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Surface crack detection using infrared thermography and ultraviolet excitation

by A. Runnemalm* and P. Broberg*

* University West, SE-461 86 Trollhättan, Sweden, *Anna.Runnemalm@hv.se*

Abstract

High signal to noise ratio is important within non-destructive testing. To achieve automatic inspection, including automatic evaluation, it is even more important. Infrared thermography is a suitable method for automatic inspection. One drawback with thermography of metallic structures is that due to shiny surfaces the reflectance is high and the signal to noise ratio will be low. This paper presents results from surface crack detection with thermography using ultraviolet excitation. The tested component is a welded Inconel plate with a highly reflective surface. Ultraviolet excitation is shown to be a suitable excitation method and high signal to noise is achieved.

1. Introduction

Surface cracks are commonly inspected using eddy current or penetrant testing. For automated testing, infrared thermography has shown several advantages [1,2]. Active thermography can be performed by using different excitation techniques, all with pros and cons. Excitation techniques such as laser, white light, induction heating and ultrasonic are found in the literature [3-5]. The physical principles are to some extent different between the techniques and the methods are either based on pulsed, continuous or modulated excitation.

For thermography inspection of metals, some problems arises. The relative high thermal conductivity of metals require a high sampling rate. The infrared cameras are today quite fast, and this problem is therefore mostly not an issue. Another problem is the surface property of metals. Due to a shiny surface, noise from reflections are introduced. To achieve a fully automated inspection, noise needs to be reduced.

In this article an alternative excitation method, for surface crack detection on a shiny surface using infrared thermography, is presented. The excitation is performed by illumination by a Mercury lamp. The experiments show good results regarding noise reduction. The principle of the method is briefly described and results from inspection of a surface crack in a laser welded Inconel plate are presented.

2. Theory

Assuming the infrared (IR) camera is viewing only the measured surface, a simplified model of the total radiance detected by the camera, L_{cam}, with the sensitivity range, $\lambda_1 - \lambda_2$, is;

$$L_{cam} = \int_{\lambda_1}^{\lambda_2} (L_{emit} + L_{refl}) S_{cam} d\lambda, \tag{1}$$

where L_{emit} is the spectral radiance emitted by the surface, L_{refl} is the reflected spectral radiance of the studied surface and S_{cam} is a wave length dependant factor describing the sensitivity of the camera detector and the transmission of the camera lens. The radiance emitted by the surface, L_{emit}, is the quantity of interest for thermography inspection, the reflected radiance, L_{refl}, on the other hand will appear as noise in the measurement. If the reflected radiance increase, as for a shiny surface, the quantity of interest may drown since the IR camera detect the sum of the emitted and reflected radiance over the entire spectra.

The emissivity, ε, and the reflectance, ρ, of a material is related to each other due to radiation balance and Kirchhoff´s law, as;

$$\varepsilon + \rho = 1, \tag{2}$$

assuming the transmittance to be low enough to be neglected. For most metals, the emissivity is low in the IR region (that of the IR camera). The influence of the reflected radiance will therefore be relatively high for measurement on metals if any objects warmer than the studied surface are in the vicinity.

Most metals have a quite high emissivity in the ultraviolet (UV) region. By using UV light for excitation, most of the radiation from the excitation source is absorbed by the metal structure, and the reflected radiation is therefore reduced. In addition, the direct reflection in the measured surface, from the UV source are within wavelengths not detectable by the IR camera. Despite that, some reflections within the IR region will appear due the heating of the light source. By selecting the wavelength of the light source in a region where the metal has high absorptivity, e.g. the UV range for metals, the energy of the light sources can be reduced and the heating of the light source itself will be lowered, i.e. the noise due to heating of the excitation source is reduced.

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3. Optical excitation for detection of surface cracks by thermography

The theory for detecting cracks by thermography using optical excitation by a flash lamp or laser has been explained by Broberg [4]. When light enters a crack it is reflected multiple times and will deposit a larger amount of energy than at a single reflection, in a similar way as in a black-body cavity, and the absorption coefficient will approach 1. Therefore, a crack that is illuminated will absorb and emit more energy than the surroundings and will be visible as a hot spot if imaged by an IR camera.

Since a crack will absorb more energy than the surroundings, the rate of heating in the area of the crack is higher than elsewhere in the studied surface. By calculating the time derivative in each pixel, the rate of heating over the test sample could be compared. In a defect free surface, the heating will be even, but in the presence of a crack, a peak in the result images will appear.

One major problem with thermography on metal structures is reflections of infrared radiation from hot objects in the surrounding, including the excitation source, in the metal surface. The advantage of using an excitation source that does not emit radiation in the infrared spectra will be an increase of the signal to noise ratio which will make it easier to detect defects. Since everything with a temperature above absolute zero emits energy in the infrared spectra, and the amplitude increases with temperature, finding an excitation source that emits low amount of infrared radiation while still emit high energy in a separate wavelength is not always easy. Pickering et al. [6] presented results on defect detection on a carbon fibre reinforced plastic by using a LED light source. They report that the LED emitted some energy in the infrared spectra, resulting in noise, as it was reflected in the studied surface. By using a Mercury lamp for illumination and using an ultraviolet band pass filter, the reduction of noise due to reflection of infrared radiation can be ensured.

4. Experiment

A laser welded test sample made of Inconel (IN718) was inspected and surface cracks within the weld were identified by use of infrared thermography.

The infrared thermography system used for the experiments was a FLIR SC 5650 infrared camera with a band width of 2.5 – 5.1 μm and a 27 mm optical lens. The camera had an InSb detector with a resolution of 640x512 pixels and the frame rate during the recording was 100 images/s. The experimental set-up was according to figure 1.

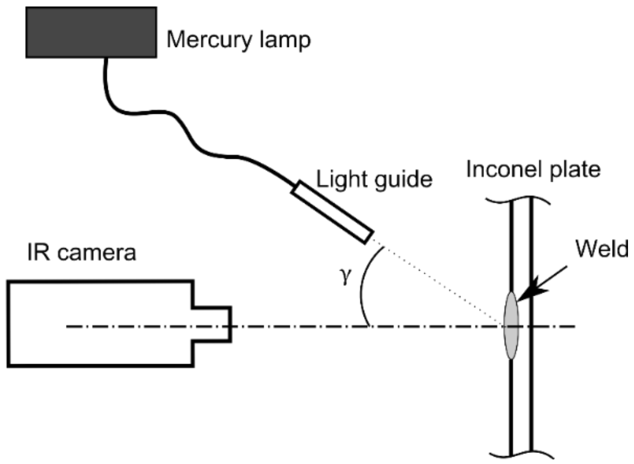

Fig. 1. *Experimental set up for thermography with ultraviolet illumination*

An ultraviolet light source was used (LUMATEC Superlite SUV-DC). The internal ultraviolet filter in front of the Mercury lamp was modified to have a band pass range between 320 and 500 nm. Using this configuration, the following of the strongly emitting spectral lines of the Mercury lamp was used: 334 nm, 365 nm, 405 nm and 435 nm. The unit was equipped with a flexible liquid light guide for delivery of the radiation to the measurement location. The light guide aperture was mounted 10 mm from the test sample, giving an illumination spot size of about 100 mm^2, and with an angle, γ, of about 10 degree. The total output power from the light guide was 1.5 W, measured at the test sample. The excitation of the structure was continuous during the recording.

The test sample used in the experiment was a laser welded plate made of Inconel (IN718). The plate was 3 mm thick and in the surface of the weld there was surface crack with a maximum width of 0.2 mm and length of 2.9 mm. During the experiment the illumination spot from the UV light source was illuminating the entire with of the weld at the position of the surface crack.

5. Results and discussion

Thermographic images with high signal to noise ratio are achieved from the experiments in this study, as can be seen in figure 2 and 3. The image is captured 2 seconds after the start of the illumination. The use of an ultraviolet light source for excitation during thermography inspection of surface cracks is shown to be a good

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alternative. The crack is 2.9 mm in length and 0.2 mm in width and is clearly visible as a hot area in the raw data images shown in figure 2. The millimetre indications and text on the ruler to the left in figure 2 appear as hotter areas, this is due to a variation in emissivity in the marking on the ruler. In figure 3 the normalized signal across the weld from the thermography image 2 seconds after start of the excitation is presented. The signal crossing the surface defect is presented as black solid line, and the signal across de weld outside the surface defect (above the defect) is presented as a red dotted line. From the figure it is clear that the signal from the surface crack is significant. It is also noticed that the signal to noise ratio is high.

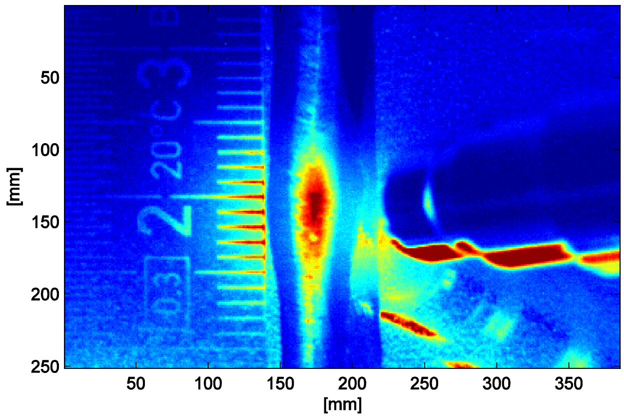

Fig. 2. *Thermography image of surface defect in weld, 2 seconds after start of excitation*

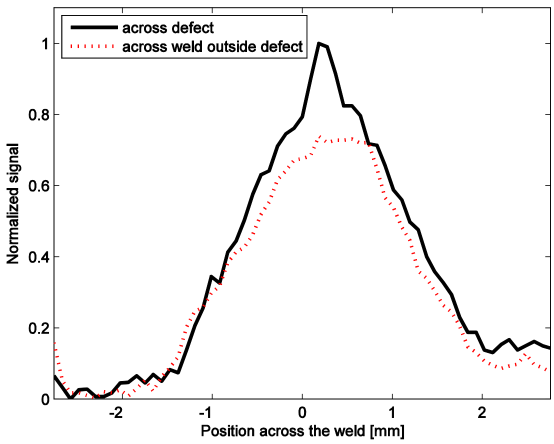

Fig. 3. *Normalized signal along a horizontal line crossing the detected surface defect (black solid line) and outside surface defect (red dotted line), 2 seconds after start of excitation.*

For comparison, images captured at 0.02 seconds after start of illumination are presented in figure 4 and figure 5. The crack is visible, even though it is harder to detect. Comparing the normalized signals across and outside the surface defects (compare black solid and red dotted line in figure 5) it is clear that the signal to noise ratio is rather low at the very start of the excitation with the UV light.

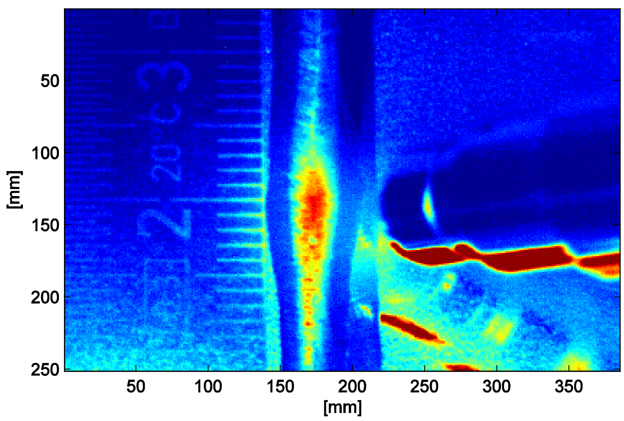

Fig. 4. *Thermography image of surface defect in weld, 0.02 seconds after start of excitation*

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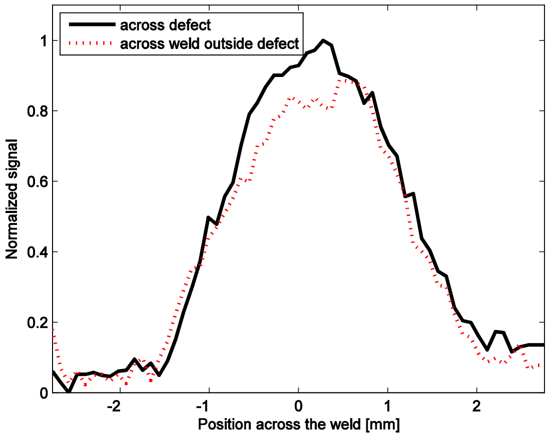

Fig. 5. *Normalized signal along a horizontal line crossing the detected surface defect (black solid line) and outside surface defect (red dotted line), 0.02 seconds after start of excitation.*

A graph of the normalised heating change in a point at the surface defect and at the weld outside the surface defect is presented in figure 6. It is clear that the measured signal raises is higher in the crack during the excitation with UV light than outside the crack. It is noticed that the measured signal have a higher time derivative in the crack than outside the crack. It is also noticed that the time derivative is higher in the beginning of the excitation, compare the slope of the black solid curve at different time in figure 6.

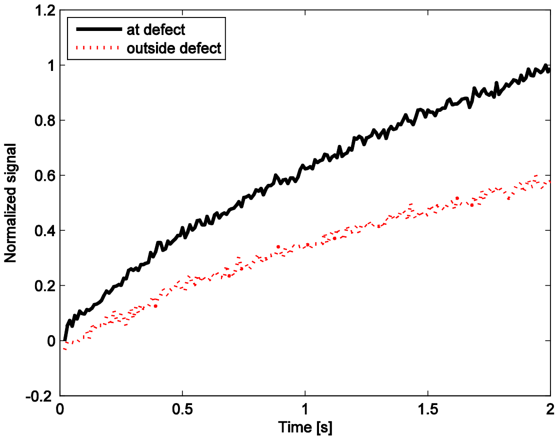

Fig. 6. *Normalized signal of the heating vs. time in a point at the surface defect (black solid line) and in a point outside the surface defect (red dotted line).*

An image of the time derivative in each pixel at 0.02 seconds after start of excitation is presented in figure 7, compare the image of the signal in at the same time (figure 4). The location of the surface defect is clearly visible. Additionally, the noise due to direct reflections in the light guide (to the right in figure 2 and in figure 4) has disappeared. This is since the direct reflection is constant over the time. The markings in the ruler are on the other hand appearing as hot areas with almost the same magnitude as the surface defects. The normalized time derivative of the signal across and outside the surface defect is presented in figure 8. Comparing figure 5 and figure 8, presenting the normalized signal and the normalized time derivative of the signal in the same points and at the same time, it is clear the signal to noise ratio is much higher using the time derivative as analysis method. The signal to noise ratio for the time derivative at 0.02 seconds after start of excitation is even higher than studying the raw signal at 2 seconds, compare figure 3.

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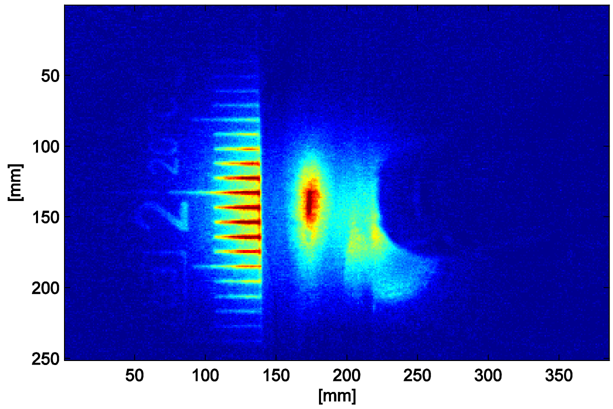

Fig. 7. *Time derivative plot of the result image captured 0.02 seconds after start of excitation.*

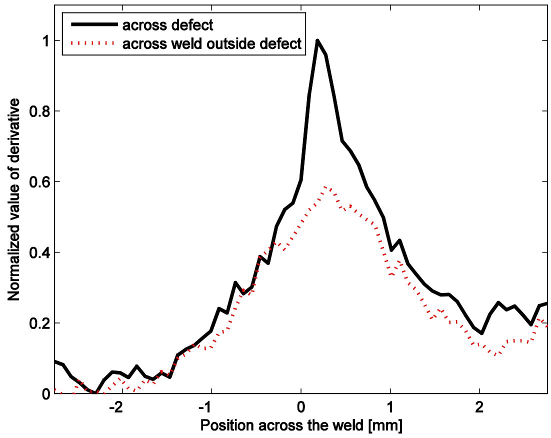

Fig. 8. *Normalized value of the time derivative of the signal along a horizontal line crossing the detected surface defect (black solid line) and outside surface defect (red dotted line), 0.02 seconds after start of excitation.*

6. Conclusion

To enable automatic evaluation of thermography results, a high signal to noise ratio is important. Thermography is a suitable method for automatic inspection, but the drawback for the method when used on shiny surfaces, e.g. metal structures, is the relatively high noise level due to reflection of IR radiation from hot objects in the surrounding, including the excitation source. This paper presents results from thermography inspection of a laser welded plate made of Inconel (IN718). The excitation used in the thermography experiments was an ultraviolet light source with that have four strongly emitting wave lengths, 334 nm, 365 nm, 405 nm and 435 nm.

The experiments show that the raw data images from the infrared camera could be used for detecting surface defects in the weld. The surface defect had a width of 0.2 mm and a length of 2.9 mm. The surface of the test sample was highly reflective, even though high signal to noise level could still be achieved when using an ultraviolet excitation source.

Since the heating at the surface cracks is much faster than in the defect free surroundings, the time derivative is a simple and useful analysis method. The experiments show that a high signal to noise ratio can be achieved almost directly after start of the illuminating the surface with the UV light. This is promising from an automation perspective. With a method that give a full field result over an area with a diameter of 10 mm (size of illumination spot) at 0.02 second, as is the case presented in this paper, results in an possible inspection speed of 500 mm/s.

REFERENCES

[1] Broberg P., Runnemalm A. and Sjödahl M., “Comparison of NDT-methods for automatic inspection of weld defects”. Accepted for publication in International journal of materials & product technology, 2014.

[2] Runnemalm A., Broberg P. and Appelgren A., “Possibilities and Limitations of Automated Non-Destructive Testing of Welds”, Proceedings of 5th International Swedish Production Symposium, Linköping (Sweden), Björkman M. ed., pp. 3-9, 2012.

http://dx.doi.org/10.21611/qirt.2014.016

[3] Almond D.-P., Weekes B., Li T., Pickering S.-G., Kostson E., Wilson J., Tian G.-Y., Dixon S. and Burrows S., “Thermographic techniques for the detection of cracks in metallic components”. Insight: Non-Destructive Testing and Condition Monitoring, vol. 53 (11) pp. 614-620, 2011.
[4] Broberg P., “Surface crack detection in welds using thermography”. NDT & E International , vol. 57 pp.69-73, 2013. doi:10.1016/j.ndteint.2013.03.008
[5] Meola C., Carlomagno G.-M., Squillace A. and Giorleo G., “The use of infrared thermography for nondestructive evaluation of joints”. Infrared Physics and Technology vol. 46(1-2) pp.93-99, 2004. doi:10.1016/j.infrared.2004.03.013.
[6] Pickering S.-G., Chatterjee K., Almond D.-P. and Tuli S. “LED optical excitation for the long pulse and lock-in thermographic techniques”. NDT & E International, vol. 58, pp. 72-77, 2013. doi:10.1016/j.ndteint.2013.04.009