USE OF IRNDT EVALUATION FOR CRACK DETECTION INDUCED BY CYCLIC LOADING

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Abstract

Infrared nondestructive testing is an inspection method based on an external excitation of a measured sample and a thermographic analysis of its thermal response. It often uses advanced evaluation techniques based on temperature spatial and temporal changes. IRNDT is a suitable method for an inspection of thin samples, near-surface layers and cracks. An application of IRNDT for detection of crack on mechanically cyclically loaded welded pipes is introduced in this contribution. The goal of the analysis was to detect location of the crack before this crack was created and visually detectable. Results showed that a thermographic record without an advanced IRNDT evaluation could detect crack just before the mechanically loaded pipe is starting to break down. An advanced IRNDT evaluation brought more evident indication of a position of the crack and its development during the test. The experiment, the evaluation method and the results are described and the IRNDT evaluation advantages and disadvantages are discussed in this contribution.

Keywords: Nondestructive testing, IRNDT, active thermography, crack detection

1. INTRODUCTION

Crack detection is an important part of material testing. Cracks can cause severe damage to the part where they are induced. In worst case scenario they can cause safety hazards. Therefore there are several methods proposed and used for crack detection. Two different approaches are often used by crack detection - Structural Health Monitoring (SHM) and Nondestructive Testing (NDT). By SHM different types of sensors are used. They are located nearby of areas of interest (places where can be expected crack inducement). Those sensors are monitoring real-time crack propagation. This approach is often used for example in civil engineering at bridge state monitoring [1]. NDT approach is based on one-time (or periodically repeated) testing of inspected part. Typically by NDT, defect is present before inspection is performed. To this group belongs for example eddy current testing, penetrant testing, ultrasonic testing. Review of crack detection techniques can be found in [2].

Infrared non-destructive testing (IRNDT) can also be used for crack detection [3,4,5]. IRNDT is based on usage of an external excitation source to induce a thermal process in a tested sample. The thermal response on the external excitation is then measured by a thermographic camera. In case of discontinuity occurrence in tested sample, the thermal response is affected by this discontinuity in its location. Different types of excitation sources, procedures and evaluation algorithms can be used for different applications. The often used sources are for example optical sources (flash and halogen lamps), ultrasound, and electric current. Excitation procedures are pulse excitation (Pulse Thermography), periodical excitation (Lock-in Thermography), step excitation (Step Thermography), etc. Differences between results obtained by different sources and procedures can be considerable. This difference can be seen for example in [6]. The thermographic testing is used in a lot of applications, often for composite structures inspection [7], but for example also for optical components [8]. Crack detection can be done for example by laser thermography [3,4,5].

Evaluation algorithms are one of the most important parts of IRNDT. Those algorithms serve for defect detection enhancement. Some of them are universal. They can be used with various excitation procedures.

Evaluations based on Fourier transform belong to this group. Fourier transform for IRNDT data is usually done by applying Fast Fourier Transform (FFT) algorithm. FFT converts a thermographic time signal to a representation in the frequency domain. FFT allows analyzing amplitude and phase of the signal. Both of these representations improve defect detection. FFT is often used for pulse phase thermography (PPT) [9,10]. Some evaluations technique are tightly connected to excitation procedure - some laser thermography evaluation algorithms [11,12], TSR algorithm for pulse thermography [13], etc.

There are several issues with both SHM and NDT for crack detection. Disadvantage of SHM is that, the sensor has to be placed nearby future crack. If it hadn't, crack couldn't be detected. It can be solved with huge amount of sensors or with picking critical areas based on simulations or experience, where to locate sensors. NDT can found cracks after they are created. It depends on control plan if this type of testing is sufficient. When crack is found in its beginning, when it doesn't influence the function of the part, the part can be easily repaired. It would be beneficial for both NDT and SHM if location of critical areas was possible to discover with some type of measurement. It would allow to deploy sensors on more suitable places in case of SHM and to found places which should be inspect more thoroughly in case of NDT.

In this contribution we propose using thermography camera and FFT algorithm to detect location of future crack induced by periodic loading. Our goal was to determine if it is possible to predict where the crack will occur with usage of thermography camera and FFT. The crack was being induced during measurement. Therefore, performed measurement isn't typical IRNDT measurement.

2. EXPERIMENTAL SETUP

Experimental measurement was performed on the welded steam pipes. Narrow pipe (diameter 51 mm, material 13CrMo4) was welded to strong pipe (diameter 108 mm, material 16Mo3). The narrow pipe was being cyclic loaded (upwards). The measurement configuration and sample itself is shown in **Figure 1**. Cyclic loading was performed in four steps with different load and frequency of loading, see **Table 1**.

Table 1 Steps parameters

Step	Load (kN)	Frequency (Hz)
1	18	5
2	21	4
3	24	4
4	18	6

For thermographic measurement, IR camera Optris PI 400 was used. One measurement step contained loading which took approximately 20 minutes. After every step the new load had to be set. To set new load the device which were causing load, had to be turned off. Camera framerate was set to 1 Hz. This framerate was selected to ensure whole measurement can be stored and evaluated. With higher framerate there would be problems with disc space. LabIR software, which was developed by University of West Bohemia, was used for measurement and evaluation.

Area of interest was created on thermographic sequences. Maximum minus minimum temperature was monitored from this area. Area of interest (AOI) is shown in **Figure 2**. In the rectangle (AOI) crack appeared during loading (based on last thermogram, where the crack was clearly visible). Due to temperature measurement it was possible to determine if there is any temperature trend in measured data.

FFT evaluation was performed on 200-frames intervals. The amplitude signal was analyzed. Peak was found in every interval on amplitude-frequency graph. Defectograms were stored on those peak frequencies.

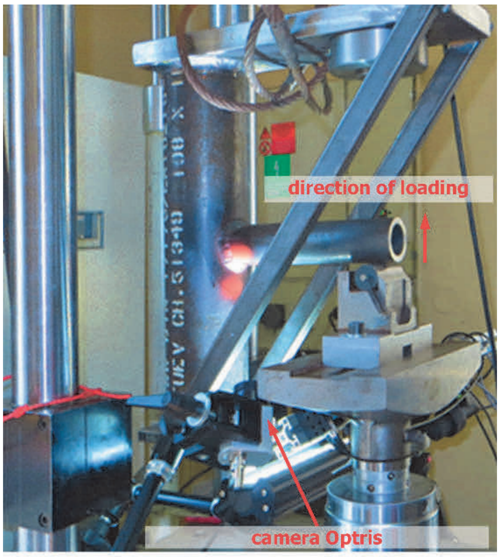

Figure 1 Measurement setup

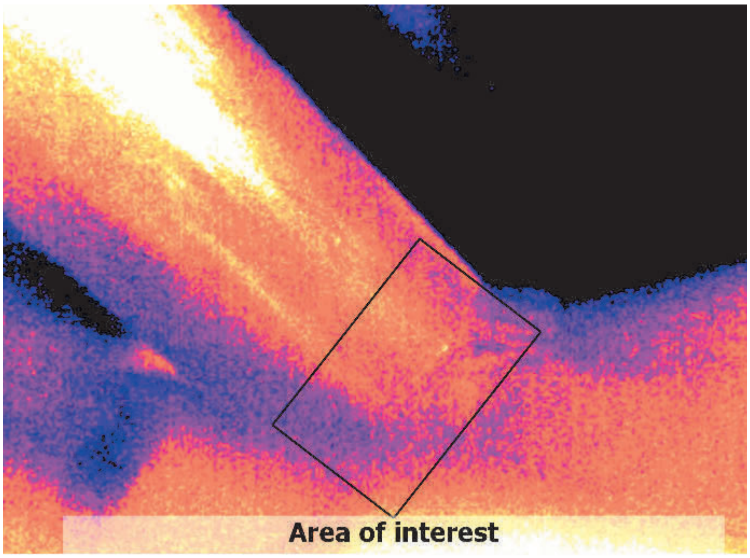

Figure 2 Area of interest

3. RESULTS

Figure 3 represents temperature changes (maximum minus minimum temperatures from AOI) in time. Other temperature analyses were performed as well, for example analysis of average temperature from AOI, analysis of maximum temperature from AOI, analysis of minimum temperature from AOI, and even point analysis. The similar trend as is shown in the **Figure 3** was found in other analyzes.

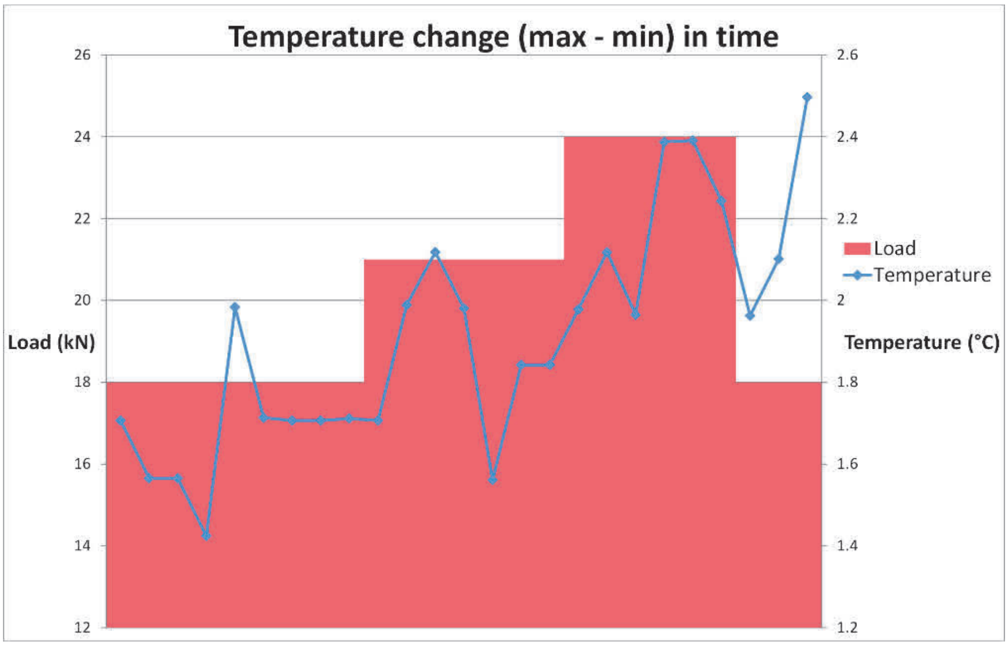

Figure 3 Temperature change in time

It is obvious that temperature is slightly going up. Nevertheless the growth is negligible. Overall temperature increase from the start to the end of the measurement is around 1°C. This small increase in temperature can be for example caused by heating of the sample from other sources for example caused by heating in testing room. From temperature trend, no dependencies can be found.

Crack wasn’t visible on thermograms, except the last thermogram in step 4 (load 18 kN, frequency 6 Hz) where the crack was clearly detected. In this moment, crack was visible even with naked eye. For this application standard thermographic evaluation isn’t suitable.

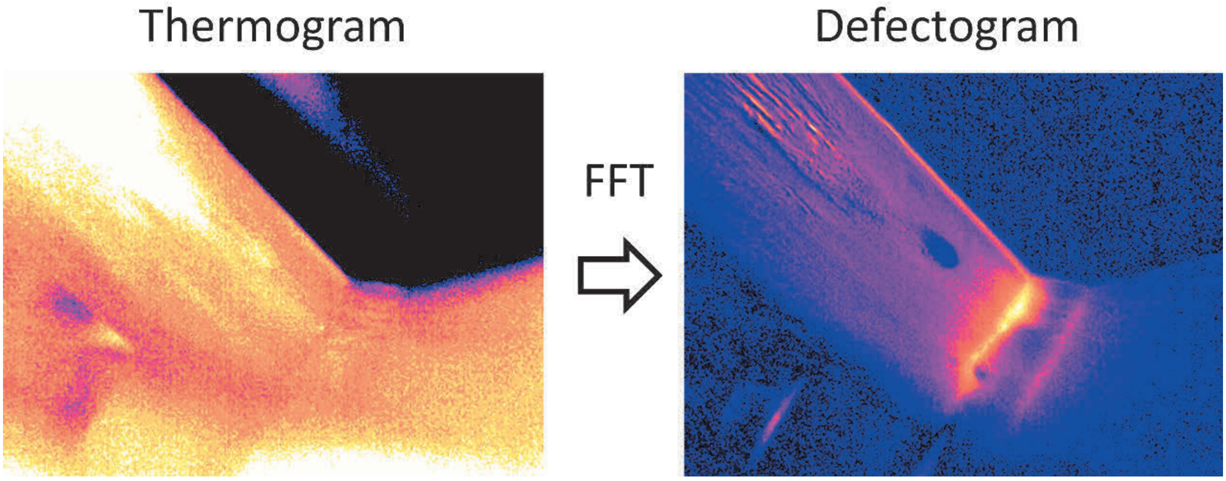

Figure 4 Comparison - Thermogram/Defectogram

Through FFT with amplitude representation, the critical area was detected even by the first load in the beginning of step 1 (load 18 kN, frequency 5 Hz). In detected critical area, the crack was created and was visible on thermogram firstly in the last step (step 4). The difference between thermogram and defectogram can be seen in **Figure 4**. Clear indication of critical area is seen on the defectogram but no indication in this area can be found on the thermogram. Energy release caused by the crack opening was captured since the step 3. This release is shown in **Figure 5**. The roots of crack were indicated bright but the rest of the crack was indicated dark. The crack was indicated as a bright indication in previous steps (this can be seen for example on defectogram in **Figure 4**).

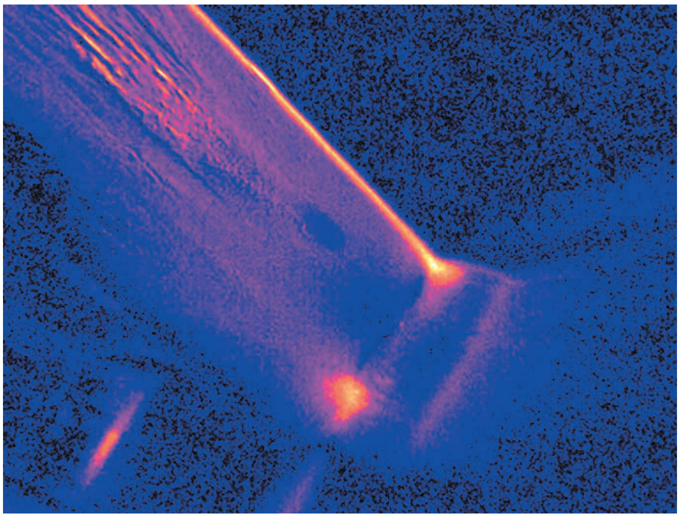

Figure 5 Defectogram of step 3

4. CONCLUSION

The thermographic testing for crack detection induced by periodic loading was introduced in this contribution. Standard temperature evaluation and FFT evaluation were compared. It was shown that the standard temperature evaluation wasn't able to detect crack before it was visible by naked eye. No temperature trend was discovered.

The measurement showed advantage of using advanced evaluation algorithms. The same thermographic data was used with FFT and the crack was easily detectable. Furthermore, it was possible to predict where the crack will be created. This was possible since the first loading (step 1). Additionally, we were able to detect energy release caused by the crack opening. Disadvantage of using advanced evaluation algorithm is that typically thermographic sequence contains a lot of data and therefore evaluation can be time demanding. It should be noted that evaluation algorithm should be chosen based on concrete application. Only then, the best performance (time, defect detection …) can be guaranteed.

Our experiment showed that thermographic inspection and suitable evaluation algorithm can determine areas in which defect can occur.

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