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Modelling of the lock-in thermography process through finite element method for estimating the rail squat defects

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ABSTRACT

Squats are a major problem on the world railways. The non-destructive evaluation technique is becoming increasingly attractive in the detection of near surface defects on track. Non-destructive thermal evaluation is one such method of inspection technique that can be used for the detection of near surface defects. Its sub-group of lock-in thermography is under analysis. Lock-in thermography utilizes an infrared camera to detect the thermal waves and then produces a thermal image, which displays the local thermal wave variation in phase or amplitude. There are few studies into the actual experimental representation of complex subsurface defects when concerning lock-in thermography processes. While this may be less of a concern given the purpose of numerical defect characterization to reduce the need for extensive experimental pre-tests, the necessity for (artificial) representations of a defect will inevitably be required for validation. The research outlined in this paper examines the use of 3D finite element modelling (FEM) as a potential flexible tool in simulating the lock-in thermography process for detecting squats in track. In addition, lock-in analysis proved that the correct frequency range had to be selected for the material to detect the defect. As maximum positive and negative phase angles were located at "optimum" frequencies, at certain frequencies lead to minimal phase angle difference to which the defects were not detectable (blind frequency) by using the incorrect testing. The 3D finite element method has advantage for determining the "optimum" thermal excitation frequencies compare with experimental investigation. The experimental results show that 3D FEM models can be used to defect the location and the depth of squats in the railway.

1. Introduction

Rail squats/damage/failure is a problem of considerable economic cost. More and more track in numerous railway systems throughout the world is being affected by squats. In Australia, they first occurred in the Hunter Valley in the early 1990s and Railcorp passenger lines in the early 2000s becoming very prolific in some locations since then, with over 500 counted in 1.4 km of the Down North Shore Line. Squats now affect a large proportion of the RailCorp System (nearly 18%) covering a wide spectrum of infrastructure configurations and traffic types [1]. Therefore the development of inspection methods to assess squat presence and measure their depths are of considerable interest.

The use of infrared thermography as a nondestructive evaluation technique is becoming increasingly attractive in the detection of surface or sub-surface defects in many diverse applications, such as bridges, buildings and aircraft industry [2–5]. Thermography offers several advantages over other non-destructive techniques in that it is non-contact, able to inspect wide areas and produce easily interpreted results. The non-destructive evaluation technique sub-group of lock-in

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thermography is perhaps the most promising technique to investigate steel structures [3–9]. Lock-in thermography utilizes a sinusoidal thermal stimulus to excite an object of interest. This stimulus can be introduced to the structure of interest internally via the thermo-elastic effect or by an external stimulus such as an array of heat lamps. These can be determined through variations in phase and amplitude of the components response, which is picked up from its surface by an Infrared camera. The equipment set-up of the "Lock-in" procedure is shown in Fig. 1.

When a photonic heating source is used in the lock-in technique, the technique is usually referred to as optical lock-in thermography. Lock-in thermography can provide both amplitude and phase angle information. The phase angle refers to the measured phase difference $\Delta\phi$ between the sinusoidal input signal and the measured thermal signal response of an object, see Fig. 2. The phase difference $\Delta\phi$ can be used to determine material properties, near surface defects and locating areas of depth changes.

At present, the qualitative potential of lock-in thermography is such that in order to establish a prediction regime for near surface defects, existing qualitative data must have already been gathered. But, in gathering this data, time and tedious procedures are required. Furthermore, to obtain the "best" inspection result, the optimum parameters, i.e. those which can lead to the "best" estimate of the plan view area, should be used. Hence the selection of the optimum inspection parameters is very important. For some simple cases, it is possible to determine the optimum inspection parameters from specimens with implanted defects. However, for most cases, defects such as squats in the rail are very difficult to simulate. Thus it is difficult to experimentally determine the optimum inspection parameters. The theoretical or numerical analysis may become efficient method.

Observed squats in the rail are non-planar 3D features that nucleate from areas of high stress concentrations in geometrically complex regions of the rail. Since the actual development pathway of squats is very complicated. Due to the diffusive nature of thermal signals in materials there is a nonlinear drop in detectability of anomalies below the surface. It is very difficult to do analytically. Hence, a numerical method such as a 3D finite element analysis may be conducted to establish the validity of the phase contrast measurements and examine the effect of lateral heat diffusion on the lock-in thermography process.

The first aim of this paper is to investigate the 3D finite element method ability of detection squat in simulating the lock-in thermography process. A second aim is to explore the effects that various factors have on phase contrast, such as defect size, crack profile shape, as well as excitation frequency and sampling rate by using 3D the finite element study models to predict optimum inspection parameters. As such, one aim of this paper is to generate a 'calibration' of the squat depth so that

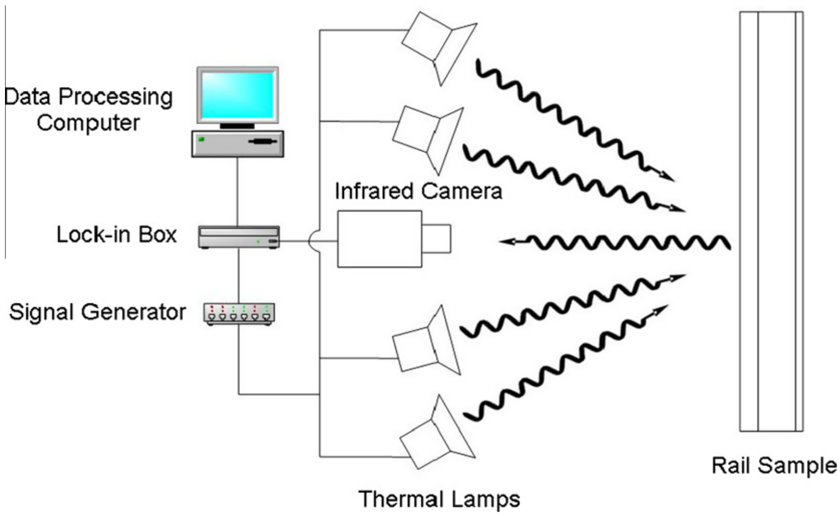

Fig. 1. Schematic of lock-in thermography experimental setup.

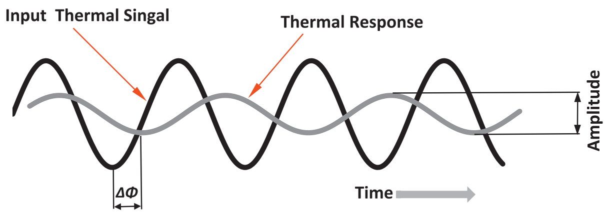

Fig. 2. Phase angle difference of thermal response.