Laser Spot Thermography – Scanning Mode

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ABSTRACT
The paper shows experimental results of fatigue crack detection, performed by laser spot thermography and vibrothermography techniques. The experiments were conducted on aluminium bar with artificially introduced crack. The paper contains theoretical background of both techniques. Also test setups including the control and signal processing software were presented and described. Semi-automatic algorithm for data processing was presented. The algorithm allows for automating measurement procedure, which limits the operator input. The paper shows that both laser spot thermography, as well as, vibrothermography can be effectively used for crack detection in metallic structures.

1. INTRODUCTION

Non-destructive testing (NDT) is an essential part of almost all engineering applications with demand for robust and safe operation. There are many successfully implemented and utilized NDT techniques [7-8] in the industry. Many such techniques are first researched and developed in scientific laboratories, and afterwards gradually transferred to the market [1-3]. Among them, laser thermography is still not widely used, but gains recognition and interest. One of promising, but still not widely used technique is laser thermography. Application of laser thermography shows promise mainly in automotive, aerospace, civil engineering, medical and space systems industries [4-6].

The following paper shows the experimental results on laser spot thermography and vibrothermography. The author provides detailed description of theoretical background and experimental setup of both techniques. In this study mentioned techniques were applied and compared on the surface crack detection in an aluminium bar. The experimental tests were performed on an aluminium bar with present fatigue crack. The paper provides.

2. EXPERIMENTALLY TESTED SAMPLE

An aluminium bar was selected, as an experimental specimen. The overall dimensions of the bar were 300x20x10mm. At first an artificial defect (a small notch) was introduced into the bar structure, using a wire-cut electric discharge machining (EDM). Then the sample was subjected to a fatigue test. The test was ended, when the crack reached the depth of approximately 10mm. At the final preparatory step, the sample was also painted black in order to improve (increase) its thermal emissivity. Figure 1 shows the photo and schematic of the tested sample and microscopic image of the introduced crack area.

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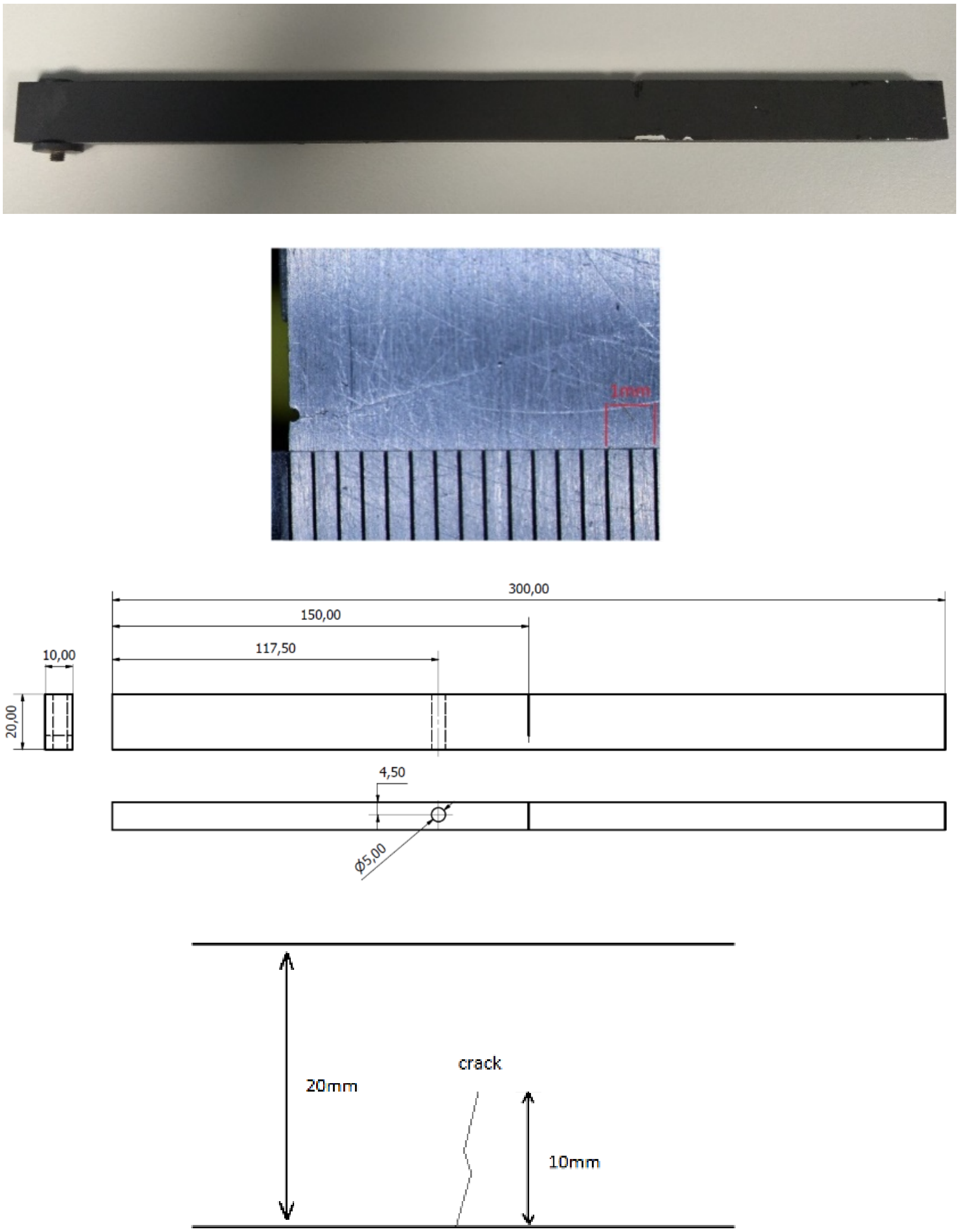

Figure 1. Tested sample – photo, schematic and microscopic view.

3. LASER SPOT THERMOGRAPHY

Laser spot thermography is a technique of active thermography, which utilizes laser radiation as a source of excitation [9-14]. In this technique, laser beam focused on the tested object is converted into heat transferring into the structure. The infrared camera is used to measure temperature of the tested object prior, during and after the laser irradiation. Damage detection is based on the analysis of the nature of heat propagation. In thermally isotropic materials, it is expected that the temperature profile after laser beam excitation would be of a symmetrical Gaussian-type. Any deviation from this shape indicates potential damages.

Experiments were conducted on a laser spot thermography test rig built at the AGH University. The system consists of: diode laser source with the peak power of 120W, collimating optics, a cooling system, stepper motors arranged in 2-axis positioning system, IR photon camera, PXIe controller and a PC computer. The described test rig is shown on Figure 2.

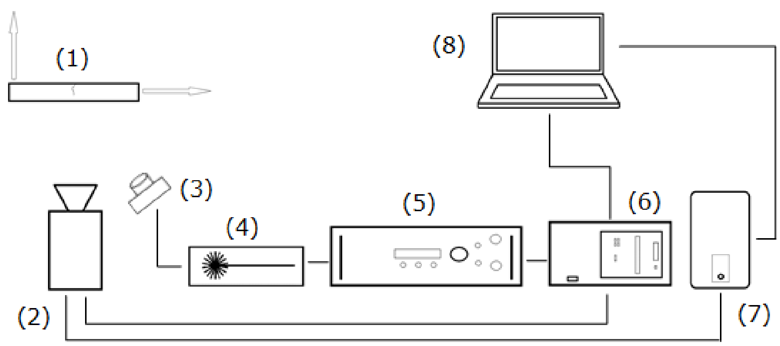

Figure 2. Laser thermography test rig. 1) sample+positioner, 2) IR camera, 3) collimator, 4) laser head, 5) laser controller, 6) NI PXIe controller, 7) frame grabber, 8) PC

Figures 3 shows real photos of the laser spot thermography test rig. In this arrangement, position of both IR camera and laser beam source were fixed. Sample scanning was performed by two axis stepper motors. There are, also other known configurations of laser spot thermography, where laser head and/or IR camera are mounted to robotic manipulator. Such arrangement is usually used for bigger structures, which could be more cumbersome to manipulate.

Laser spot thermography can be divided into several techniques, depending on how energy is delivered to the tested object. It could be a short pulse, constant excitation or modulated waveform in a lock-in setup [15]. Scan of the surface can be obtained in a point by point manner or with a continuous movement of the laser spot. Also, the shape of the laser beam can differ depending on application. Circle is the most popular shape; however a linear shape is also an interesting proposition for improving speed of the scan.

This article shows the results from laser spot thermography, where scanning was performed in a point by point manner. Figure 4 shows the laser spot measurement procedure. In this procedure short (100ms) laser pulse was delivered to the structure, at each measurement point. The IR camera synchronized with the laser controller captures the thermal signature prior, during and after the laser excitation event. The whole experiment consists of 13 single excitations, each at a different position of the laser beam.

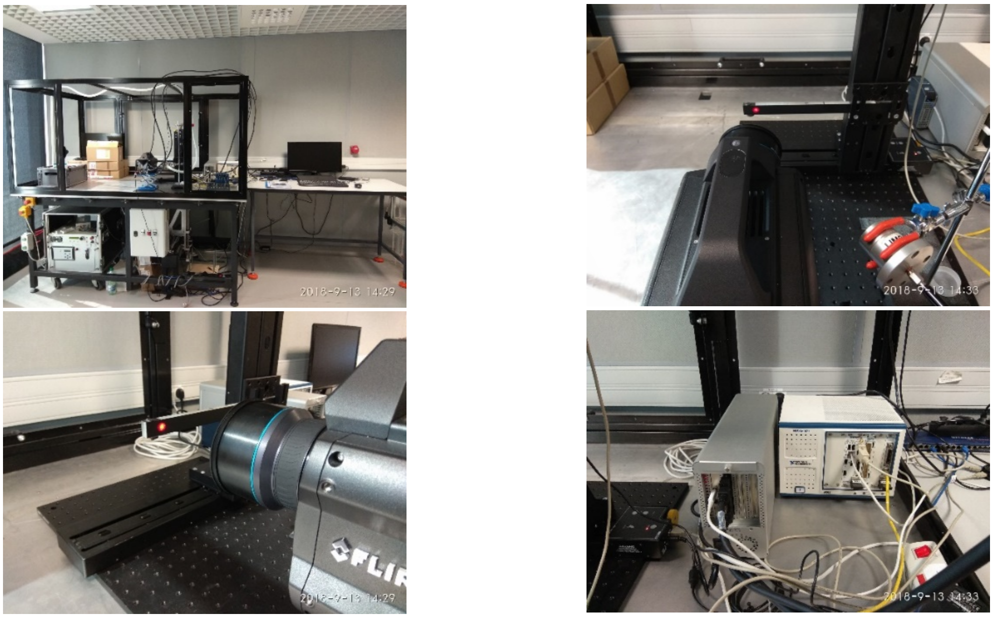

Figure 3. Laser thermography – test rig (photos)

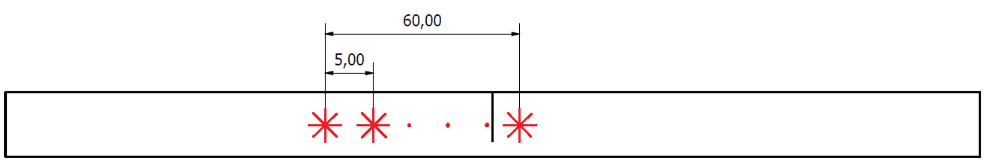

Figure 4. Laser spot thermography measurement procedure

Measurements were performed with the following parameters: laser power 100W, excitation time 100ms and beam diameter equal to 10mm. The IR camera captured thermal signature of tested object with resolution 640 x 512 pixels and frame rate equal to 200Hz. The sensitivity level of the camera was less than 7,1 mK. The excitation points were collinear and distributed at 5mm distance between each other.

Figure 5 shows the laser spot thermography results, in particular the thermal signature and time chart for laser excitation pointed on non-defected area. Single laser pulse locally heated the structure by almost 10K above initial temperature. The one measurement event can be divided into two phases. In the first phase, laser radiation generates rapid growth of the temperature. This phase is ended with switching off the laser, which begins the second phase. In the second phase, the temperature rapidly drops down due to the heat dissipation in the material. The second phase takes from several milliseconds to a few seconds depending on the material thermal properties like heat conductivity and capacity.

Figure 6 shows temperature distribution of defected area after the laser pulse. The horizontal and vertical cross-sections across arbitrary selected lies (dash lines) are shown. The temperature vertical cross-section is quite smooth, which implies no present rapid changes in material thermal parameter. The nature of horizontal temperature cross-section is substantially different. A very strong visible temperature gradient suggests a rapid change in material properties corresponding to actual crack location.

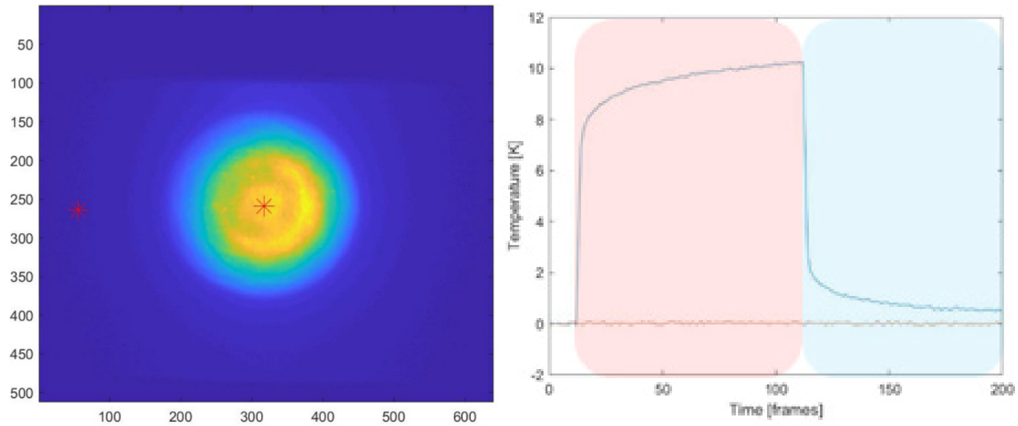

Figure 5. Thermal signature and time chart for laser excitation pointed on non-defected area

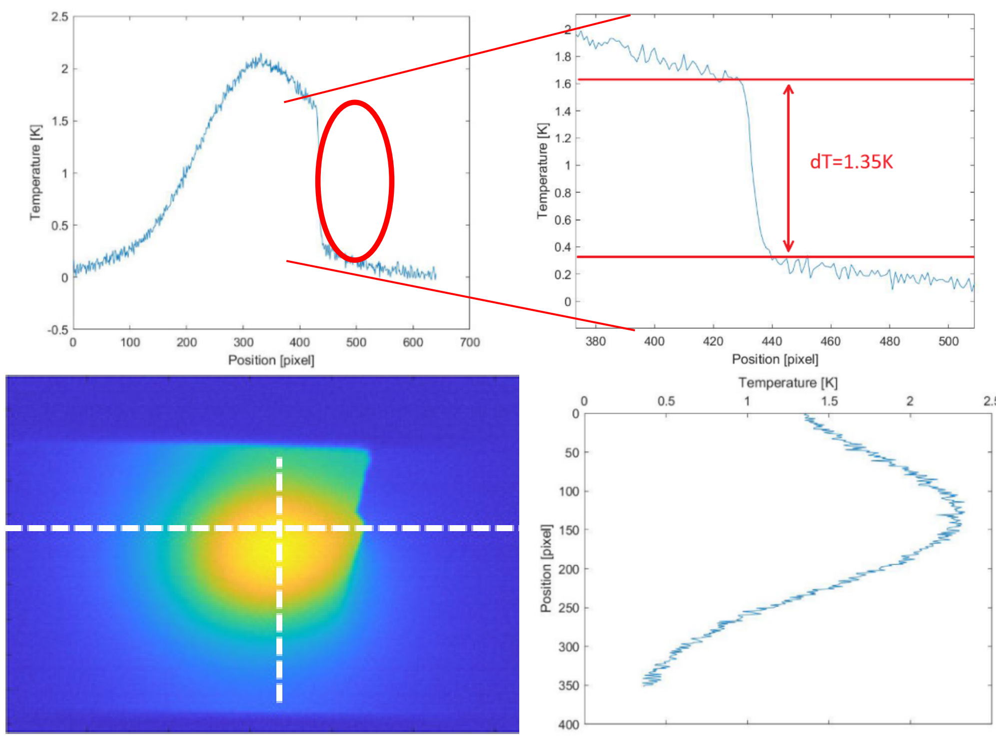

Figure 6. Thermal signature and time chart for laser excitation pointed on defected area

Figure 7 shows results of laser spot thermography post processing procedure. The semi-automated algorithm includes: loading data, background subtraction, frame fitting and sizing. Crack detection was done with the use of the Roberts filter. This filter is meant to detect sharp edges, which corresponds to thermal barriers introduced for example by cracks.

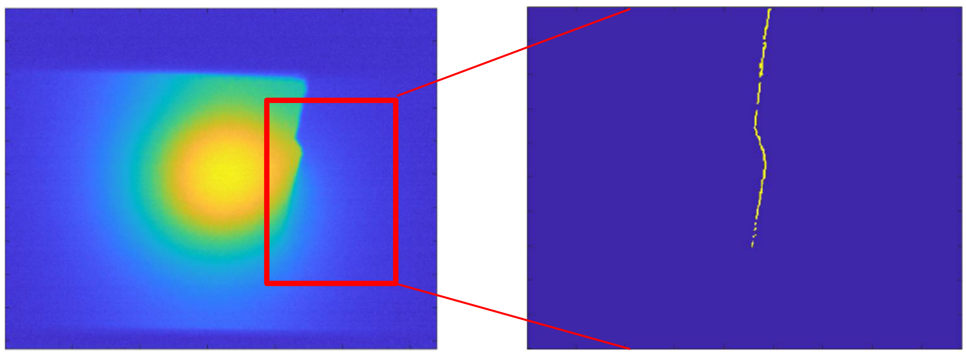

Figure 7. Laser spot thermography – semi-automated algorithm

The experimental results proved the effectiveness of laser spot thermography for barely visible surface crack detection. It has been also proved that semi-automatic algorithm is an effective tool for both, crack detection and evaluation.

4. VIBROTHERMOGRAPHY

Vibrothermpgraphy is another technique of active thermographic testing. The method is based on a local heat generation [16-19]. During vibrothermographic testing, energy is pumped to the tested object within electromechanical transducer. Mechanical waves of frequency usually in range from 15 to 70kHz propagate through the tested sample. If they encounter defects, such as cracks or delaminations, a heat friction phenomenon could occur.

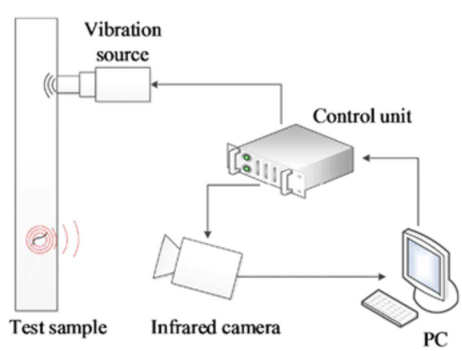

Figure 8. Vibrothermography setup - schematic

One of products of friction is heat, which transfers in all directions around its origin. If heat reaches a surface of a tested object, it can be detected by a IR camera. Figures 8 and 9 show vibrothermography test system, which consists of: vibration source, IR camera, control unit and a PC computer for data acquisition.

Figure 9. Vibrothermography setup – real photo

Figures 10 and 11 show the bars temperature before and during the excitation. Friction caused by the mechanical waves locally increases temperature of the sample (Fig 12). The crack localization and shape were easily detected with a simple postprocessing method (background subtraction).

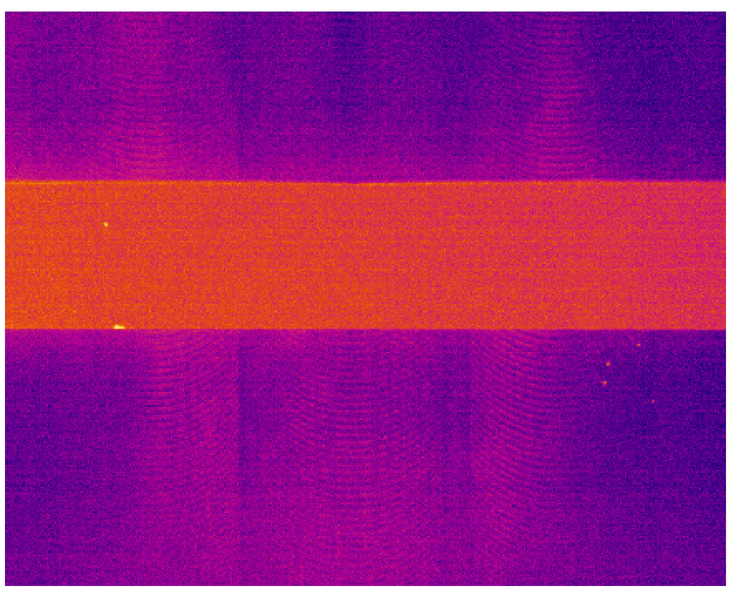

Figure 10. Vibrothermography – bevore excitation

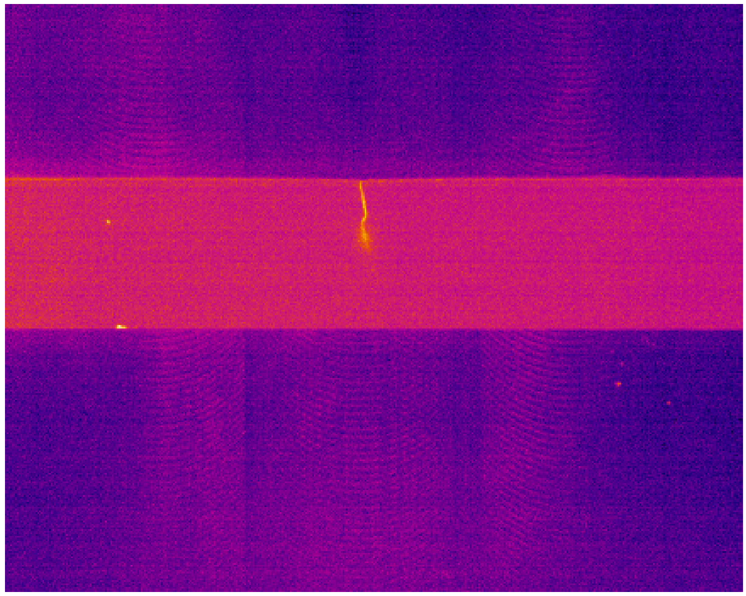

Figure 11. Vibrothermography – during excitation

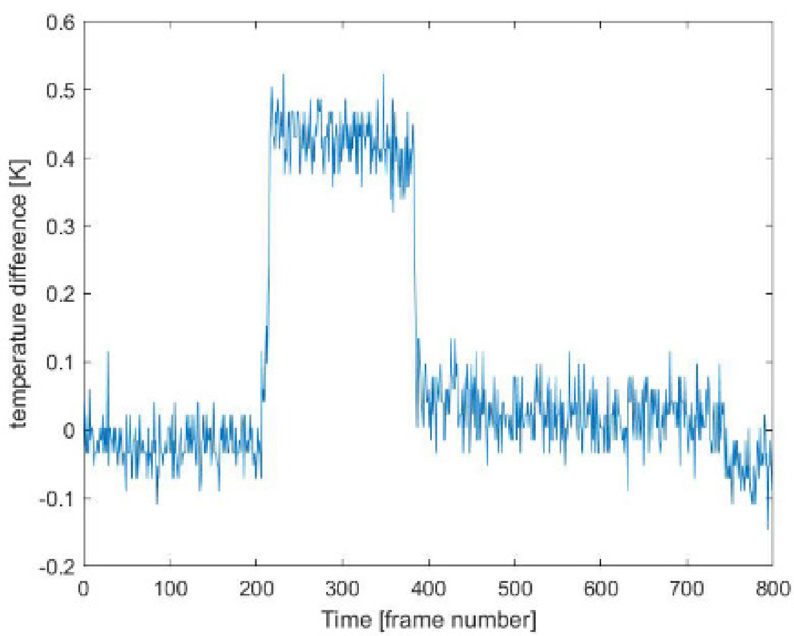

Figure 12. Vibrothermography – temperature vs time

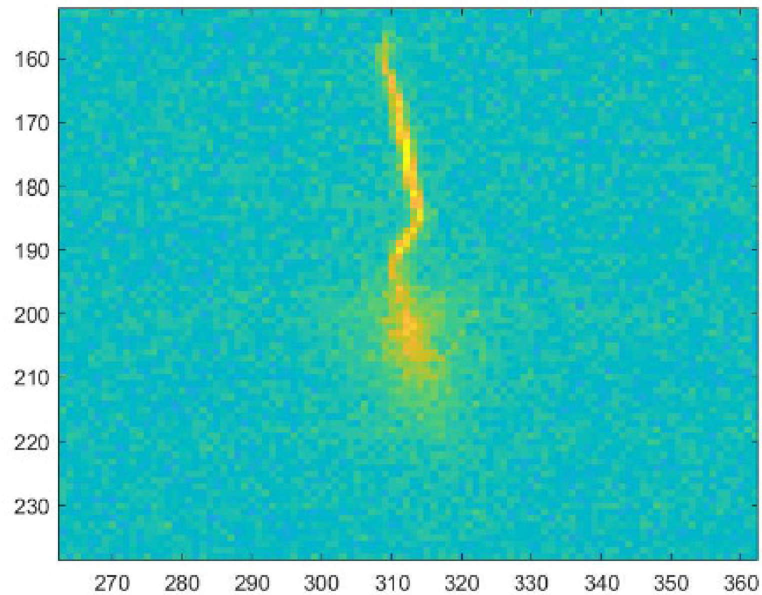

Figure 13. Vibrothermography – frame after background removal

5. CONCLUSION

Figure 14 presents the comparison between results obtained from laser spot thermography and vibrothermography experimental tests. The right image shows thermal signature of the damaged area recorded during the excitation. Only standard background subtraction procedure was applied. The position and shape of the crack is clearly visible. The left image shows results obtained from laser spot thermography experiment. The location and shape of the crack was revealed by semi-automated algorithm. Very good agreement between both results was obtained.

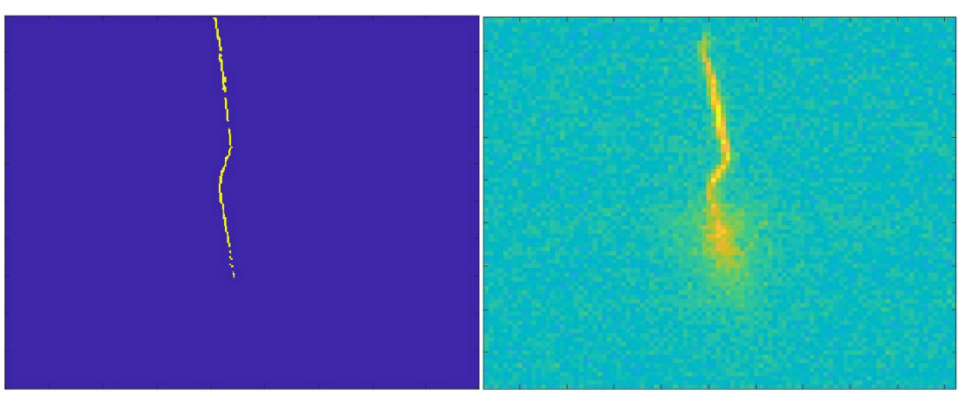

Figure 14. Comparison between laser spot thermography and vibrothermography test results

The paper shows results obtained from two thermal imaging based techniques. Both considered techniques utilize external sources of energy, however the mechanisms of their delivery are substantially different. In vibrothermography energy is pumped into the tested structure by electromechanical transducer. Principle of operation of vibrothermography is based on observation of thermal response for mechanical excitation. Mechanical waves could propagate for a long distance. One measurement can cover relatively big area, therefore vibrothermography could be considered as a global method. In laser spot thermography energy is instantly converted into the heat, which propagates through the material. Defect detection is based on observation of the nature of heat propagation . Laser spot has usually a diameter of a few millimetres, while heat propagates for less than twice of that distance. Single laser thermography measurement covers relatively small area, therefore this method has rather local nature.

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