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Quantitative defect detection on the underside of a flat plate using mobile thermal scanning

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Abstract

Computational simulation is used to investigate mobile thermal scanning for the detection and quantitative measurement of defects along the underside of a steel plate. Comparisons are made between mobile and stationary heating regimes. The Full Width Half Maximum (FWHM) method is applied to determine the defect size, and the second order peak derivative method to determine the defect depth. Results for near-surface defects showed good accuracy, however errors are shown to grow with increasing defect depth.

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Keywords: Thermography; Mobile heating; Defect size; Defect depth; FWHM; Defect detection

1. Introduction

Nomenclature

D_S	defect size
D_{SE}	predicted defect size
D_d	defect depth
k	thermal conductivity
α	thermal diffusivity
e_s	thermal effusivity

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Thermographic inspection employing stationary heating is well established, reasonably effective in characterising the depth and size of certain types of defects [1-3] and very rapid compared to other inspection methods. Two quantitative approaches commonly applied are the second order peak derivative [1, 4, 5] and the Full Width Half Maximum (FWHM) methods [2], which furnish estimates of the subsurface depth and lateral extent of a defect respectively. There are other methods capable of measuring material local thickness such as the temperature contrast method, contrast derivative method, emissivity compensated peak algorithm and pulse phase thermography (PPT) [6-8], however, some require a priori knowledge of the structure which may not always be available.

The in situ detection and characterisation of defects in steel rail is a challenging problem because of the need to inspect long lengths of rail rapidly. Conventional stationary forms of active thermographic inspection are obviously unsuitable for this type of problem however mobile thermal scanning has some potential. Previously, it was shown that the response of certain rail-defect structures to high-speed mobile thermal scanning is similar to that for a stationary heating regime which enabled a simplified approach to simulating a moving heat source [9]. The present study extends the previous work by applying the second order peak derivative and FWHM methods to furnish estimates of the depth and lateral size of defects based on simulations of the temperature response to mobile thermal scanning.

2. Methodology

2.1. Second Order Peak Derivative Method

For a semi-infinite homogeneous solid subject to an instantaneous heat pulse, the temperature response at the surface is given by Equation (1) [6]. This equation describes the cooling of the surface as a function of time. Taking the natural logarithm of this equation reveals an important characteristic of the cooling behaviour that leads to a basis for estimating the local thickness of the structure [4].

$$T(0,t) - T_i = \frac{e_s}{e\sqrt{\pi t}} \tag{1}$$

$$\ln \Delta T = \ln \frac{e_s}{e} - \ln \sqrt{\pi t} \tag{2}$$

$$L = \sqrt{\pi \alpha t} \tag{3}$$

where T(0, t) is the surface temperature (^{o}C) with respect to observation time, t, T_i is the initial temperature of the body, e_S is the input energy per unit area (J/m^2), e is the thermal effusivity, and L is the material thickness.

For heat diffusion in a semi-infinite solid, a log-log plot of temperature versus time per Equation (2) reveals a slope of -0.5 [4], which occurs irrespective of the material properties. The introduction of an adiabatic back wall leads to a disruption of this log-linear behaviour (see Fig. 1) which occurs at a time related to the distance between the back wall and the surface (L in Equation 3) [5]. However, as the transition occurs gradually it is difficult to pinpoint the deviation time. The second derivative is more readily identified and can be related analytically to the back-wall distance L [1].