Dynamic Inspection of Surface-Breaking Defects using Induction Thermography

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Abstract

In comparison to other active thermography techniques, induction thermography can provide instantaneous results, is not affected by material emissivity/reflectivity and is indifferent to surface geometry. These advantages make it a promising technique to be applied for in-line/dynamic inspections. In this work, the thermal signatures from a titanium sample under selected excitation parameters and moving speeds will be studied. To simulate surface-breaking cracks, electrical discharge machined (EDM) notches of varying lengths, widths and depths were made on the titanium sample. As with most applications, only a single side is accessible for inspection. Therefore, induction thermography in the reflection mode is utilized in this work. After evaluating the signal-to-noise ratio (SNR) under selected conditions and inspection speeds, the observations will be presented. The findings will be beneficial to researchers interested in implementing induction thermography in an in-line/dynamic inspection setting.

Keywords: Non-Destructive Testing, Induction Thermography, Active Thermography, Dynamic Inspection, In-Line Inspection

1 Introduction

Induction heating is a widely popular heating technique used not only in medical and domestic but also in industrial applications due to its many advantages such as rapid heating, efficiency and accuracy [1]. It is also used in the field of non-destructive testing (NDT), often referred to as induction thermography, where a short heating pulse is applied to induce heat within the material and a thermal camera is utilized to record the temporal changes [2]. Induction thermography can be used to detect surface-breaking flaws such as cracks. Cracks cause a change in the local distribution of the eddy currents that are produced by a high frequency induction coil, resulting in a generation of higher heat around the crack region which can be detected by a thermal camera [3]. Induction thermography is a great technique to detect surface-breaking defects such as cracks due to its non-destructive nature and contactless method; plus, there is potential to automate the inspection process [2].

Induction thermography is a method of active infrared thermography which is commonly performed in a static configuration where all elements, \textit{i.e.}, the thermal camera, excitation source and object of interest do not move with respect to each other [4]. This configuration poses challenges when inspecting larger surfaces and is particularly time consuming when inspecting many identical parts. Incorporating automation with induction thermography to perform a dynamic inspection should reduce inspection time, increase cost-effectiveness and enhance the reliability of the inspection [5].
2 Methodology

A dynamic inspection of the titanium notched sample is performed using induction thermography. The data obtained is analyzed to better understand the correlation between the SNR and the depths and widths of the respective notches, while also evaluating the impact of varying the inspection speed.

2.1 Material Characterization

The sample used for this experiment as seen in Figure 1, is a titanium block measuring $50.8 \times 50.8 \times 6.35$mm with electrical discharge machined (EDM) notches of different lengths, depths and widths to simulate surface-breaking defects. The cross-sectional view and dimensions of the respective notches are also shown in Figure 1. For the purposes of this experiment, the focus will be on notches N1, N4 and N7 for width comparison and N7, N8 and N9 for depth comparison.

![Figure 1. Titanium EDM notch sample details](image)

<table>
<thead>
<tr>
<th>Notch</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
<th>N4</th>
<th>N5</th>
<th>N6</th>
<th>N7</th>
<th>N8</th>
<th>N9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
</tr>
<tr>
<td>Depth (mm)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.25</td>
<td>0.375</td>
<td>0.5</td>
<td>0.25</td>
<td>0.375</td>
<td>0.5</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

2.2 Experimental Setup

A schematic of the experimental setup is depicted in Figure 2. An induction system is used to thermally excite the sample via a heating coil attached to a work head. A long-wave infrared (LWIR) camera operating at a wavelength of 7.5 – 14µm is used to record the thermal behaviour of the sample during the experiment. A collaborative robot (cobot) is used to move the sample across the induction coil, thereby creating a dynamic inspection.
Three different speed settings are used for the dynamic inspection, 5, 10 and 15 mm/s while the excitation current for the induction heating unit is set to 300A. Figure 3 illustrates the orientation of the sample and the lift-off distance of 5 mm used between the coil and sample surface.

3 Results & Discussion

As mentioned, the focus of this experiment will be on notches N1, N4 and N7 for width comparison and N7, N8 and N9 for depth comparison. In the thermal imaging software, measurement cursors are placed over the desired notches as seen in Figure 4 (a) to extract the temperature readings.
As the sample moves across the heating coil, N7, N4 and N1 will pass through Cursor 1 in that order. Similarly, notches N7, N8 and N9 will pass through Cursors 1, 2 and 3 respectively. The peaks in the plots represent the presence of a notch i.e., signal and the region just before the peak occurs is used as the ‘noise’ reading. The SNR data is extracted to calculate the difference in temperatures, Delta T ($\Delta T$) and the respective width and depth graphs are plotted at the three different inspection speeds as seen in Figure 5.

![Graphs](image.png)

Figure 5. $\Delta T$ plots for width and depth comparisons at different speeds

As seen in Figure 5 (a), (b) and (c), the $\Delta T$ readings for N1 and N4 are similar however there is a significant increase in readings for N7. The $\Delta T$ values for the depth comparison plots depicted in Figure 5 (d), (e) and (f) reflect a noticeable increase with reference to the notch depth.
N1 is 0.03mm narrower than N4, while N4 is 0.05mm narrower than N7. From Figure 5 (a), (b) and (c), it is observed that this difference in width correlates with the increase in ΔT values whereby a 0.03mm width difference results in negligible ΔT while a 0.05mm change in width results in a 0.2°C - 0.4°C ΔT. In the case of the depth comparison data, the depth of notches N7, N8 and N9 increase by 0.125mm and the ΔT readings also increase in a steady manner. The observed correlations are based on limited sets of data and further investigation is required to form any conclusions. Some variations in the readings may be due to experimental error.

When comparing the three different inspection speeds, the ΔT readings vary and this is better reflected in Figure 6 as seen below.

For the selected notches, regardless of their width or depth, an increase in inspection speed results in a decrease of the ΔT values. At a slower inspection speed, the notch is exposed to the heating coil for a longer period translating to an extended excitation duration, hence the ΔT readings are higher. Whereas with the faster inspection speeds the excitation duration is minimized, resulting in lower ΔT readings. It is worth noting that while a faster inspection speed may reduce inspection time, inspection reliability may be compromised as certain defect sizes may be missed.

It is observed that by increasing the speed from 5mm/s to 10mm/s, the ΔT readings are almost halved, especially for the smaller notches. Therefore, it is recommended to utilize a slower inspection speed to increase the possibility of detecting smaller sized cracks. However, if the inspection is performed on a conveyor system and the speed is fixed at 15mm/s for example, there is some limitation in detecting the smaller sized cracks. This can potentially be overcome by adjusting variables like reducing the lift-off distance and/or increasing the induction current to improve the ΔT values. Therefore, further investigation is needed to identify the limits and suitable inspection configurations of this dynamic induction thermography inspection, to not only improve inspection time but also confidently detect the defect size of interest.
4 Conclusion

In this study, dynamic induction thermography is performed on a titanium sample with EDM notches that simulate surface-breaking defects. After gathering and evaluating the data, a couple of trends are observed. The width and depth of the notches are proportional to the $\Delta T$ readings while the inspection speed is inversely proportional to the $\Delta T$ readings. These observations are based on limited sets of data and further investigation is necessary. Ultimately, there is potential for incorporating automation with induction thermography and implementing it in a dynamic setting. However, caution must be exercised when selecting the inspection configuration to ensure the inspection process is both efficient and reliable.

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References


