17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Research on Surface Defect Detection Using Pulsed Eddy Current Testing Technology

Deqiang ZHOU [1], Binqiang ZHANG [1],Guiyun TIAN [1, 2], Haitao WANG [1], Ping WANG [1], Hua LIANG [3]

[1]College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, 29 Yudao St., Nanjing 210016, China

[2] College of Electrical, Electronic and Computer Engineering, Merz Court, University of Newcastle Upon Tyne, NE1 7RU, Newcastle Upon Tyne, UK

[3] Nanjing Boiler&Pressure Vessel Supervision and Inspection Institute, 340 Hongwu Road., Nanjing 210002, China

Abstract:

This paper introduces the state-of-the-art of pulsed eddy current NDT systems and their practice for surface defect measurement. Experiments of pulsed eddy current inspection on the cracks with the dimensional parameters varying in three cases: (1) different depths; (2) different widths; (3) variable depth and width with fixed crack volume have been reported. Quantitative surface defects can be estimated by a substantial relations between the defect depth, width and the peak amplitudes. It can be derived that the differential output peak value is more sensitive to the depth of surface defects than the variation of width in static measurement.

Keywords: Pulsed eddy current; NDT; GMR sensor; Surface defect detection

1. Introduction

Pulsed eddy current (PEC) testing is a new technology of eddy current testing technology. PEC testing possesses over many advantages against the conventional eddy current testing, including more wider detection depth, rich information about defects and high robustness of anti-interference[1]. Most of the eddy current applications use single frequency excitation, which means that a sinusoidal current with a well adapted frequency is employed for each particular application. In this case, the information is generally given from the analysis in terms of amplitude and phase. But these two parameters can be insufficient to characterize or discriminate some discontinuities of conductivity in the materials. So, a multiple frequency method can be used. To obtain the depth information of defects, multiple frequency measurements have been combined to provide a more rigorous assessment of structural integrity by reducing signal anomalies that many otherwise mask the flaws[2-5]. PEC sensing is a new and emerging technique that has been particularly developed and devised for surface and subsurface flaw measurements. PEC techniques excite the probe's excitation coil with a repetitive broadband pulse, usually a rectangular wave. The probe provides a series of voltage-time data pairs as the induced field decays, and since the produced pulses consist of a broad frequency spectrum, the reflected signal contains important depth information. Physically, the field is broadened and delayed as it travels deeper into the highly dispersive material, and flaws or other anomalies close to the surface affect the eddy current response earlier than deeper flaws[6-7]. Peak values and zero crossing times have been used for flaw detection and identification[8]. At present, this method obtains the widespread applications in the airplane structure, the pressure vessel, the nuclear power station heat change pipeline and so on for key equipment's flaw testing.

2. Experimental Principles

Figure1 is the pulsed eddy current non-destructive testing system. The system mainly consists of the signal generating device, the eddy current probe with the giant magnetic resistance sensor (GMR), signal conditioning circuit and the signal processing and so on. The sample has a surface slot. Briefly, the system works as follows: the waveform generator produces a rectangular waveform with variable frequency and duty cycle. The waveform is fed to a coil driver circuit, which excites the induction coil in the probe with pulsed current. The pickup sensor measures the vertical resultant magnetic field, which is the sum of the one generated by the excitation coil and the opposing one generated by the induced eddy current in the sample. A voltage amplifier with variable gain then amplifies the signal so that the dynamic input range of the data acquisition card [or analogy-to-digital (A/D) converter card] can be used effectively. The A/D card will convert the input signal into digital data ready to be processed by software in the PC. The software performs communication with the data acquisition card, the control of the data transfer from DAQ card buffer to the PC RAM, signal pre-processing of the results on the PC monitor. Peak values , zero crossing time and peak time have been used for flaw detection and identification.

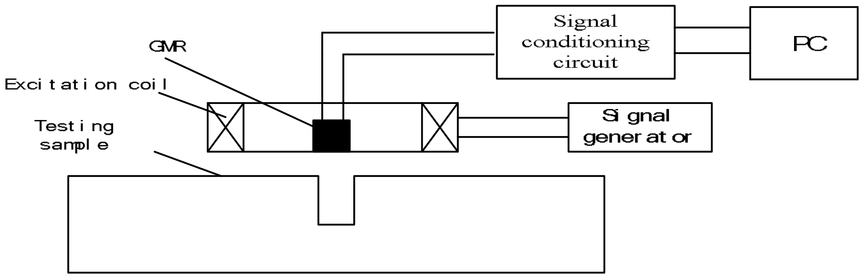


Figure 1. The pulsed eddy current non-destructive testing system

2.1 Signal generator

The CALTEKCA1640-02 function generator is used as the signal generator, which produces the 0.02Hz~2MHz duty cycle. It is a continuously adjustable square-wave signal, and the frequency is also continuously adjustable. Signal scope output is not along with frequency shift. We use 50% duty cycle in the pulsed eddy current testing system, the frequency is 1kHz, and the peak-to-peak value takes the drive signal for - 5V to the +5V square-wave signal.

2.2 Design of probe framework dimension

Figure 2 is the dimension of the probe. It is made of cylindrical magnetic core wound with circled 220 turns of lacquer wires. The cylindrical magnetic core is 27mm in height with inner diameter of 9mm, and outer diameter of 16mm. The lacquer wire is the line diameter 0.3mm line loop. And at the centre of cylindrical magnetic core giant magnetic resistance sensor AAH002-02 is deployed, and it is used to acquire the PEC signal. To reduce the influence of lift-off effect, the probe is close to the testing sample surface

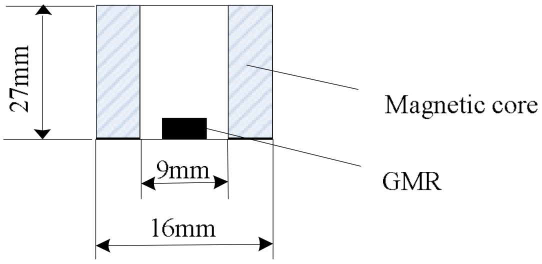


Figure 2. The dimension of the probe

2.3 Giant magnetic resistance sensor (GMR)

As shown in Figure 2, giant magnetic resistance sensor AAH002-02 is at the centre of cylindrical magnetic core. Probes based on pickup coil, Hall sensor and GMR sensor became research focus on satisfying fast, accurate and complicated surface flaw measurement for nondestructive testing. The conventional pickup coil is applied to the high frequency testing, its sensitivity is very low in the low frequency area[9]. But GMR sensor's frequency range is very wide (0~1MHz). GMR sensor is very small, and the output circuit integrates on the sensor chip. It will have the better anti-interference ability than the conventional probe of pickup coil.

GMR sensor has two merits compared with the conventional Hall sensor. First, it also can produce good output in very weak magnetic field. The sensitivity of typical Hall sensor is 50V/T under the 5V power supply, while that of GMR sensor can reach 200V/T. Second, the maximum ambient temperature of steady work for GMR can reach 150℃ but that for Hall sensor is only 100℃. The weak signal of GMR’s output can be amplified by INA129. Output of INA129 can reach±10V. GMR can be applied to current testing, displacement testing, speed and place testing, and so on.

2.4 Signal processing unit

The signal processing unit consists of data acquisition and data processing. The Adlink DAQ2010 data acquisition card is used to acquire the data; The sampling frequency is 100 kHz. Through filtering, analyzing and processing of acquisition data by MATLAB, the main flaw features can be extracted, thus surface crack is detected and quantified.

3. Surface crack experiments

3.1 Flaw characterization

First, simulated cracks were characterized using the samples described in Figure 3. The flaws are indicated by the notation: D-W-L (mm).

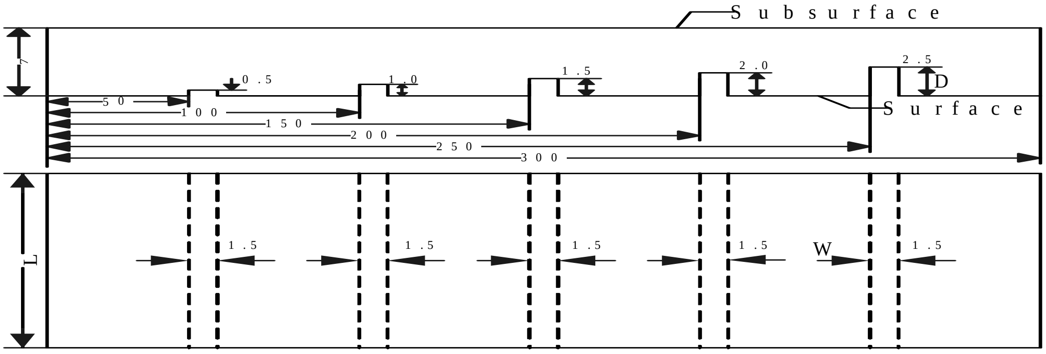


Figure 3. The dimension of the surface crack

3.2 Simulated crack description

First, we considered a large flaw of 30×1.5 mm2, positioned at different surface depths D which is different from 0.5mm to 2.5mm , with step of 0.5mm (Table 1).

Second, The characterization of the width W of the flaws is made of five flaws at the same depth D (1.5mm) and the same length L=30mm (Table 2).

Finally, in order to differentiate influence factors between the depth D and the width W, we considered to use the same surface flaw volume, which length is same, while its depth D and width W are different (Table 3).Through some experiments, the quantitative conclusions on surface defect can be made by a strong relation between defect depth and defect width and the peak amplitude.

Table 1. Simulated cracks used to characterize the surface depth D

Flaws	D1	D2	D3	D4	D5
Size: L×W	30×1.5 mm^2				
D(mm)	0.5	1.0	1.5	2.0	2.5

Table 2. Simulated cracks used to characterize the width W

Flaws	W1	W2	W3	W4	W5
Size: L×D	30×1.5 mm^2				
W(mm)	0.5	1.0	1.5	2.0	2.5

Table 3. Simulated cracks used to characterize the surface cracks volume V

Flaws	V1	V2	V3	V4
L(mm)	30			
D(mm)	1.5	2.0	3.0	4.0
W(mm)	4.0	3.0	2.0	1.5

3.3 Signal processing

Generally, the PEC differential signal is used for defect detection because its peak value can be used to be as defect characterisation. This differential signal is computed by subtracting the reference signal detected on a flawless section of the material from the response signal. It is obvious that the differential signal is noisy. As a result, it is hard to obtain a robust peak value from a single noisy response. A noisy removal method, filter is required. We use the experimental set-up of a GMR PEC probe to detect the surface slot defect of an aluminium sample as shown in Figure 3. Figure 4 shows the denoised differential PEC signal by wavelet transform. The quantitative conclusions on surface defect can be made by the peak value and zero crossing time and peak time.

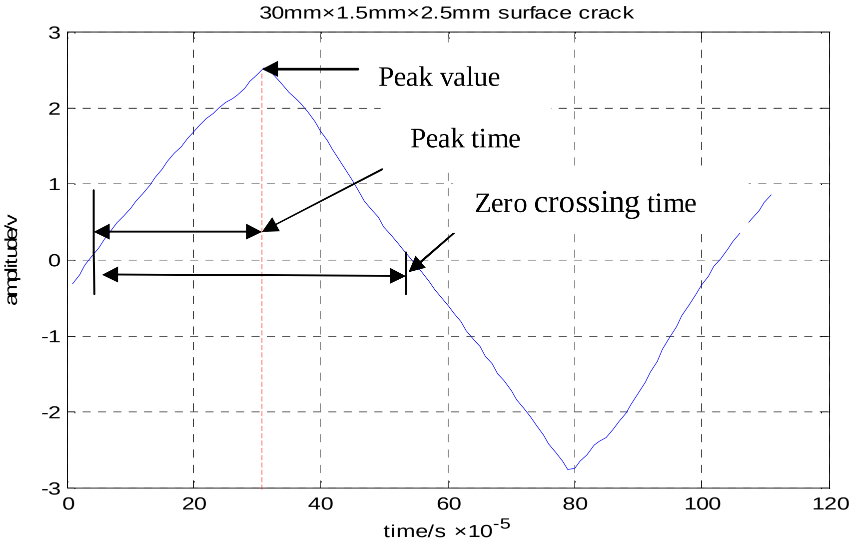
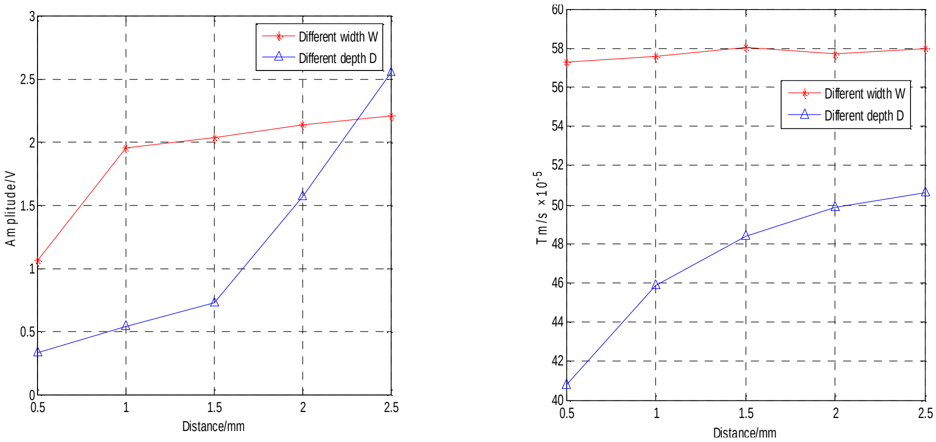


Figure 4. Denoised differential signal

4. Experimental results

Using the above methods, we test the defects that only surface depths are different (Table1), only widths are different (Table2), and, depths and widths are different, but defect volumes are the same (Table3). The experimental results are shown in the following figures, and the curves respectively describe the peak value, zero crossing time and peak time of different defects.



(a) (b)

Figure 5. Output peak value for different crack width W and different crack depth D (a) and Tm for different crack width W and different crack depth D (b)

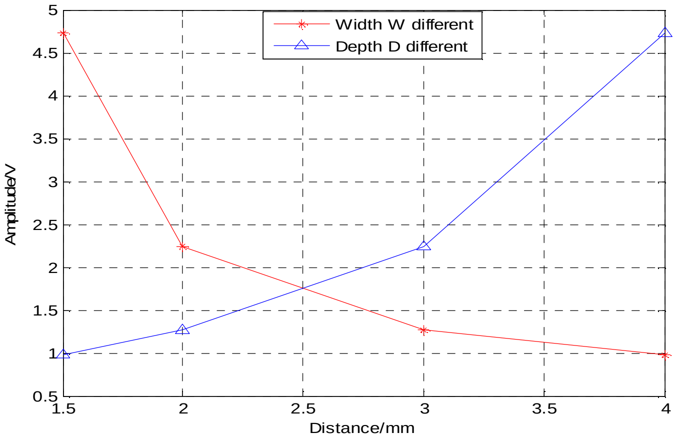


Figure 6. Output peak value for different crack width W and different crack depth D at the same surface crack volume

First, when the depth D and the length L are the same, only the width is different, the experimental results show that the output peak value increases as the flaw width W widens, but the zero crossing time is nearly the same. Tm is the zero crossing time. The slope curve is smooth gradually, when the surface defect width W reaches the certain extent, the curve peak value will keep constant.

Second, when the length L and the width W are the same, only the depth is different, the experimental results show that the output peak value increases as the flaw depth D increases. It can test 0.5mm surface flaw depth. The flaw depth has the very good testing effect when it is bigger or equal to 1.5mm. The experimental results are in Figure 5(a).

Figure 5(b) proves that the zero crossing time of depth D has bigger variety than that of the width variety. While the width is different, the zero crossing time is nearly the same. When the depth D is different, the zero crossing increases as the flaw depth D rises. Therefore, it means that the zero crossing time describes the defect depth.

Finally, when both the depth D and the width W are different with the same volume, the influence of the crack depth D to the peak value is much larger compared with the width W, and it shows that the output peak value is more sensitive to the crack depth D. Therefore, it is necessary to determine the depth D prior to the width W, because the maximum △Bym depends on these three parameters. △Bym is the differential magnetic field measured respectively on a healthy and flawed area. The experimental results are shown in Figure 6.

5. Conclusions

This paper introduces the state-of-the-art of pulsed eddy current NDT systems and their practice for surface defect measurement. Experiments of pulsed eddy current inspection on the cracks with the dimensional parameters varying in three cases: (1) different depths; (2)

different widths; (3) variable depth and width with fixed crack volume have been reported. Experimental results indicated: Using the pulsed eddy current transient behaviour and the frequency range wideband characteristic in the surface defect testing, it can give quantitative evaluation of flaw in terms of the position, the size and so on, according to the peak value preliminary. It can be derived that the differential output peak value is more sensitive to the depth of surface defects than the variation of width in static measurement.

6. References

[1]Sphian, A., Tian, G.Y., Taylor, D., and Rudlin, J. , A feature extraction technique based on principal component analysis[J], *NDT&E Int*.,2003,36, pp.37-41

[2]T.Clauzon, F.Thollon, and A.Nicolas,Flaws characterization with pulsed eddy currents[J], *IEEE Trans.Magn.*, pt.1,vol.35,no.3,pp.1873-1876,May 1999

[3]Tian, G.Y., Sophian, A., Taylor, D., and Rudlin, J.,Wavelet-based PCA defect classification and quantification for pulsed eddy current NDT[J], *IEE Proc., Sci.Meas. Technol*.,2005,152,pp.141-148

[4]Tian, G.Y., Sphian, A., Taylor,D., and Rudlin, J.,Multiple sensors on pulsed eddy-current detection for 3-D subsurface crack assessment[J], *IEEE Sens.J.*,2005,5,pp.90-96

[5]G.Yang, G.Y.Tian, P.W. Que and Y.Li., Data fusion algorithm for pulsed eddy current detection[J],*IET Sci.Meas. Technol.*,2007,1,(6),pp.312-316

[6]T.Clauzon, F.Thollon, and A.Nicolas, Flaws characterization with pulsed eddy currents[J], *IEEE Trans.Magn.*, pt.1,vol.35,no.3,pp.1873-1876,May 1999.

[7]J.Bowler, Pulsed eddy-current inversion for the determination of crack shape[J], *Electromagn. Nondestruct.Eval.*, pp.263-269,1997.

[8]Mottl, Z., The quantitative relations between true and standard depth of penetration for air-cored probe coils in eddy-current testing[J], *NDT International*, 1990,23(1),11-18

[9]D.J.Harrison, Eddy-current inspection using Hall sensors and transient excitation[J], DRA, Famborough, U.K., Defence Research Agency, Tech.Rep.DRA/SMC/TR941 008,1994.