AUTOMATED INSPECTION OF WELDS WITH LIMITED ACCESS BY USE OF ACTIVE THERMOGRAPHY WITH LASER LINE EXCITATION

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Abstract. Inspection of welds for detecting surface breaking defects is traditionally performed by using NDT methods such as Fluorescent Penetrant Inspection, Visual Inspection or Eddy Current. All those well-known techniques have drawbacks, as they need access to the surface, either for preparation with e.g. liquids or for using contact probes. Traditional methods also require a skilled operator to carry out the inspection, and moreover to analyse the obtained results. Furthermore, for the inspection of welds with limited access, the use of those traditional methods is even more complex, resulting in increased inspection time and reduced detection capability or in worst case, areas impossible to inspect. Therefore, the development of a fully automated non-contact method overcoming these limitations is desired.

Active thermography is a novel NDT technique for weld inspection. The method has shown promising results for replacing traditional techniques when it comes to detection of surface breaking defects in metals. The method make use of an excitation source in order to heat the sample in a controlled manner during the test, and an infrared thermal camera for recordings of the thermal evolution.

In this work, an automated solution developed and demonstrated for inspection of welds in a jet-engine component with limited access is presented. The NDT system is mounted on an industrial robot, making it possible to automatic scan the inspected area. The system consists of a, continuous laser-line excitation source together with a FLIR SC 655 microbolometer thermographic camera. In order to access limited areas, two polished aluminium mirrors have been used for both infrared radiation monitoring and laser excitation respectively. A solution for automatic analysing, defect detection and sizing is also included and presented.

1. Introduction

Different inspection and non-destructive testing (NDT) methods are today being used for weld inspection. Current techniques such as Visual Inspection, Fluorescent Penetrant Inspection, Eddy Current and Radiography have limitations in applicability and detectability, especially for inspection of parts with complex geometries and difficult to reach areas, but also their ability to detect some defects. Inspection of welds with limited access puts specific requirements on the NDT-method to be used.

In order to accomplish the future targets of reducing the environmental impact of aviation, effective, cost efficient and reliable aero engines are developed. By using the light weight technology based on fabrication, engine components can be built that meet those targets. Fabricated components are components assembled from smaller sub-components in mixed material forms, preferably joined together by welding. With lighter structures the margin to safety might be reduced, and this makes the requirement on the inspection, to be even more important to maintain the safety levels. For example, the occurrence of surface cracks and lack of fusion in hidden welds need to be secured on all welds by a reliable inspection method.

Given the need of weld inspection of fabricated aero engine structures with limited access, and the drawback with the conventional NDT-methods available, there is a necessity to develop new robust and efficient inspection methods. A non-contact method without the need of special preparation is desired for fast and cost efficient inspection with the possibility of automation.

Thermography as an NDT-method has been known for quite a long time [1]. Today the methods is mainly used for inspection of composite structures. It has been reported that thermography as well has the possibility to inspect metals, for example inspection of spot welds [2, 3] and to detect surface cracks [4, 5]. One major advantage with the method is that it allows an object to be inspected without contact or any special preparation. The method is based on an infrared camera that registers the heat variation, excited by a locally heated area, on the surface of the structure. One key aspect is the method of excitation, and how to optimize the excitation to have robust measurements. Several methods have been used previously with success, such as laser pulse, flash lamp and induction. For inspection of welds with limited access it is also important to study the conditions for miniaturization of the inspection equipment.

In this paper an automatic inspection cell for inspection of surface flaws in welds with limited access is presented. In section 2 the different parts of an automatic inspection cell is described and in section 3 the demonstrated set-up is presented. In section 4 and 5 the results are presented and conclusions stated.

2. Automated Inspection cell

The different parts of an automated inspection cell for inspection of surface flaws in welds with limited access based on thermography are presented in this section. The basic principle is to mount a measuring device on a scanning equipment suited for automation. The acquired data from the measurement are analysed and reported by software designed for the purpose.

2.1 Scanning

The automatic motion during inspection includes the manipulation of the measuring head (NDT equipment), i.e. the scanning. The scanning equipment can be of different types and several manipulators exist that are used in an automated NDT-systems. Most of these are specialized to be used for specific and simple weld geometries, although some more advanced and flexible ones do exist. Welding in the production industry today is most often performed using industrial robots. An industrial six axis robot offers great flexibility, excellent support organization and the know-how about such equipment is often high since robots are used extensively in the production industry. Another benefit is that a robot can carry several types of equipment.

2.2 Excitation Method

Different excitation methods may be used in thermography, such as flash lamp, induction and laser heating. Among different laser excitation strategies that can be applied (pulsed laser, spot-heating…) it has been found that laser line excitation is an interesting strategy given the nature of this project [6]. The major advantages of this method include the application of excitation in a more controlled manner compared with other excitation methods which makes the analysis step much precise. Besides, it makes it possible to excite the entire welded region in a single scan. Additionally this method allows the analysis of a single line instead of the whole image, which increase the processing speed.

2.3 Measuring head

The measuring equipment consist of an IR camera and a source for heat excitation, in this case a laser with lenses producing a laser line. The laser line illuminates the weld, with a small angle, in the middle of the field of view from the IR camera. In order to be able to reach welds with limited access, a periscope was designed. The periscope had two mirrors mounted on a rod. One mirror was used to view the inspected area by the IR camera. The other mirror was used for illuminate the inspected weld by the laser line. The principle design of the measuring head with the periscope is presented in Fig. 1.

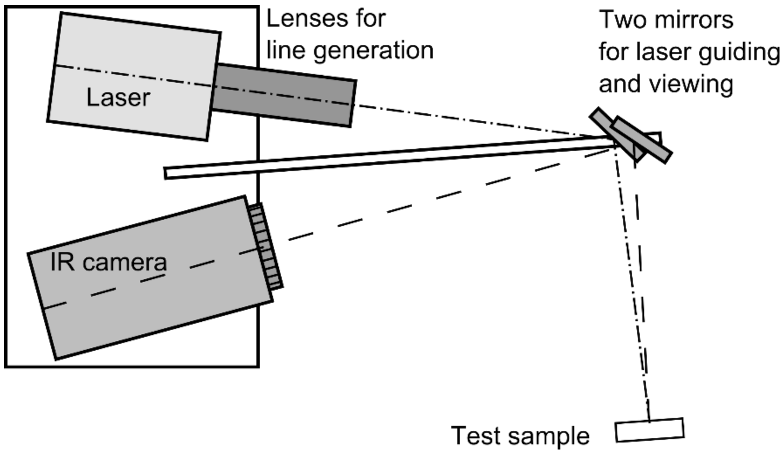


Fig. 1. Measuring head for inspection of surface cracks in welds with limited access.

2.4 Automated Analysis

Detection of surface flaws is more difficult in a raw weld surface compared to a smooth metallic surface. This is due to the surface structure of the weld which increases the noise and produces false positives. It is therefore important to have good analysis methods that can improve the signal to noise ratio and reduce the amount of false positives. Since the calculation for the analysis needs to be performed for each point in the reconstructed data it needs to be relatively computationally light to reduce the run time.

For heat excitation with light, the principle that surface flaws have a higher absorptivity and emissivity than the surrounding metal due to multiple reflections of the light within the crack can be used [5]. If the temperature is plotted, as a function of time, for several surface flaws (e.g. notches) in a welded plate, together with the background temperature and some false positives, the results are as seen in Fig. 2. It can be noticed that the temperature increases more in notches and false positives than in the background. Notches can also be separated from false positives since the width of the heating curve is wider, due to faster heating and slower cool down.

By using the width heating curve in each pixel of the image from the IR camera and using a local threshold value on the results it is possible to automatically detect the surface flaws in the weld.

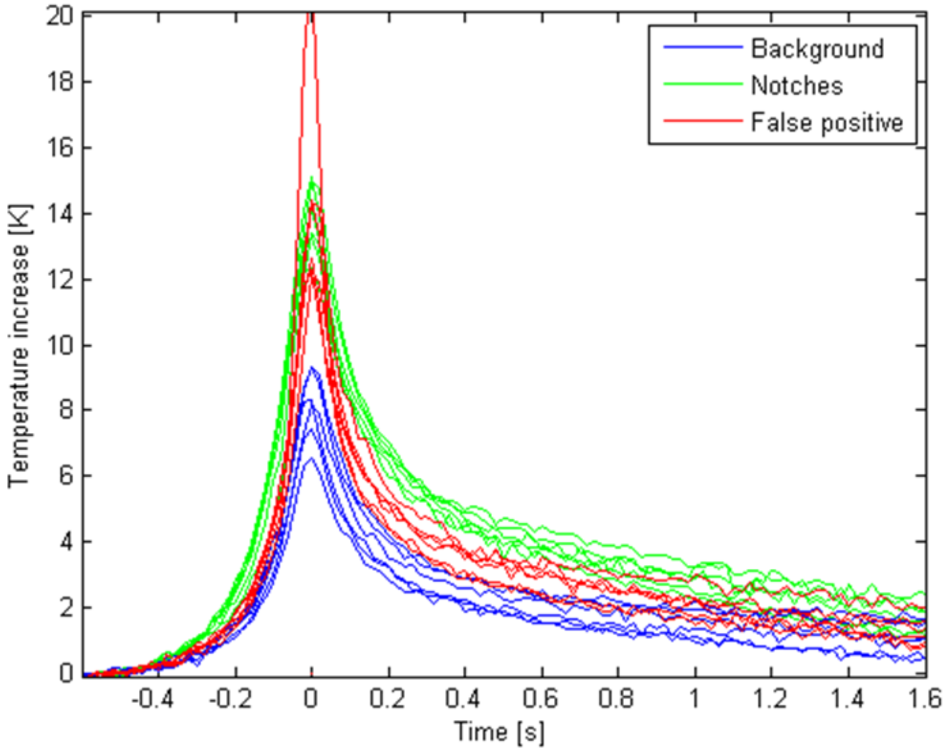


Fig. 2. Temperature increase in several notches, background points and false positives.

3. Demonstration

In the demonstration the measuring head, IR-camera and laser in combination with the periscope as in Fig. 1, was mounted on a six axes industrial robot. The robot was used for manipulating the measuring head in order to the scan the entire inspection area. In the measuring head a FLIR SC 655 microbolometer thermographic camera and a 10W Nd:YAG laser with a 10º power lens was used. Lenses producing a short line across the weld, with focus at the surface of the test plate, was used in order to maximize the energy density. In the measuring head a periscope with two mirrors made of polished aluminium was mounted. The part used for inspection in the demonstration was a mock-up of a jet-engine component (welded guide vane on a turbine exhaust case) with two small welded test plates mounted inside the mock-up. The test plates were made of Inconel with a welded bead on plate, named “sample 4” and “sample 9”. The weld had some real heat cracks with the width down to about 30µm. The inspection cell with the mock-up is presented in Fig. 3 and Fig. 4.

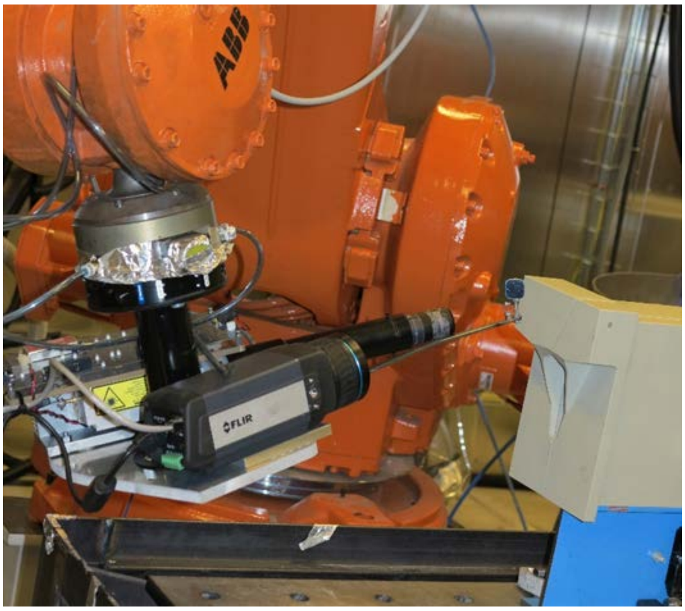


Fig. 3. The inspection cell with the measuring head mounted on a six axes industrial robot.
The mock-up, shown at the right in the picture, resembles inspection of a jet-engine component with limited access.

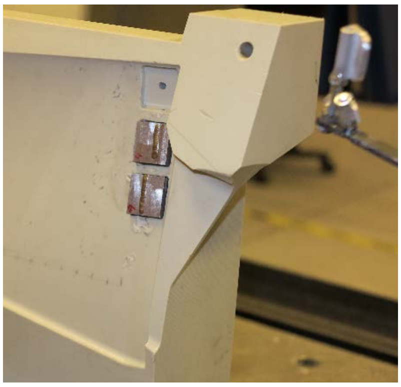


Fig. 4. The open mock-up with the welded test plates visible.
The upper test sample is named "sample 4"
and the lower "sample 9".

4. Results and Discussion

The demonstration of the automatic inspection cell showed that inspection of welds with limited access is possible. All cracks in each test sample were detected by the analysis algorithm developed within the project. Test plate, "sample 4", had two cracks across the weld and "sample 9" had one crack, see Fig. 5 and 6.

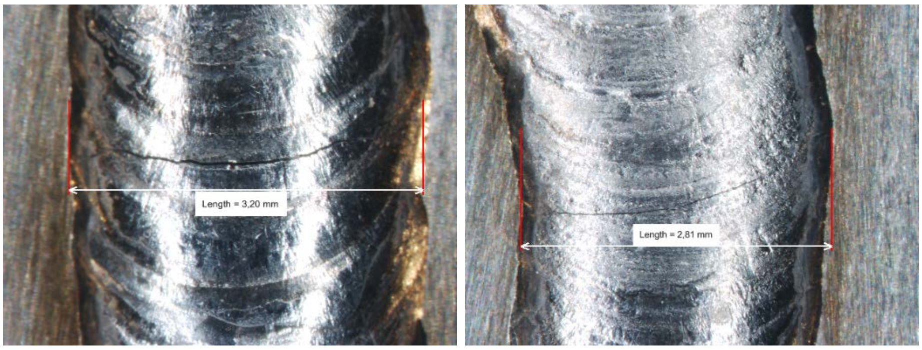


Fig. 5. Two cracks across the weld in test sample 4.

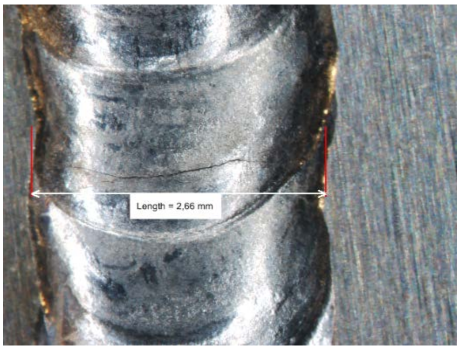
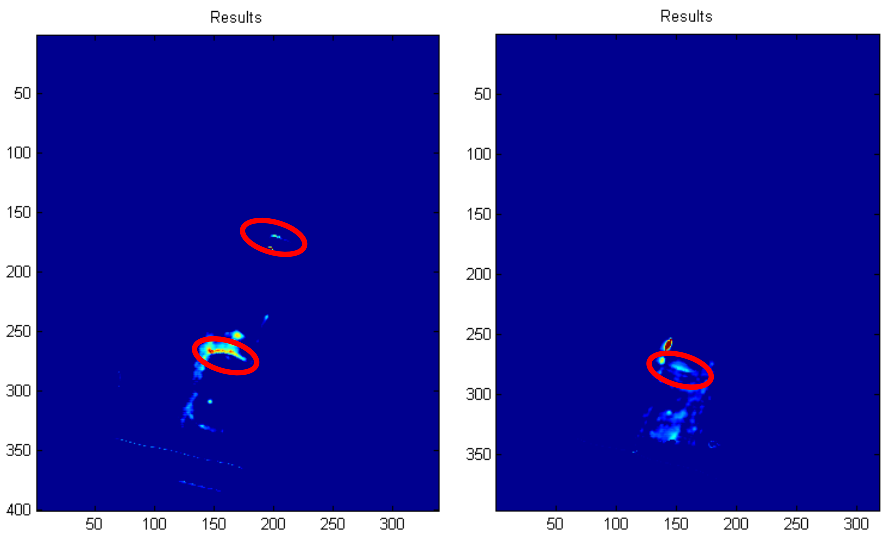


Fig. 6. The crack across the weld in test sample 9.

The results from the measurement of test plates in the demonstration are presented as thermogram images in Fig. 7. Both defects in sample 4 are found (Fig. 7a), even if the upper crack is on the limit for detection, and also the crack in sample 9 is detected (Fig. 7b).



(a) (b)

Fig. 7. Thermography results for (a) test sample 4 and (b) test sample 9. Real cracks detected by the analysis are marked with rings

In the results, Fig. 7, there are indications of defects, which are so called false positives. The false positives can be due to surface irregularities and oxides in the weld area. The analysis algorithms need to be developed further to be able to robust distinguish between false positives and real defect.

5. Conclusion

An automated inspection cell for surface crack detection in welds with limited access was demonstrated. The cell was based on a six axis industrial robot with a measuring head mounted on the robot arm for scanning the inspected area. The system was able to automatically scan a hidden weld on an aircraft component, which during the demonstration was performed through inspection of welds with limited access located inside a mock-up of a real jet-engine part. The demonstrator also showed the automated algorithms for analysing the data achieved from the measuring system. It was shown that surface cracks in the weld were located by the system. The study has not been able to quantify or size the defects, further research is needed to fulfil those requirements.

Acknowledgement

The work has been carried out within the project "Automatic thermography inspection of welded components with limited access" (18-WeLdt) and was financially supported through the Air Transport Net, AirTN, by Vinnova in Sweden and CDTI in Spain.

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