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Research Article

Detection of cracks using active thermography for Non-Destructive Testing of Steel Materials

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Abstract

Infrared non-destructive evaluation (IRNDE) is an emerging approach for non-contact inspection of various solid materials such as metals, composites and semiconductors for industrial and research interest. This paper focuses on inspection of plain carbon steel materials, which are widely used, particularly in the power and steel industries. This paper describes some applications of recently proposed pulse compression based approach to the inspection of steel specimens. Present work highlights both phase and correlation based approaches for defect detection using frequency modulated thermal excitation scheme and comparison has been made on these proposed schemes.

Keywords: IR themography, Chirp excitation, nondestructive testing, pulse compression, thermal waves

1. Introduction

The basic principle of NDE is the energy imparted into the structure to assess (identification of defects, voids, inclusion etc) the condition of the material. Based on method of excitation, it was classified in to several categories viz. ultrasonic imaging, radiographic, or eddy current, acoustic emission, heat energy (Infrared testing), vibration etc. Infrared thermography has become a more popular nondestructive inspection method to evaluate subsurface defects in metallic, insulating, and composite materials, because of its fast inspection rate, noncontact, portability, and easy to interpret. In thermography the surface temperature of the structure is monitored using an infrared camera, and anomalies in the temperature distribution reveal the presence of defects. Thermographic methods broadly divided into two types: passive, in which the temperature pattern of the surface of material is measured without any external thermal excitation, and active in which thermal energy is artificially injected in to the material to be tested (1). The presence of delamination defects in any material can cause significant improvement in failure probability, therefore, they must be detected and evaluated. Although several methods have been proposed in the literature to detect delamination defects in solid materials, three of them are predominantly in use: Pulse Thermography (PT), lock in Thermography (LT) and Pulse Phase Thermography (PPT) (2-4). However, none has so far been free from certain limitations: Pulse thermography(PT) requires high peak power heat sources and being sensitive to surface emissivity variations and nonuniform heating on the surface of test sample, lock in Thermography (LT) suffers with limited depth resolution and long processing time

(5,6), and Pulse Phase Thermography (PPT) needs high peak power heat sources to detect deeper subsurface defects, which however may damage the surface of the test sample. In this paper, Frequency Modulated Thermal Wave Imaging (FMTWI) (7) was employed to identify the defects in solid material and depth resolution capability was compared with the conventional phase-based techniques.

2.Theoretical background on Frequency Modulated Thermal Wave Imaging

The principle of frequency modulated thermal wave imaging consists of introducing frequency modulated heat flux into an object to be tested and resulting temperature field in the transient regime is remotely recoded through its thermal infrared emission with IR camera(7). When frequency modulated heat flux is exited into the specimen, and the infrared camera controlled by the computer monitors the surface temperature profile on the heated sample as shown in figure 1. The expression for a thermal wave propagates into the interior of the solid when a linearly frequency modulated heat flux of duration τ with a bandwidth B at surface (x=0) incident on the sample is given by (7)

$$T(x,t) = T_0 e^{-x\sqrt{\frac{\pi}{\alpha}(f+\frac{Bt}{\tau})}} . e^{j\left[2\pi\left(ft+\frac{Bt^2}{2\tau}\right)-x\sqrt{\frac{\pi}{\alpha}(f+\frac{Bt}{\tau})}\right]}$$

$$= T_0 e^{-x\sqrt{\frac{\pi}{\alpha}(f+\frac{Bt}{\tau})}}[Cos(k) + JSin(k)]$$

Where $k = 2\pi\left(ft + \frac{Bt^2}{2\tau}\right) - x\sqrt{\frac{\pi}{\alpha}(f + \frac{Bt}{\tau})}$

From above equation the diffusion length μ_{fm} can be written as

$$\mu_{fm} = \sqrt{\frac{\alpha}{\pi(f+\frac{Bt}{\tau})}}$$

Therefore , above equation indicates that the thermal diffusion length depends on the bandwidth of frequency modulated thermal excitation over the sample surface. This helps to scan the entire depth of the sample with time during one frequency modulated cycle. The thermal wave length (λ) in case of frequency modulated thermal wave imaging is given by

$$\lambda = 2\pi\mu_{fm} = 2\pi\sqrt{\frac{\alpha}{\pi(f+\frac{Bt}{\tau})}}$$

Hence, the wavelength will vary with time leading to variation in the depth resolution for detection of defects at different depth.

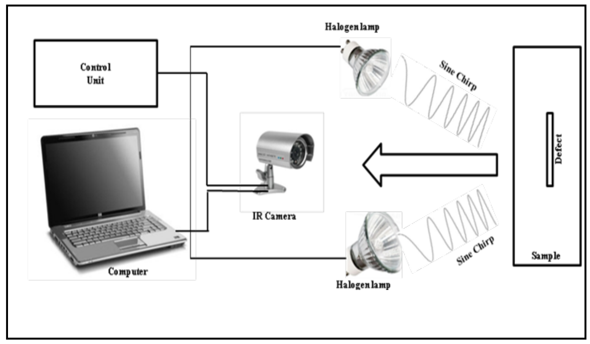

Figure 1: Set up for Frequency modulated thermal wave imaging(FMTWI)(7)

2.1 Principle of Pulse compression

The pulse compression approach was introduced for NDE in infrared thermography applications by Tuli.S etal in 2005(8), which allows transmission of a low peak power and long duration modulated wave. This gives better depth resolution capability and Signal to noise ratio comparable to short duration, high peak power techniques. Pulse compression is achieved by taking cross correlation between two sequences at defective and non-defective regions.

2.2 Pulse and Lock-in thermography:

In pulsed thermography (PT), the surface of a sample to be tested is heated with a short duration pulse and the subsequent cooling is observed on the surface of the sample [9]. The duration of pulse depends on material to be tested i.e few milliseconds for high- thermal diffusivity material and few seconds for low thermal diffusivity samples. Pulsed thermography (PT) is one of the most promising thermal stimulation methods used for material/structure characterization/testing due to its unique features: non-contact high-speed, large area inspection technique and portable. [10,11]. Lock-in thermography(LT) involves a periodic heat wave is applied to the specific area of sample and the resulting oscillating temperature field is recorded remotely through its thermal infrared emission by an IR camera in the stationary regime [12].

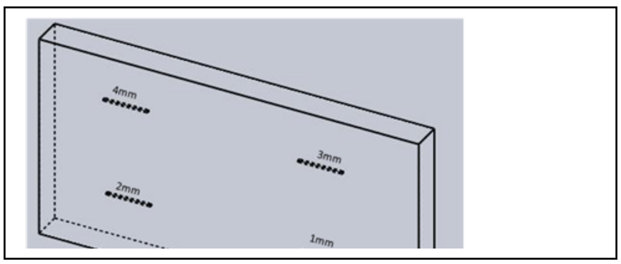

Figure 2: (a)Sample geometry (thickness 10 mm) (b) Surface temperature distribution over the surface at nondefective and defective regions

3. Results and discussions

The sample plate of plain carbon steel having dimension 100mm X 50mm X 10mm with 4 cracks all of the same dimension(15mm x0.5 mm x1mm) are located at different depths(1mm to 4mm from the surface)as shown in figure 2a was designed and simulations of pulsed thermography (PT), Lock-in thermography(LT) and Frequency modulated thermal wave imaging (FMWTI) were carried out using SolidWorks® 2009 .A frequency modulated thermal wave signal (figure 1) of 100 sec duration with its frequency varying from 0.01Hz to 0.1Hz was applied to cracked sample surface(Heat flux :1000 W/m^2), and the resultant temperature distribution over the surface as shown in figure 2b . The sequence of images are generated from simulated data at sampling rate of 0.1sec. The transient temperature profile over the surface of the cracked sample at non defective and all defected locations were extracted, and response at non defective location was considered as reference. The cross correlation of temperature profile at different defective region with reference profile were obtained. The image obtained from correlation approach as shown in figure 4. In PT, a pulsed excitation of 5 s with a

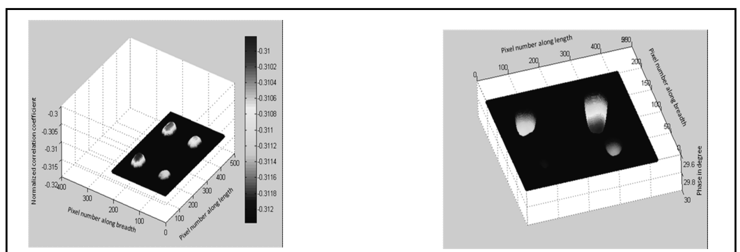

Figure 3: Images obtained in different schemes (a) FMWTI(pulse compression) (b) FMWTI(phase) (c) PT(phase) (d) LT(Phase)

heat flux density 3000 W/m^2 applied to surface of cracked sample and surface temperature over the sample is generated from simulated at sampling rate of 0.1 sec for a duration of 100s. In LT a sinusoidal excitation of frequency of 0.02 Hz, 0.03Hz and 0.5Hz with a heat flux density of 500 W/m^2 imposed to sample for100 s. Figure 3 shows the phase images of plain carbon steel sample of FMWTI, PT and LT . These results highlights both phase and correlation based approaches for defect detection using frequency modulated thermal excitation scheme with respect to pulsed thermography (PT), Lock-in thermography(LT). From 3, it is observed that pulse compressed images clearly preserve the contrast over all defect compared to phase contrast over defects. In order the asses the detectability of defect detection, the SNR of all schemes were calculated and compared as shown in figure 4. FMTWI exhibits better detectability than the remaining schemes.

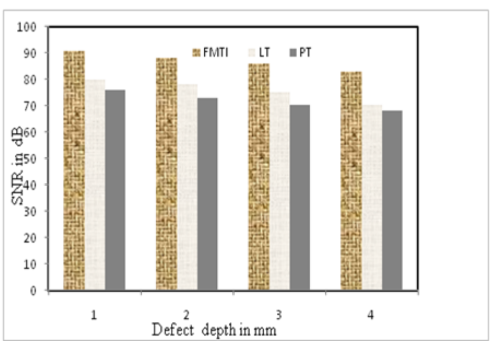

Figure 4: SNR values of different schemes

4. Conclusions

In this paper, the efficiency of FMTWI to detect a choice of defects and subsurface crack features on plain carbon steel was studied. The defect detection capability of Frequency Modulated Thermal Wave Imaging (FMTWI)with pulse compression approach was demonstrated by simulating plain carbon steel having cracks at different depths and comparison has been made on these proposed schemes with LT and PT. Based on images obtained, we conclude that, FMTWI with pulse compression approach has high depth resolution over other schemes. Furthermore, the use of FMWTI proved to one of the promising approach in the evaluation of defects in solid materials.

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