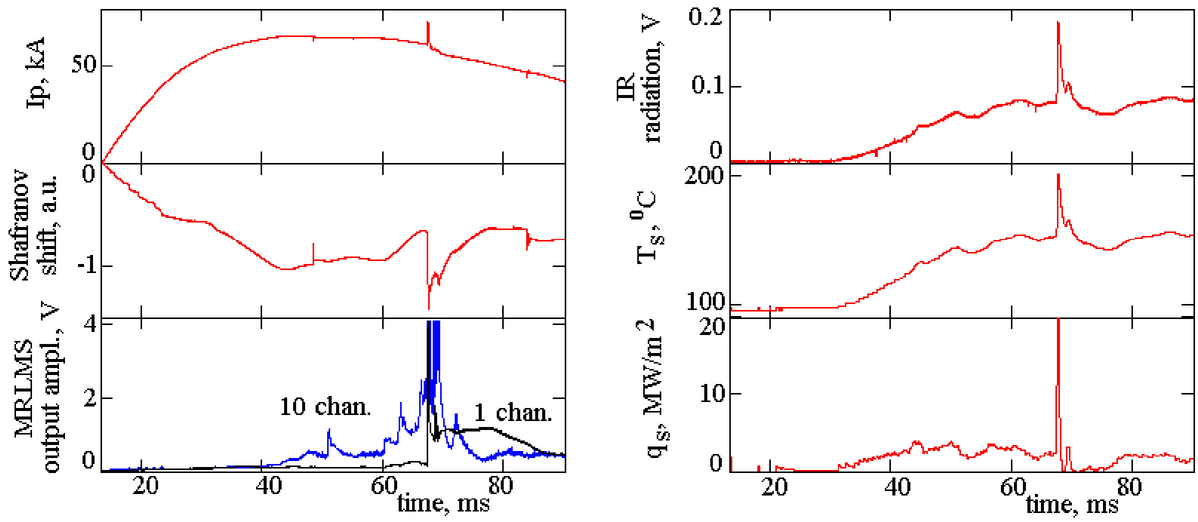

Fig.2. A typical evolution of the major disruption with lithium limiter.

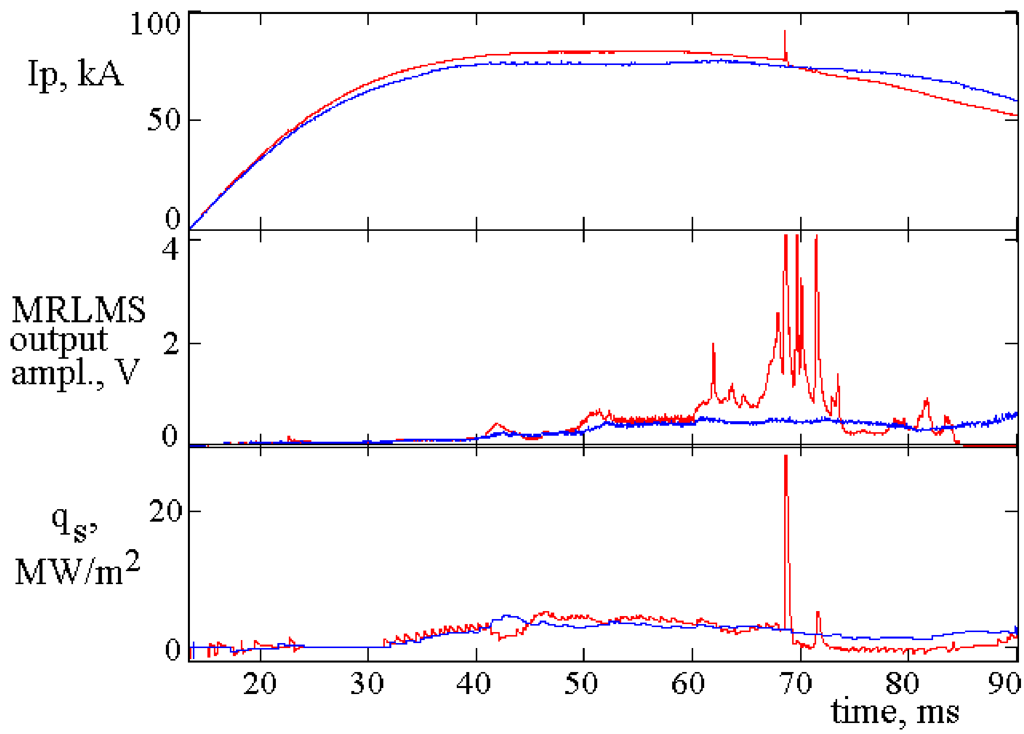

Fig.3. The evolution of heat loading of Li limiter in disruptive and non-disruptive discharges.

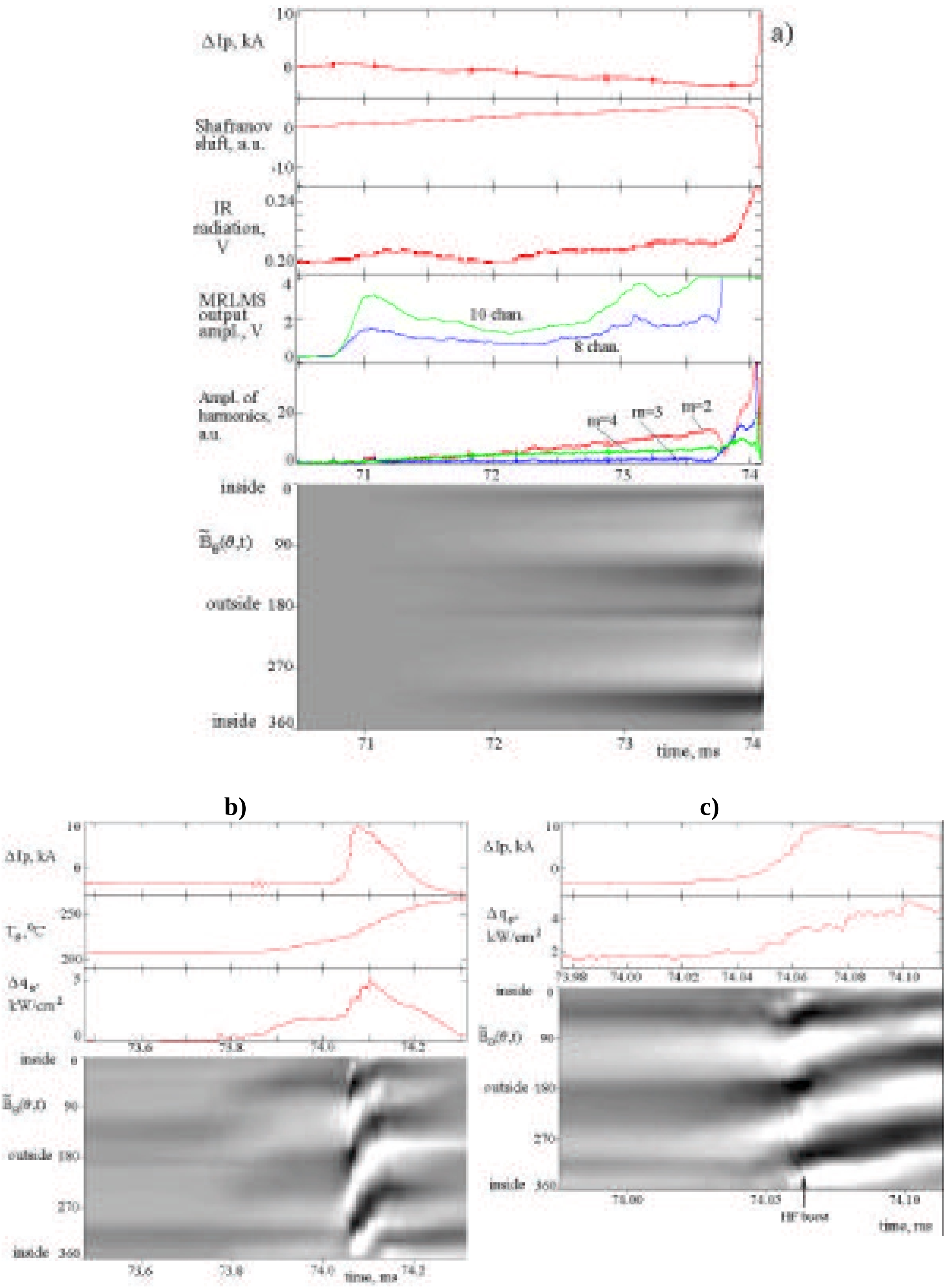

Fig.4. The evolution of the limiter heat loading during the development of a locked mode, which ultimately caused a major disruption. The evolution of magnetic perturbations $B_\theta(\theta,t)$ is present in grayscale over the poloidal angle θ, maximum of magnetic perturbation – positive current modulation.

A typical example of a major disruption in the T-11M tokamak with Li rail limiter is shown on Fig.2. It contains the following traces: plasma current (Ip), Shafranov shift (ΔR), 2 MRLMS channels (related to the limiter and plasma core regions), infrared radiation of the limiter surface (IR radiation), and corresponding limiter surface temperature (T_s) and heat loading (q_s). A major disruption is commonly initiated by Li impurity influx from the limiter and the development of a large LM.

An evolution of heat loading of the Li limiter surface in disruptive and non-disruptive discharges with 20 μs temporal resolution is shown in Fig.3. Obviously, the increase of Li impurity influx from the limiter starts 8 ms prior to the disruption, whereas the heat loading remains constant. The nature of this influx increase still is not clear.

In Fig.4 is shown an analogous disruption event sampled with better 1 μs temporal resolution. The Li influx starts 3 ms prior to the disruption. The details of limiter surface IR emission reveal the correlation between the rises of surface temperature and Li influx. The magnetic probes register simultaneous start of the LM growth, reaching the level of 3-4% Bp (see Fig.4a). Just before the positive current spike (PCS, - see Fig. 4b) the mode m=2 splits into the m=3 harmonic. During PCS (see Fig.4c) the HF bursts and abrupt increase of limiter heat loading are observed. The originating of HF bursts apparently testifies about magnetic reconnections during transformation of modes.

The total energy deposition at the limiter surface of 30…50 J was estimated by the IR emission assuming that the final area of power deposition does not exceed an initial one more than twice. The total plasma energy loss during the disruption, estimated by the Shafranov shift was ~ 800 J. Notice, that in the non-disruptive discharges up to 50% of total plasma energy was deposited at the limiter. Total energy losses due to the Li impurity emission were evaluated by the coronal model code [2] under an assumption that the electron temperature rises up to at least 20…50 eV during the disruptions. The “energy price” of each Li atom penetrating into the plasma was found to be of ~ 1 keV.

Finally, we conclude that an explicit Li self-isolation effect was observed in the disruptive discharges of T-11M tokamak. The measured heat flux to the limiter surface during the disruption (~ 10 kJ/m^2) was found to be >10 times lower than the anticipated level (100-200 kJ/m^2). In addition, an evaluated fraction of plasma energy losses due to the radiation of Li atoms (~ $3{\cdot}10^{18}$ total) was found to be of the same order as the total magnetic and thermal energy losses. Taking into account that the heat loading level to the Li limiter was close to the values supposed for the ELM-induced divertor loading in ITER-FEAT, the results obtained are quite promising for the application of Li-filled porous capillary assemblies.

References

[1] Evtikhin V.A., e.a. 16th IAEA Fusion Energy Conference, IAEA, Vienna, 1997, v.3, p.659.

[2] Lazarev V.B., e.a. 26th EPS Conf. on Contr. Fusion & Plasma Phys., 1999, v.23J, p.845.

[3] Belov A.M., e.a. 27th EPS Conf. on Contr. Fusion & Plasma Phys., 2000, v.24B, p.596.

[4] Alekseev A.G., e.a. 26th EPS Conf. Contr. Fusion. & Plasma Phys., 1999, v.23J, p.833.

[5] Alekseev A.G., e.a. Plasma Devices & Operations 1999, v.7, p.139.