Some Researches on UT and Laser Thermography for NDT Tokamak Plasma-Facing Components

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Abstract: During manufacturing and operation, delamination and surface cracks may be initiated in the plasma-facing components (PFCs) of Tokamak devices. To ensure the quality of the PFCs and safety of Tokamak, NDT techniques of different method are needed. This paper introduces recent researches of authors on UT and laser thermography techniques for inspection of PFCs during manufacturing and in-service. For W/Cu mono-block of divertors, the bonding quality was qualified by using the rotating UT with a focus probe. An EMAT system was established for the in-vessel inspection of delamination defect in first wall of blankets. A laser infrared thermography testing method is highlighted then for the on-line inspection of delamination defect in FW through the vacuum vessel window of the Tokamak device. Finally, a new laser thermography method using laser spot array was introduced for the online inspection of the surface cracks in FW.

Keywords: Plasma-facing components; Ultrasonic testing; Laser thermography; Delamination; Surface crack

1. Introduction

The plasma facing components (PFCs) are designed to protect the vacuum vessel, injection power system and diagnostic components from the plasma particles and heat loads. Manufacturing of PFCs has a number of challenging material engineering tasks in respect to welding of specific bimetallic or trimetallic compounds. The inspection of the manufacturing quality of PFCs is crucial to guarantee the proper operation of the fusion devices. Besides, the exposure to the high heat flux and particles may damage the structural integrity of PFCs and significantly shorten their service lives. Suitable NDT techniques are important to evaluate the structures in-service.

The selection and applicability of the NDT methods depends on many factors. The mono-block type geometry is the most potential design for PFCs of divertor. The mono-block consists of armor blocks of Tungsten (W) with a hole in which a cooling tube of a copper alloy (CuCrZr) is joined together by using solid welding technologies. The quality of W/Cu joint for this type of components is particularly important. Several researches on the development and application of UT C-scan of mono-block Cu-W joints with a small focused probe during the mock-ups manufacture and also after their thermal fatigue testing have been conducted. These researches indicate that the water immersion UT technique is reliable to control the bonding quality of mono-block Cu-W PFCs. A typical study on the UT of the upper divertor of Tokamak system of EAST is introduced in the first part of this paper.

The PFC of first wall (FW) panel is the main components of the blanket module system to provide the main thermal and nuclear shielding of the vacuum vessel (VV) during plasma operations. The FW panel consists of multilayered plate of three metallic materials bonded together with hot isostatic pressure (HIP) welding technique. During the plasma operation, the NDT of the FW is of great importance for the maintenance of the fusion reactors. The inspection procedure of the conventional UT method is complex and the inspection speed is limited due to the liquid couplant, which also has to be cleaned carefully after inspection as it pollutes the VV. Therefore, a noncontact and coupling-free UT method is needed for the in-vessel inspection of FW in the maintenance of future Tokamak fusion reactors. As EMAT is a noncontact and coupling-free ultrasonic testing method that directly generates and detects ultrasonic waves in specimen following electromagnetic mechanisms, a study on the combination of EMAT with the robotic and remote handling inspection manipulator for the in-vessel inspection of delamination defect in the FW was conducted and introduced in this paper.

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Beside the UT techniques, the infrared thermography testing (IRT) has drawn a lot of attention because of its feature of remote sensing and high detection efficiency. Several infrared thermography inspection researches for the plasma facing components have been done in recent years. Most of them mainly focused on the mono-blocks inspection and have not concerned the online inspection. The possibility of online inspection of the FW blankets by using laser infrared thermography testing (LIRT) was investigated by authors. On the other hand, the conventional LIRT technique is not suitable for the detection of surface breaking crack, which usually grow perpendicularly to the material surface. In contrast, laser spot thermography (LST), which uses a laser to generate a highly localized heating spot and an infrared camera to detect the heat distribution, is very sensitive for surface crack. However, the inspection time for large structure (such as FW in the fusion reactor) with conventional LST method can be very long due to point by point scanning. In order to reduce the inspection time by simplifying the measurement system and data processing procedure, a new LST method is developed by authors with using laser spot array source for the surface crack

2. Some Typical NDT Results

To investigate the performance of the developed new LST system, measurements on a steel specimen with artificial cracks were conducted. Fig. 1 shows the experimentally measured thermal image on the steel specimen irradiated by 9 × 9 laser array spots with the developed LST system. It can be observed that the 9 × 9 laser array spots are clearly captured by the IR camera and the adjacent laser spots are separated with each other. From the results shown in Fig.1, it can be seen that most background noise is properly removed, and both the laser array spots pattern and crack heat pattern become clearer after signals processing. There is still some noise in the lock-in amplitude images and the noise is randomly distributed while the crack heat pattern in each thermal image is almost the same.

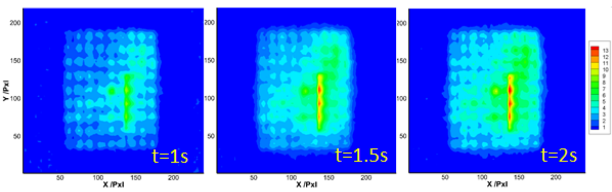

Fig. 1. Measured Thermal images for different time instant

After calculating the background free sequence, the surface pattern can be further eliminated. The crack image can be extracted from the lock-in amplitude images by using a holder exponent analysis. However, this method only uses a single image to visualize the crack and may cause loss of information and increase noise level. To solve this problem, an improved crack extraction method was developed and applied to the recorded thermal images for crack visualization. Instead of using a single lock-in amplitude image for crack imaging in the present lock-in LST method, multiple lock-in amplitude images were applied to further reduce the random noise that may cause false indication of cracks. The details of the improved crack extraction method have been given in the previous paper. Fig. 2(a) shows the crack extraction image with a single lock-in amplitude image. The crack can be clearly observed, though there is still some random noise. Fig. 2(b) shows the superimposed result by images from t=1 s to 2.5 s (a total of 13 frames from frame 9 to 21), and a reduction of noise can be witnessed. At last, the edges are removed by comparing with the heating area in original thermal image, as shown in Fig. 2 (c).

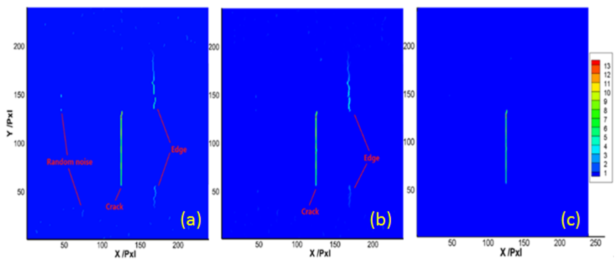

Fig. 2. Noise elimination for extreme value image

参考文献

[1] H. Liu, C. Pei, J. Qiu, Z. Chen. Inspection of Delamination Defect in First Wall Panel of Tokamak Device by Using Laser Infrared Thermography Technique. IEEE Trans. Plasma Science. 46(7), 2699-2707, 2018.

[2] J. Qiu, C. Pei, H. Liu, Z. Chen, K. Demachi, "Remote inspection of surface cracks in metallic structures with fiber-guided laser array spots thermography", NDT and E Int. 92: 213-220, 2017.

[3] T. Liu, C. Pei, X. Cheng, H. Zhou, P. Xiao, Z. Chen. "Adhesive debonding inspection with a small EMAT in resonant mode". NDT and E Int., 98: 110-116, 2018.

[4] J. Qiu, C. Pei, H. Liu and Z. Chen, "Quantitative Evaluation of Surface Crack Depth with Laser Spot Thermography", Int. J. Fatigue, Vol.101, 80-85, 2017.