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Array Pulsed Eddy Current Imaging Technique for Nondestructive Testing of Aging Aircraft

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Abstract

It is different to detect defect in multilayer structure of an aging aircraft fuselage, pulsed eddy current (PEC) technique has been demonstrated to be capable of quantifying this defect. Based on theoretical analysis of PEC technique, the array probe is designed and the array PEC imaging technique has been supposed to detect corrosion in the multilayer structure. By selecting peak amplitude and the zero-crossing time of the time domain transient signal as the imaging features, corrosion can be imaged and detected effectively. It's shown that the technique has the advantage of different imaging mode, fast detecting speed and quantitative measurement and has a lighting application foreground in the field of nondestructive testing.

Keywords: Array pulsed eddy current; Corrosion detection; Multilayer structure; Eddy current imaging

1.Introduction

Because of the multilayer structure of the aging aircraft fuselage, second layer corrosion and hidden corrosion have been identified as major aging aircraft problems in aeronautical nondestructive testing. Traditional ultrasonic, eddy current and radiometric methods can detect first layer corrosion of an aircraft structures, however, it is difficult for these methods to detect second layer defect. The pulsed eddy current (PEC) nondestructive testing method is a new technology developed in recent years, which is the effective method that has been demonstrated to be capable of quantifying corrosion in the second layer[1]. Imaging detection can get the shape of defect and is more intuitive than traditional nondestructive testing methods, which is currently the subject of widespread interest because of its excellence. Imaging testing has become the development trend of nondestructive testing apparatus[2]. Nowadays, all of the PEC imaging technique use single probe to scan the corrosion areas[3-5], which causes long scanning times and low scanning efficiency. The array PEC imaging technique is proposed. This method reduces the price of the scanning system and improves the scanning speed. It is very adaptable in that it can be used to detect large areas of corrosion.

2.Pulsed Eddy Current Principle

The probe is excited with a repetitive broadband pulse; the resulting transient current through the coil induces transient eddy currents in the specimen, which is associated with highly attenuated magnetic pulse propagating through the material. Physically, the pulse is broadened and delayed as it travels deeper into the highly dispersive material. Therefore, defect or other anomalies close to the surface will affect the eddy current response earlier in time than deep defect. Since a broad frequency spectrum is produced in one pulse, the reflected signal contains important depth information of the material[6].

Typical features such as peak and zero-crossing time are used to detect and characterize defect. The key features of time domain PEC transient response signal are shown in Figure 1. Because peak change with the changing of defect length and zero-crossing time change with the changing of defect depth, based on this principle, the time domain PEC transient response signal is analyzed to get the quantitative information of the depth and length of defect. It was also found that the peak is proportional to the amount of metal loss, the more the amount of corrosion the more the larger amplitude of the signal, the time of zero-crossing has a close relationship with the depth of corrosion, the deeper position leads to the longer time of zero-crossing, as a result, the quantitative information of corrosion can be get from extracting this two features.

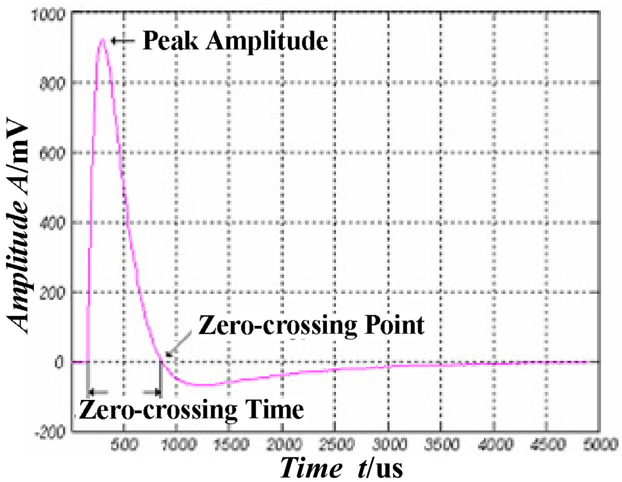

Figure 1.The key features of the time domain transient response signal

3.Experimental System

The array PEC imaging system used for this work consisted of exciting pulser, power amplifier, signal process, data acquisition module and array probe. Figure 2 shows a schematic diagram of the experimental system designed to produce pulsed eddy current signals and measure the transients affected by defect in scanned specimen.

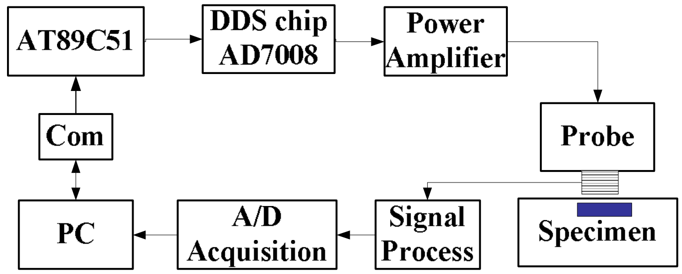

Figure 2.The schematic diagram of the experimental system

In this experimental system, Direct Digital Synthesizer (DDS) chip AD7008 is used to generate the exciting pulser, AD7008 chip is a numerically controlled oscillator employing a 32-bit phase accumulator, sine and cosine look-up tables and a 10-bit D/A converter integrated on single CMOS chip. Modulation capabilities are provided for phase modulation, frequency modulation, and amplitude modulation. The amplitude of the exciting pulse is 15 V, the repetition rate of the excitation is 100 Hz and the pulse duration is 5 ms. Power amplifier is employed to enhance the exciting magnetic field. Some sheets of aluminum are fastened by screws to simulate multilayer structure of an aging aircraft fuselage. Different size of slots and holes are machined on one sheet of aluminum, which are used to simulate the corrosion appears in real situation. The schematic plan of specimen is shown in Figure 3.

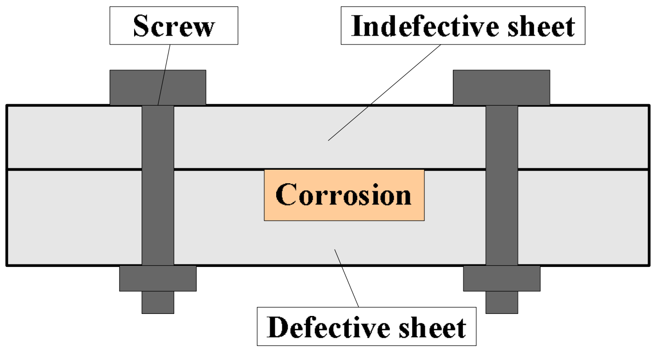

Figure 3.Schematic plan of specimen

The array probe consists of one exciting coil and eighteen pick-up coils, which is shown by Figure 4. The pick-up coils are located in the center at the bottom of the exciting coil, side by side. The radius of the pick-up coil is 1mm, which is driven synchronously to detect the perturbed magnetic field along the scanning path. The inconsistency of pick-up coils will lead to a change in the induction signal and a software compensation technique is used to eliminate this effect. The transient signal of the each pick-up coil is sampled by 1 MHz sampling rate using data acquisition module and recorded for the purpose of off-line post processing.

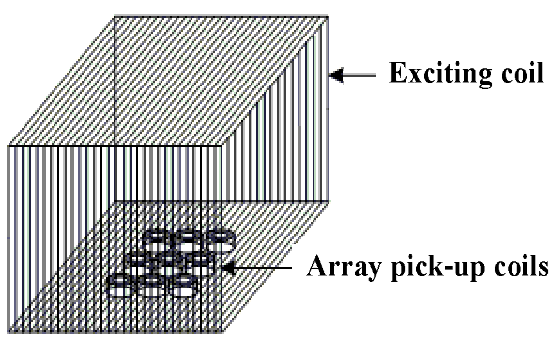

Figure 4.The schematic diagram of array PEC probe

4.Principle for Software Design

It can be concluded from the analysis in Section 2 that the peak amplitude and the zero-crossing time of transient induced signal change with the amount of metal loss and depth of corrosion, which combines with function p(x,y,z) and u(r,b,g) to accomplish imaging testing. The p(x,y,z) is the position function, which represents the corresponding coordinate of the scanning point in the imaging area; The u(r,b,g) is the grey scale function, which is used to regulate the color of imaging point. In the process of imaging testing, the coordinate of the imaging point is determined by the position function p(*x*,*y*,*z*) firstly. Then, according to the different imaging mode, the peak amplitude or the time of zero-crossing is used by grey scale function u(*r*,*b*,*g*) to get the image of corrosion in the specimen.

Software plays an important role in the imaging detection system, which is programmed by Microsoft Visual C++ 6.0 and modularized frame is adopted in order to upgrade software conveniently later. Software is comprised of parameter setup, data acquisition, *A* scan wave display, features extraction, *B* scan image display, *C* scan image display, data saving and data playback. The flowchart of software is shown in Figure 5.

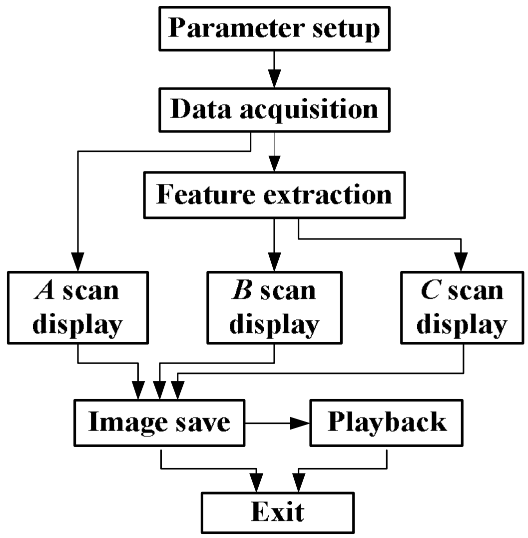

Figure 5.Schematic flowchart of software

In the course of array probe scanning, the peak amplitude curve of the transient induced signal will be displayed simultaneously in the imaging region, therefore *A* scan wave comes into being. Features extraction is the base of *B* and *C* scan imaging. The peak amplitude and the zero-crossing time are extracted and used as the parameters for *B* and *C* scan imaging, these features are recorded in a database table. According to the relation between the zero-crossing time and the depth of corrosion, the zero-crossing time is presented in grey scale, thus forming the image of *B* scan. When the gray scale of the image is adjusted by the peak amplitude of the transient induced signal, the image of *C* scan comes into being. For the purpose of a countercheck later, the image will be saved after detection and can be played back in a while.

5.Results and Discussions

Six foursquare areas and six rounded areas milled to different sizes and depths are machined on second layer of specimen to simulate the corrosion appears in real multilayer situation.

The *A* scan wave is shown in Figure 6, there is a maximum and minimum amplitude in scanning wave, they represent the times when the probe entered and left the corrosion area respectively.

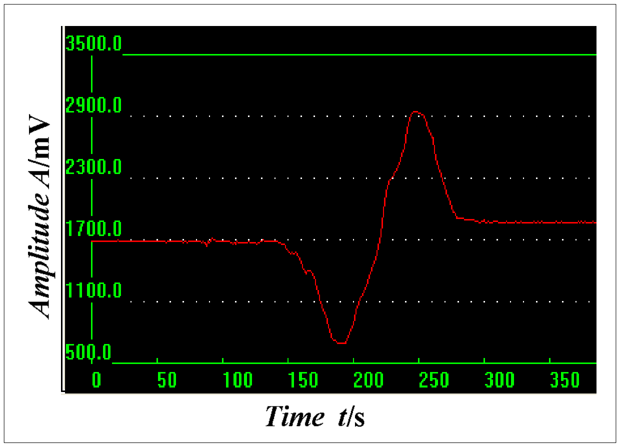

Figure 6.*A* scan wave

The imaging results of *B* scan of the foursquare defect with the length of 30mm and depths of 0.2mm, 0.4mm, 0.6mm and rounded defect with the diameter of 30mm and depths of 0.2mm, 0.4mm, 0.6mm are ranged in Figure 7 from a to c. The imaging results of *B* scan of the foursquare defect with the length of 20mm and depths of 0.2mm, 0.4mm, 0.6mm and rounded defect with the diameter of 20mm and depths of 0.2mm, 0.4mm, 0.6mm are ranged in Figure 7 from d to f. As discussed in Section 4, the image of *B* scan depends on the features extraction, the length and depth of corrosion has been determined in the course of the extraction of features and will be displayed on the software interface with the *B* image.

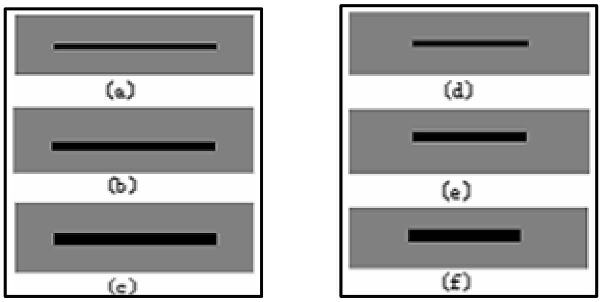

Figure 7.*B* scan image

The imaging results of *C* scan of corrosion with different lengths and depths are shown in Figure 8. There is a calibration table from which the corresponding relation between the color of image and the amounts of metal loss can be ascertained. The shape and severity of the corrosion can be intuitively quantified from the *C* scan imaging results. When the results of *A*, *B* and *C* scan are analyzed together, the hidden corrosion can be detected quantitatively by the array PEC imaging method.

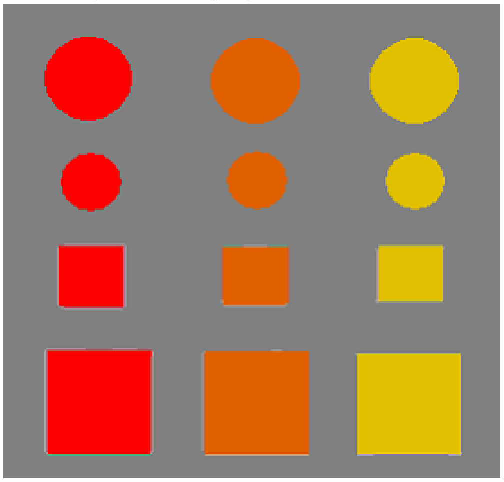

Figure 8.*C* scan image

6.Conclusion

Corrosion often appear in multilayer structure of an aging aircraft and threaten the safety of aviation. Array pulsed eddy current imaging technique is used to detect the corrosion in multilayer structure of an aircraft fuselage. In experiment, corrosion between three and four layer of specimen can be detected effectively at the condition of increasing amplitude of exciting signal to 20 V. Compared with other methods, it can scan large areas of complex structure without the need to change the probe. Besides its application in the field of aeronautical nondestructive testing, the array PEC imaging technique can also be used in the detection of fleet, oilcan and pipeline and will play an important role in the field of nondestructive testing.

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