Research on Identification Algorithm for Defects Based on Pulsed Alternating Current Field Measurement Technique

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Abstract

Alternating current filed measurement (ACFM) has high sensitivity and quantitative accuracy for surface defects detection. Because of skin effect, ACFM has difficulty in detecting hidden defects such as internal defects of multi-structure. Based on traditional ACFM technique, the hidden defects detection was investigated by introducing pulsed excitation by experiment method in this paper. An identification algorithm for defects is proposed based on the time-frequency analysis method. The detection experiments of surface and hidden defects has been carried out with artificial defects. The results show that the constructed algorithm can distinguish between surface defects and hidden defects, and also can qualitatively compare remaining ligament of hidden cracks.

Keywords

Hidden Defect, Pulsed Excitation, Time-Frequency Analysis, Defect Identification.

1. Introduction

Alternating Current Field Measurement (ACFM) is a new electromagnetic nondestructive testing technique, which is based on the Faraday's law. Fig.1 shows the theory of ACFM. The driving coil loaded with sinusoidal voltage induces approximately uniform current on the surface of the specimen. The defact on the specimen disturbs the induced current, as a result of which the induced current gathers at both ends as well as flows through the bottom of the crack. The disturbed induced current affects the space magnetic field in turn, and the magnetic field signal Bx and Bz are used as characteristic signals for recognizing and quantifying surface crack[1-2].

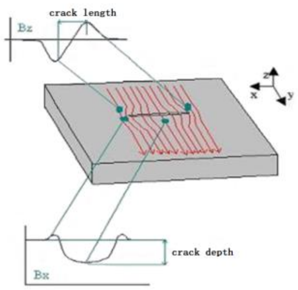


Fig.1 The theory of ACFM

ACFM technique has high sensitivity and accuracy to the surface crack, but has difficulty in detecting subsurface or hidden cracks such as cracks in multilayer structures because of the skin effect restricting the induced current in the area near to surface. The traditional electromagnetic NDT technique combined with the low frequency pulsed excitation makes it possible to detect hidden defects. Previous researches have been done with the focus on the detecting, classifying and quantifying the hidden defects with pulsed eddy current (PEC) and pulsed magnetic flux leakage(PMFL). In the field of pulsed eddy current, Giguere et al used the peak amplitude and the time of lift-off point of intersection to determine defect location in multilayered structures [3]. Ali Sophian et al used principal component analysis to extract feature for detecting and classifying defects from corrosion, surface cracks and subsurface cracks [4]. Tian G Y et al applied principal component analysis to the wavelet transform of the PEC differential signals to extract feature for defect classification and quantification [5]. In the field of pulsed magnetic flux leakage, Wilson et al used

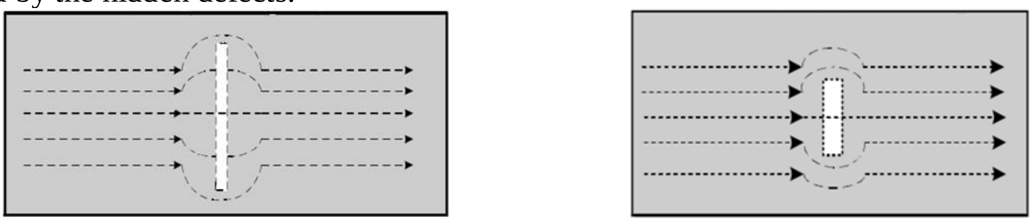
PMFL system to examine internal and external defects in rolled steel water pipes, and predicted defect depth and discriminate between internal and external defects with feature extraction and integration techniques [6]. Ying Tang et al used PMFL with three dimensions measurement to give the shape and orientation about defect by finite element and experiment [7]. As for pulsed alternating current field measurement (PACFM), the feature in time domain has been studied referred to the PECT, but feature in time–frequency domain has not been studied in the literature regarding the PACFM.

In this paper, the time-frequency feature for hidden defect detection using the PACFM technique is studied, and the PACFM system is set up for acquiring transient response signal. An effective method is proposed to classify surface and hidden defects. The rest of paper is organized as follows: the principle of PACFM is introduced in Section 2. The time-frequency analysis method is presented in section 3. In section 4, the PACFM detection system is set up and the experiments for both surface and hidden defects are carried out, and the characteristic of time-frequency analysis is discussed. Finally, an effective method is proposed to classify surface and hidden defects.

2. Principle of PACFM

Pulsed alternating current field measurement (PACFM) technique adopts low frequency square signal to drive exciting coil. The exciting coil generates a dramatically fluctuating magnetic field in space at the rising edge and falling edge of the square signal. The fluctuating magnetic field induces current both at the surface and internal of the specimen. In the field of induction mechanism of pulse excitation, scholars at home and abroad generally hold that the penetration depth of the induced current generated by the fundamental wave of the square signal is the largest and decreases with harmonic frequency increasing from the perspective of Fourier transform[8]. To increase the penetration depth of induced current, the frequency of the pulse signal should be as low as possible. But considering the detecting sensitivity to surface and near-surface defects, the frequency of the square signal should be improved properly. Previous studies have shown that the pulse signal with the parameters of frequency = 100 Hz, amplitude = 5 V and duty cycle = 50% perform well in detecting both surface and hidden defects [8].

Similar to the surface defects, the hidden defects also disturb the induced current as shown in Fig.2. In XY plane, the induced current gathers at both ends of the defect, which causes the magnetic field distortion in Z direction (Bz). In YZ plane, the induced current bypasses top and bottom of the hidden defect, which causes the magnetic field distortion in X direction (Bx). The detection and evaluation of hidden defects can be achieve by acquiring and analyzing the signal of the distorted magnetic caused by the hidden defects.



（a） Disturbed current in XY plane （b） Disturbed current in YZ plane

Fig.2 Disturbed current caused by hidden defect

3. Identification Algorithm

Response signal of hidden defects under pulsed excitation contains abundant information in both time and frequency domain. Pulsed response signal is traditionally interpreted in time and frequency domain separately, which provides a set of data, for example a set of time-amplitude data in time domain. However, it is susceptible to noise and also can not reveal the whole information about the defect. Time-Frequency analysis is an effective method to interpret pulsed response signal and provide three-dimensional representations with time, frequency and amplitude. In this paper, the smoothed pseudo Wigner-Ville transformation is employed to analyze the pulsed response signal as a time-frequency method. The output of smoothed pseudo Wigner-Ville transformation for each signal is a n×n matrix and represent by an image.

The smoothed pseudo Wigner-Ville transformation is as:

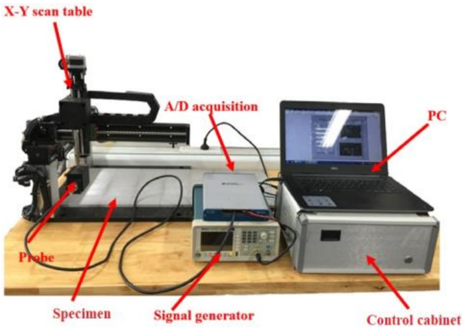
$$SPWD(t,f)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}g(u)h(\tau)x(t-u+\frac{\tau}{2})x(t-u-\frac{\tau}{2})dud\tau \tag{1}$$

where $x(t)$ denotes pulsed response signal, τ denotes time shift variable, $g(u)$ is time domain window function and $h(\tau)$ is frequency domain window function. By introducing window function, smoothed pseudo Wigner-Ville distribution can suppress the interference of cross terms in Wigner Ville distribution, while retaining the advantages of high resolution, time shift invariance and frequency shift invariance of Wigner-Ville distribution as well as filtering white noise [9].

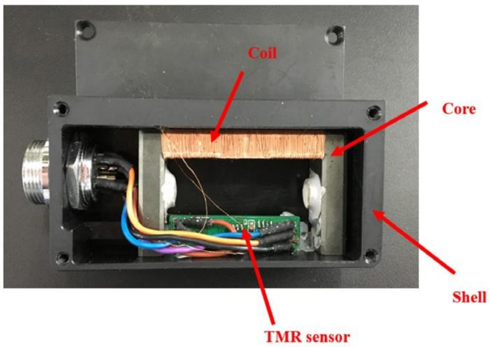
4. Detection experiment and results

4.1 Experimental set-up

The PACFM detection system was setup as shown in Fig.3 (a), which consisted a probe, A/D acquisition card, signal generator, a PC installed with intelligent defect identification program and a X-Y scanner with control cabinet. The probe was assembled as shown in Fig.3 (b). In this paper, 500 turns coil was wounded on the U-shape core as excitation unit, and a tunnel magnetoresistance sensor was used as detection sensor. The output signal of TMR sensor was filtered, amplified in sequence , and then digitized with an NI A/D acquisition card. Finally, the acquired pulsed response signal was interpreted with the smooth pseudo Wigner-Ville transformation and the results was presented in picture.



(a) Detection system



(b) Probe

Fig.3 The Detection system and probe

The specimen was used for surface and hidden defects detection and identification as shown in Fig.4, and five notches were fabricated in the aluminum plate. The thickness of the plate was 10mm, and the length and width of the notches were 30mm and 0.5mm respectively. The depth of the notches was 9, 8, 7, 6 and 5mm respectively. For hidden defects simulation, we place the probe next to the surface of the specimen, and for surface defects , we place the probe next to the other side.

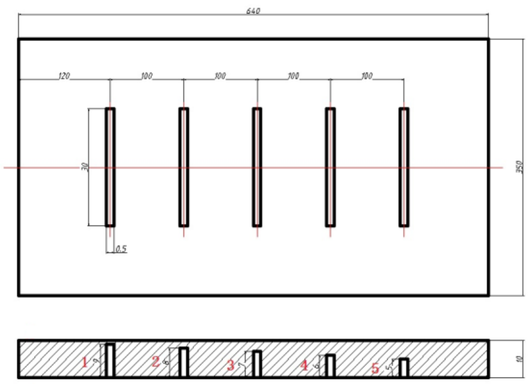
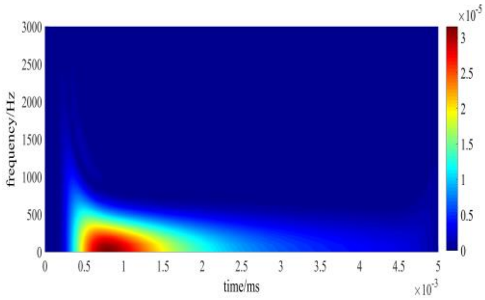


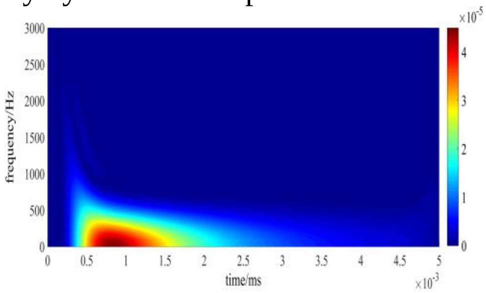
Fig.4 Specimen with artificial defects

4.2 Results and discussion

The pulsed response signal in a period was measured for each defect on both sides of the plate, giving in total 10 sets of signal data. The smooth pseudo Wigner-Ville transformation was conducted to every set of signal data. In Fig.5, the time-frequency distribution of surface defects with depth of 5mm and 9mm are presented. As can be seen from the picture, the depth of surface defect doesn't affect the shape of time-frequency distribution, but influences the value of the pixel. Therefore, the depth of surface defects can be determined qualitatively by the value of pixel.

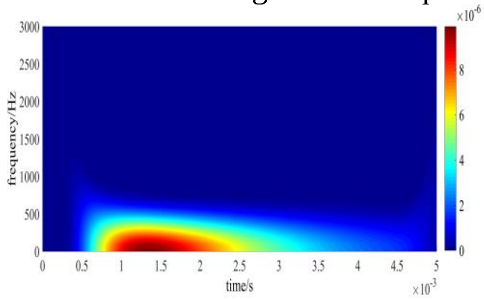


（a）5mm

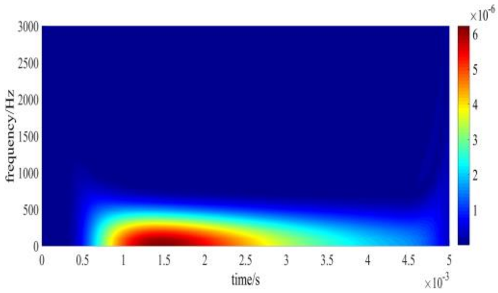


（b）9mm

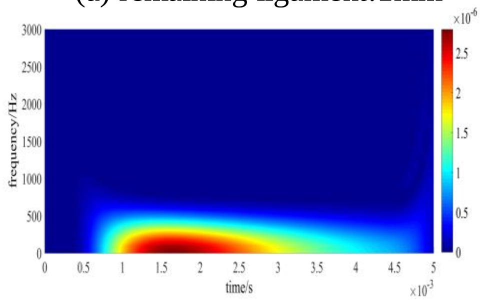
Fig.5 Time-frequency distribution of surface defects



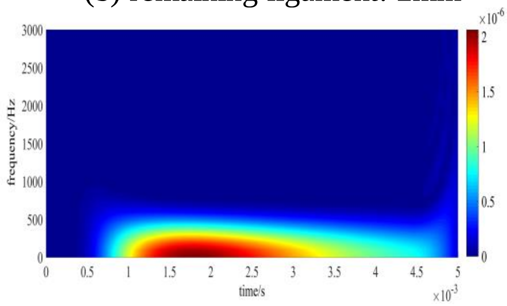
(a) remaining ligament:1mm



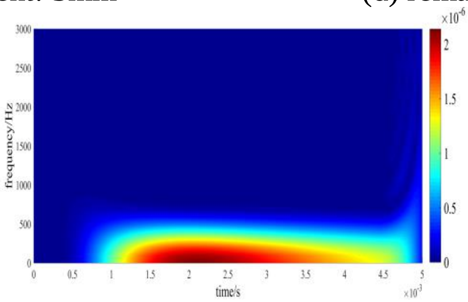
(b) remaining ligament: 2mm



(c) remaining ligament: 3mm



(d) remaining ligament: 4mm



(e) remaining ligament: 5mm

Fig.6 Time-frequency distribution of hidden defects

In Fig. 6, the time-frequency distribution of hidden defects with remaining ligament range from 1mm to 5mm are presented. Comparing Fig.5 with Fig.6, there are obvious differences in time-frequency distribution between surface defects and hidden defects. The time-frequency distribution of surface defects concentrates in time and extends in frequency, while the distribution of hidden defects extends in time and concentrates in frequency. Therefore, the shape of time-frequency distribution can be used to identify the type of defects efficiently.

5. Conclusion

The identification algorithm for surface and hidden defects through the PACFM technique has been studied by experimental methods in this paper. We can conclude as follows:

(1) The smooth pseudo Wigner-Ville transformation is used to interpret the transient response signal of defects under the pulsed excitation as a time-frequency method, and provides three-dimensional representations with time, frequency and amplitude.

(2) A PACFM detection system has been set up, and the detection experiments of surface and hidden defects has been carried out through a specimen with artificial defects.

(3) The results of smooth pseudo Wigner-Ville transformation for pulsed response signal show there are obvious differences in the shape of time-frequency distribution between surface defects and hidden defects. The shape of time-frequency distribution can be used to identify the type of defects while the value of pixel can be used to compare depth of surface defects or the remaining ligament of hidden defects qualitatively.

Acknowledgements

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