

## **A software tool for the correction of infrared images for fusion applications**

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### **Abstract**

Infrared (IR) thermal cameras are often used to measure surfaces temperature and heat loads in environments with extreme operating conditions. IR devices had always revealed to be useful in nuclear fusion experiments, especially to monitor the thermal behavior of plasma-facing components (PFCs). The main drawback in using IR thermography relies on the fact that measurements are always affected by an error due to the different emissivity of the materials pointed by the IR camera with respect to the ideal black body. As a consequence, an image processing stage is required in order to correct raw data. Furthermore, in the specific conditions at which PFCs operate, unwanted phenomena, such as oxidation, deviates the actual emissivity values from the tabulated ones. Therefore, specific strategies to cope with these issues must be developed. In Frascati Tokamak Upgrade (FTU), two cooled liquid metal limiter devices have been investigated: a cooled liquid lithium limiter (CLL) and a liquid tin limiter (TLL). In this paper, we introduce a software tool for the automatic correction of the emissivity error exploiting a-priori knowledge on the specific metal. The output of the procedure is the definition of suitable correction maps based on the detection of the metal melting point.

### **Introduction**

In the last decades, one of the challenges that the nuclear fusion community has dealt with has been to find the appropriate material able to face plasma during nuclear fusion reactions. Power load on the divertor is one of the main problems to be solved for steady state operation on the future reactors. Transient loads, as ELMs, could cause irreversible damage and/or deep erosion of the target plates well before the established device lifetime [1]. Liquid metals (Li, Sn) embedded in the Capillary Porous System (CPS) could be a viable solution for the target materials. Up to now, only liquid lithium has been extensively tested on tokamaks with very promising results, but other liquid metals as well, such as Sn, could, in principle, guarantee even better capability of withstanding heat load as high as tens of MW/m<sup>2</sup>. In Frascati Tokamak Upgrade (FTU), a medium-size tokamak located at the ENEA laboratories in Frascati, Rome,

PFCs based on liquid metals have been deeply investigated. In particular, a cooled liquid lithium limiter (CLL) and a tin liquid limiter (TLL) have been tested in the last few years. Lithium has proven to be very efficient to reduce plasma contamination and particle recycling from the walls. These results refer to the first experiments on FTU for testing a liquid lithium limiter (LLL) as a conditioning technique by depositing a lithium film on the walls (lithization). After lithization very good plasma results have been obtained with the increase of plasma performances[2]. Tin has higher boiling point than lithium but it is not a reactive metal, rather it may introduce impurities inside plasma [3]. In order to investigate their performance, in terms of heat loads resistance, several thermal diagnostics have been used: a fast infrared (IR) camera observing in real time the whole limiter, a pair of thermocouples located on the limiter cooling system, and Langmuir probes measuring the local electron temperature and density. The IR camera provides spatio-temporal thermal information allowing to study how plasma hit the limiter surface. It is inserted through a port within the vacuum chamber wall and points to the limiter surface. The output of the camera is a video stream where each pixel represents the temperature of a given area. When using IR cameras, a calibration phase is needed due to the fact that the camera see the target as an ideal black body characterized by a unitary emissivity coefficient. In order to calibrate the IR camera, either the tabulated emissivity coefficient is used or the emissivity coefficient is computed by using the temperature measured by another diagnostic as reference [4]. Performing this procedure in FTU means taking into account several practical aspects. Firstly, the langmuir probe that is usually used as reference measurement, is located close to the limiter rather than on its surface thus being not the best choice. Secondly, since spatio-temporal phenomena may occur over the PFCs, a unique thermal measure is not sufficient to correct the spatio-temporal measurements given by the IR camera. In this paper, a tool able to estimate the spatial distribution of the emissivity coefficients which takes also explicitly into account the emissivity dependence on time is presented. In particular, we will define a procedure able to cope with both the limiter tested in FTU and to automatically create the related emissivity map.

### **Tool Design**

The idea behind this new procedure relies on the fact that the liquid metals have well known melting points. As a consequence, using the IR camera to monitor the cooling of the limiter after the plasma shot allows to get the free thermal evolution for each pixel. Since, during the recording, the metal will undergo a phase transition, the dynamical evolution of the temperature will be characterized by an horizontal flat section corresponding to the melting point of the metal. Thus, this temperature will represent the thermal reference for that pixel allowing the indirect estimation of the emissivity coefficient for that area. In order to do this, at the end of

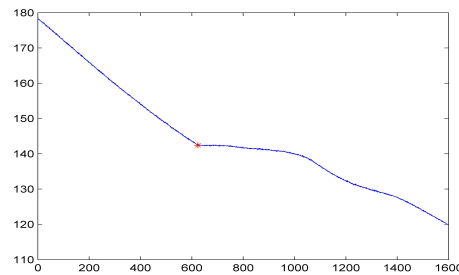


Figure 1: Thermal evolution and corresponding melting point for the pixel (110,65) of the CLL recorded on the 07/13/2016

each day, the free evolution of the temperature over the liquid metal limiter has been recorded. The tool detects the flat line as well as the melting point for each pixel creating a Thermal Reference Map. Then, each coefficient of the Emissivity map is computed as the ratio between the tabulated melting point and the one retrieved from the designed tool. When considering the CLL, the tabulated melting point used as reference has been  $180.6^{\circ}\text{C}$ , while when considering the TLL, the tabulated melting point used as reference has been  $232^{\circ}\text{C}$  [3].

## Results

Let us now discuss at first the results obtained from the campaign of July 2016. During these shots, the CLL has been used but it got damaged during the experimentation thus leading to a very high oxidation level and consequently a not uniform emissivity map. The tool needs two inputs, namely the free evolution recorded at the end of each experimental day and the tabulated melting point of the investigated liquid metal. The tool automatically computes the melting points corresponding to the flat line as shown in Fig.1 where the thermal evolution and the melting point detected for CLL limiter are shown. The tool output is shown Fig.2(a-d) where the emissivity maps for four consecutive days are reported. Finally, the TLL analysis has been done by using shots of the November 2016 campaign. As a result, a more uniform map is obtained as shown in Fig.2(e) In this case, the emissivity values distributed over the limiter surface are almost constant and equal to the tabulated emissivity value (0.4).

## Discussion

The main result is the relevance of this kind of approach in the perspective of monitoring how oxidation evolves especially in the case of damages leading to an high level of oxidation over the liquid lithium limiter surface. In fact, being lithium reactive due to its electron configuration, it easily bonds with oxygen. So it can be noticed that, starting from a uniform oxidation distribution, the oxidation level decreases day by day till day 14th (Fig.2(c)) because of the in-

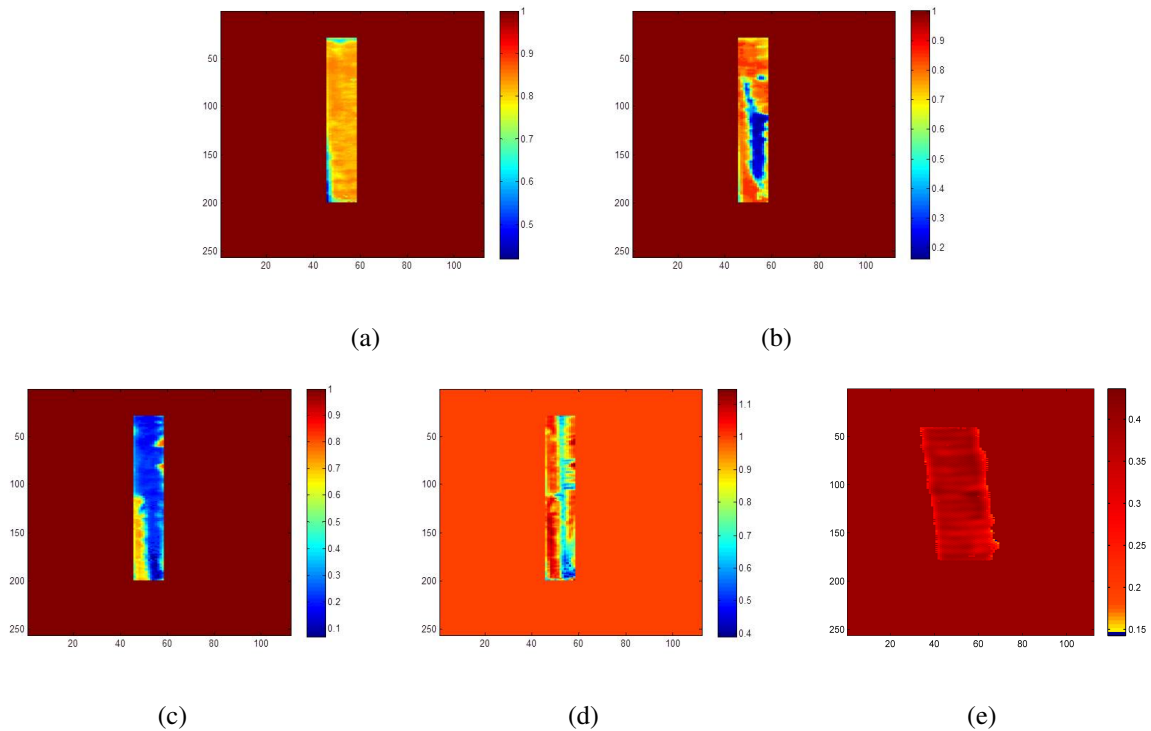


Figure 2: CLL and TLL emissivity maps for each day of the experimental campaigns 2016:(a) CLL 07/12,(b) CLL 07/13, (c) CLL 07/14, (d) CLL 07/15, (e) TLL 11/11

teraction with plasma. The last day, CLL was taken outside the nuclear chamber before the use and then a different level of oxidation is visible. In conclusion, the procedure proposed in this paper, allows to monitor how CLL limiter is oxidated thus providing a way to correct corrupted IR data. While, the analysis of the TLL case confirms that the spatial emissivity distribution is approximately uniform over its surface linked with its low reactivity.

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