Automatic Detection of Defects on Radiant Heaters Based on Infrared Radiation

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Abstract. A non-destructive testing method for automatic testing radiant heaters in an industrial quality control process based on statistical analysis of the distribution of the radiation intensity is proposed. A heater is measured by an infrared thermographic camera after a short pulse excitation. A method to locate and classify defects based on the statistical analysis of the sequence of images is developed. The distribution of the radiation intensity in each image is regulated by a fixed histogram pattern which is modified by the appearance of a defect. The histograms of the intensities are studied and the slopes, peak positions and values of the associated histogram-function define the position and kind of the defects. Fast mathematical algorithms to find peaks permit the automation of the defect-detection. The proposed technique was successfully validated with experiments in the laboratory.

Introduction

In manufacturing, the inspection (evaluation and testing) of products has traditionally been the way to ensure that products are designed and fabricated meeting customer requirements. However, nowadays inspection assessment has become one of the most important goals in any industry. Globalization and strong competence have led to taking special care on the free-defect products to maintain some commercial advantage. Several Evaluation and Testing Techniques have been developed during the past years. These have been improved to the point of almost making them independent of human subjectivity. Each different technique, supported by a huge range of diverse industries, has been optimized in its correspondent niches. Obviously, Non-Destructive Evaluation and Testing techniques (NDE&T) have obtained a special importance and attracted a great interest because the samples under inspection are not lost.

In the manufacturing process of radiant heaters, an aspect of the quality is the number and type of defects in the heater [1]. Defects can result in a less effective heater and a higher chance of breakdown. It is desirable to have these defects identified quickly, safely and non-destructively when determining the quality of a heater. Infrared thermography is a technique that can be used for this [2].

To investigate a heater using infrared thermography, the heaters are heated with an electrical pulse. The power dissipated in the wire heats the wire due to Joule heating. The radiation of the wire as a function of wavelength can be detected with a detector. In this case, an infrared camera is used. Since defects represent a different heating and cooling tendency due their different amount of energy transfer with the surroundings, these defects can be localized and identified by analyzing their heating and cooling tendency.

In this paper, a statistical method to identify and classify defects will be explained, the intensity behavior of the heater over time when applying a short pulse will be described, and the transfer functions will also be discussed.

Measurement Setup

The used measurement setup shown in the figure 1, consists of a radiant heater, an electrical system connected to the heater used to generate a pulse (consisting of a control and a timer), and an infrared camera connected to a computer.

A manufacturer of radiant heater has provided the heaters that were studied. Both a defect-free heater and a heater containing artificially created defects have been used. These defects include, linked material which creates an excess of heating material in a small area and llack of material as a consequence of a cut on the surface of the wire. Another example is defects due to a deficiency in heating material. The figure 2 shows examples of these and other kinds of defects.

The heater is electrically heated using an electrical control. The time of the pulse is set using a Crozet timer, which can produce pulses of about 0.05 s and higher.

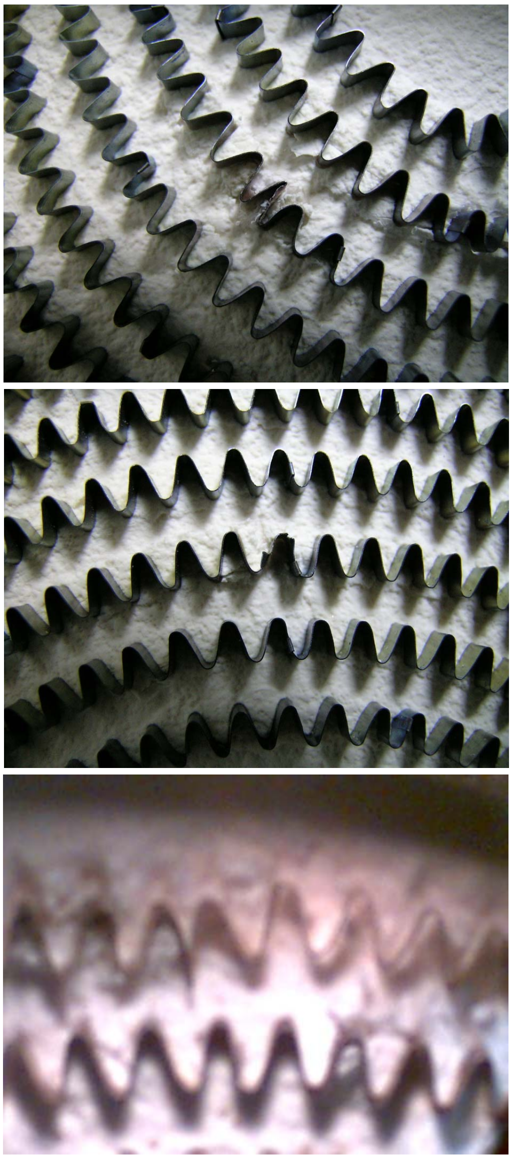
For the measurements, a Thermosensorik CMT 128M infrared camera is used. The main strong point of this camera is its high frame rate, which is desirable when the behavior of the heater during the application of a very short pulse is studied. The temperature resolution of this camera is also very good with an NETD (Noise Equivalent Temperature Difference) lower than 20 mK.

Analysis of results

In order to study the intensity of the different points in the image, only the wire itself needs to be studied. Including the background values is not necessary, because they do not give information about the defects. Therefore, the wire must be separated from the background.

Figure 1. Measurement setup

Multiple image processing methods exist that can be used to separate the wire from the background. Here, a method based on a threshold intensity value and neighboring pixels is used. The pixels with intensity higher than the threshold value are selected as the pixels to be studied. The image used for this is an image that is taken shortly after applying the pulse to ensure that the temperature contrast between the wire and the background is large. A threshold value equal to the mean with one third of the standard deviation subtracted is found to give good results. It is desirable to exclude the boundaries of the wire too, since the pixels at the boundaries represent both a part of the wire and of the background, creating unrepresentative intensities of the wire. To exclude the boundaries of the wire, an algorithm based on studying neighboring pixels is used. This algorithm excludes the pixels that are not part of a 3 by 3 block of initially selected pixels. This way, boundary pixels are excluded. In the following image, the part of the heater studied is shown, and the eventual selection of pixels that is studied is also shown. The figure 3 show the image studied that all have a pixel size of 128 by 128.



a) b) c)

Figure 1. Real and artificial defects on radiant heaters: a) Excess of material as a consequence of a link. b) Lack of material as a consequence of a cut on the surface of the wire. c) Parts of the wire that are not in contact with the substrate.

The intensities in the wire are assumed to be normally distributed in a defect-free heater without brackets. In a heater with defects, however, the intensities will not be normally distributed, since defects can exhibit a very different intensity distribution than the normal wire. Furthermore, in practice the wire is connected to the substrate with brackets, which results in a lower temperature in the parts of the wire that are connected to brackets. Therefore, defect selection based on the assumption of a normal distribution is not possible, because a method that assumes a more or less normal distribution of the intensities is only valid for a defect-free heater without brackets.

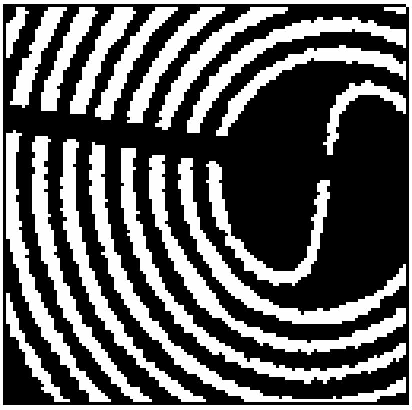


Figure 3: Selection of the wire to be studied

Because a normal distribution cannot be assumed, the histogram of the intensities should be studied. When making a histogram, the number of bins should not be too low, because in that case, one cannot distinguish small peaks well due to the fact that they disappear into larger bins as the number of bins gets smaller. It should also not be too high, because in that case small peaks disappear and eventually every peak is represented as a bar with a value of one. It is found that a value of 100 for the number of bins is a good value for the images made in these measurements. Furthermore, the difference in intensity between images at two different times (taken at the highest average intensity and after some cooling has taken place) is used to enhance the intensity contrast. A typical histogram of the eventual selection of points of an image of a defect-free heater is shown in the following picture. This histogram clearly shows that the intensities are not normally distributed.

The unsymmetrical shape of the distribution is due to the fact that a significant part of the wire is connected to brackets, which has on average a lower temperature than then part that is not connected to brackets. The shape of the histogram also depends on which part of the heater is studied, since the amount of brackets can vary between different parts of the heater.

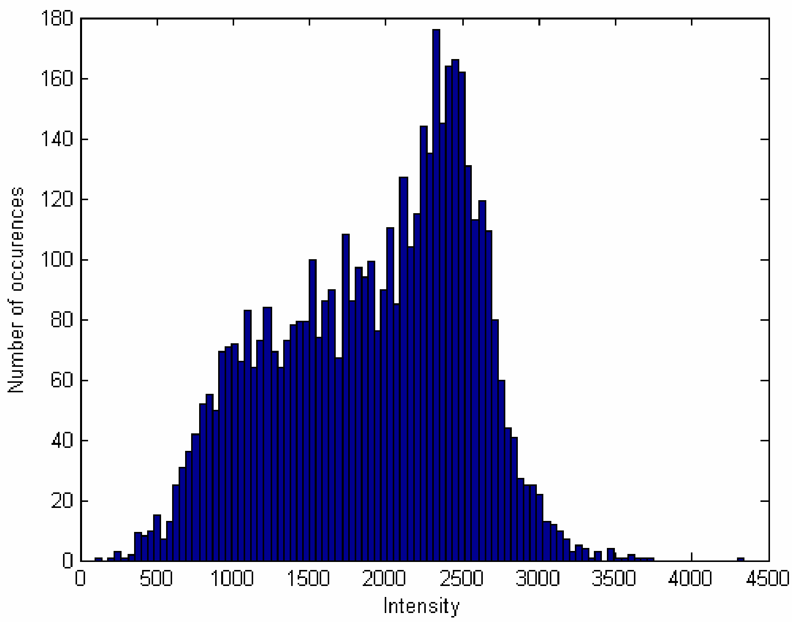


Figure 6: Histogram of the difference of two images of a heater with defects and a pulse time of 0.3 s

Because the intensity distribution of points that are clearly defects differs markedly from the distribution of normal points, these defects will generate peaks in the histogram after some ranges that contain zero or only a few occurrences in the histogram. When these defects are large, the histogram should have clear peaks representing these defects. However, the defects can also be small, in which case only small peaks in the histogram are seen. A threshold value based on the number of occurrences in the histogram can be set that identifies intensity ranges with occurrences lower than that value as defects. Since the normal points of the wire will have many occurrences in the corresponding ranges and defects will be located at the lower and higher end of the histogram and will have a few occurrences in those ranges, setting a threshold value based on a percentage of the number of occurrences in the highest peak of the histogram is justified. With this method, the defects can also be classified as a hotter or colder defect (relative to normal points on the wire) based on their relative intensity. The following images show identified defects in a heater using this method.

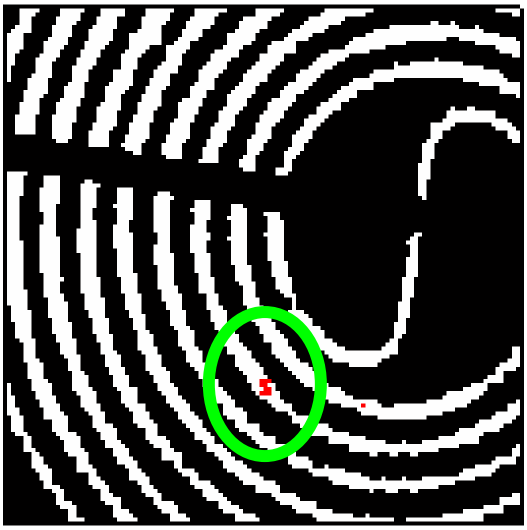


Figure 7: Defects in a heater excited with a pulse of 0.2 s

The defect on the left is a defect that is hotter than the rest of the wire (due to a link), and the defect on the right is a colder defect (due to a cut). Since these were the only defects in this image, the defects in the part of the heater studied have been successfully identified. The percentage of the number of occurrences in the highest peak in the histogram that was used to detect these defects was 6. A part of the top and the left of the image has been excluded, since it seems to be non-perpendicular to the camera in that part and generates false defects.

The method works well for pulse times of around 0.2 to 0.3 s. significantly larger pulse times result in saturation of the heater, and significantly shorter pulse times do not generate enough contrast to detect all the defects. This method does also not work well in case there are very much defects, because in that case some of the intensity ranges representing the defects will be above the threshold value. However, it is assumed a heater contains only a small number of defects. This method allows for setting an arbitrary threshold value. Therefore, producers of radiant heaters can adjust this value in order to set a certain quality threshold.

Conclusions

A NDT technique method to localize and classify defects on radiant heaters has been successfully developed. The method is based on an analysis of the histogram of the intensity distribution of a radiant heater as detected by an infrared camera after exciting it with a short pulse. A threshold value based on the number of occurrences in the highest peak in the histogram is used to the defect detection.

The heater is followed to found Joule's law in the first part of the heating phase. Later in the heating phase, convection and conduction start to play a significant role as well, and heating starts to slow down in that phase. In addition to that, the heater also acts as a capacitor.

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