EFFICIENT SNR DETERMINATION ALGORITHM FOR PULSE COMPRESSION DEFECT DETECTION AND QUANTIFICATION

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Abstract

Lock-in thermography and pulse thermography are some conventional active thermography techniques. Pulse compression is a relatively new signal processing thermal imaging technique for defect detection. A frequency modulation excitation signal in pulse compression technique is expected to improve the defect detectability. However, the quantification of detected defects are challenging due to the nature of data that requires processing of entire video. An algorithm for signal to noise ratio (SNR) calculation for a given defect is proposed here.

Keywords: Thermal NDT, pulse compression, SNR calculation

1. Introduction

Lock-in thermography [1,2] and pulsed thermography [3,4] are both conventional active thermography techniques for defect detection. For a pulsed thermography the test-piece is exposed to a very high intensity light for a short duration. Lock-in thermography comprises of a modulated excited signal where the signal varies periodically with time. The frequency of modulation is known as lock-in frequency. The change phase and amplitude of the resultant thermal waves are studied [5]. A parameter known as diffusion length determines the deep defect detectability. Diffusion length is defined as the distance where the sample temperature reduces to 1/eth of that on the surface.

\[ \mu = \frac{2k}{\omega \rho c} \]

Where \( \mu \) is the diffusion length, \( k \) is thermal conductivity, \( \omega \) is the angular frequency, \( \rho \) is density and \( c \) is the specific heat.

The frequency modulation [6,7] is an extension of lock-in frequency where a band of frequencies are incident on a sample. The frequency range of the excitation source produces thermal waves with diffusion range that covers the range of defect range to be detected. The pulse compression is a relatively new thermal imaging technique [8,9]. The original idea of pulse compression thermal wave imaging is based on the signal processing technique used in RADAR [10]. Herein, the chirped response of the sample is correlated with the reference signal to generate a compressed pulse thermal response. The abstract describes the application of a pulse compression based defect detection technique. The paper explores the role of different pulse compression parameter for defect quantification. Further, a SNR calculation algorithm for defect quantification is presented.
2. Experiment Set-up

The basic set-up comprises of a test piece, a set-up to record the reference signal, an infra-red camera, an excitation source along with its modulation circuitry and a computer. Fig. 1 depicts the complete experimental set-up. The CFRP test-piece sample is shown in figure 2.

A 40 W LED source is the excitation source with a relay that turns on-off to modulate the source. An ldr records the reference signal at an interval of 10msec. A FLIR Silver 5000M infra-red camera is used to record the sample response. The camera has a resolution of $320 \times 240$ and the samples are acquired at a rate of 10 frames per second.

![Fig 1 Experiment Set-up](image)

The excitation signal is a linear up-chirp with frequency varying from 0.01 - 0.09 Hz with corresponding diffusion length from 8.1 to 2.7 mm respectively. The following CFRP thermal parameters are used for thermal diffusion length– thermal conductivity $4 \text{ W/m}^0\text{C}$, density $1600 \text{ kg/m}^3$, specific heat $1200 \text{ J/kg}^0\text{C}$.

![Fig 2 CFRP sample](image)

Post-processing-

The chirped experiment for duration of 900 sec is processed off-line. Both the reference signal and the recorded thermal response of test-piece are polynomial fitted to remove the dc component. The resultant
offset-removes signals are cross-correlated in frequency domain to obtain the resultant compressed pulse signal.

3. Results

The resultant compressed pulse is described in figure 3(a) for a single pixel. The thermal image of the sample from the processing technique is described in figure 3(b).

\[ x \times 10^5 \]

\[ -5 \quad -400 \quad -300 \quad -200 \quad -100 \quad 0 \quad 100 \quad 200 \quad 300 \quad 400 \]

Figure 3 (a) Timing diagram for a single pixel (b) thermal image for a frame from the resultant Compressed Pulse

A defect is quantified in pulse compression with different pulse compression parameters like pulse peak amplitude, peak side-lobes and pulse peak time.

A SNR calculation based on pulse peak amplitude is described here. Since SNR for a given defect is dependent on the way a signal is defined, well formulated algorithm is required for its calculation–

1. The first step is to remove the non-uniformity in heating. The thermal images are considered as a 2-D surface with temperature representing the z-axis. A polynomial surface fitting of the image removes the surface non-uniformity arising due to non-uniform heating. A non-uniformity removed surface is depicted in Figure 4 (a)

2. Each defect location is identified manually, and a gaussian surface is fitted individually to defects (Figure 4(b)). The step 1 and 2 are applied to each frames separately. The variation of the fitted Gaussian surface amplitude with time is plotted in figure 5 for individual defects. The curve resembles a contrast curve in pulse thermography. The peak in the curve is considered as signal.

3. The background noise is determined by identifying and removing the defective zones.

Figure 6 shows the variation of SNR with defect depth for defect with diameter 4 mm and 6 mm respectively. The figure shows that SNR reduces considerably with defect depth. The results resemble with pulse thermography.
4. Conclusion

The application of pulse compression for defect detection is a new and effective technique. However, a defect analysis and quantification is carried out by a sequence of steps. The implementation of the SNR calculation algorithm for defect quantification will further help in comparing the pulse compression technique with the prevalent techniques. An efficient SNR calculation algorithm is described in the paper. The results are similar to pulse thermography. Additionally, the pulse compression parameters like pulse amplitude and peak side-lobe levels and peak time can be used for defect quantifications.
5. References


