Non-Contact NDE for Thin Aerospace Structures

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Abstract
The detection of defects in aerospace structures with nondestructive techniques is an important requirement for quality checks not only during production phase but mainly during in-service maintenance operations. Visual inspection allows only the analysis of surface characteristics of materials. For subsurface defects like corrosion or cracks a deeper analysis is required. For aerospace structures are mainly used two different approaches. The first method is based on induction of currents in tested electrically conducting material also known as Eddy Current inspection. Changes in electromagnetic field are used by signal analysis system to identify or differentiate between wide variety of physical, structural and metallurgical characteristics of the tested material. The second method uses high frequency sound waves which are sent into the object under the test. A probe picks up the reflected waves and an analysis of received signal is done to locate flaws in the tested object. Ultrasonic inspection can detect defects such as cracks and discontinuities.

In this paper, we address the problem of different detection performances of nondestructive inspection methods using comparison of several industrial and experimental probes. We designed 4 different eddy current probes. We made an analysis of coil and GMR sensor and we tested this design on Dural plate used a part of standard airframe. We used two different data acquisition systems. After that we evaluated this sample with certified industrial Eddy Current system. We propose to use new experimental Electromagnetic Acoustic Transducer (EMAT) probe with multidimensional signal processing. Same as in case of experimental Eddy Current system we verified final analyses with industrial piezoelectric ultrasonic transducers.

1. Introduction
One of the principal NDE techniques are eddy current testing (ECT) and ultrasonic testing (UT). ECT technique is based on induction of currents in electrically conducting material being inspected and observing the interaction between these currents and the materials. Induced eddy currents produce their own magnetic field, which oppose the excitation field. Thus the resultant field is changed and can be measured. For detecting of these changes common coils or novel GMR sensors can be used. This technology offers high sensitivity, temperature stability in small physical size and low power consumption. Higher sensitivities on lower frequencies in compare to widely used coils are part of this research.

UT is inspection method where high frequency sound waves are sent into the object under test. The sound waves travel through the material. During their path of travel they suffer loss of energy and are reflected at interfaces. To produce and detect ultrasonic wave inside the studied material Electro-Magnetic Acoustic Transducer (EMAT) technology should be used instead of common piezoelectric crystal technology. The main advantage of this alternative technology is that no couplant medium is necessary for inducing and detecting ultrasonic waves. This technology is non-contact in the same way as ECT.

This paper present performance evaluation, of the experimental and their industrial NDE counter parts systems and is organized as follows. In the second section will be described all used experimental systems. The third section will describe signal processing techniques needed for data filtering and visualization. The fourth section will present experimental results. The fifth section will conclude the main objective of this work that is to construct and evaluate automated system for non-contact non-destructive evaluation of aerospace structures.

2. Experiment setup
The schematic of the specimen geometry is shown in Fig. 1. We used 1 mm thick aluminum 2024-T3 aircraft plate. 1st and 2nd defects perforate the plate and the others simulated 60% of initial plate thickness. Parallel defect lines have the same geometry. To eliminate rim conditions area 290 x 145 mm of the plate was used where scratches were placed inside this area with spatial offset bigger than diameter of the probes. We designed this specimen for the first verification of new system and probes performance.

3 Ultrasonic
See Fig. 2 where are signals from piezoelectric and electromagnetic-acoustic transducers. Piezoelectric probe was connected to 320 MHz sampling system and worked on 25 MHz. Thickness evaluation is not difficult with this system. The time difference between two corresponding echoes is 0.33 µs. This time with 6150 m/s speed of sound gives direct information about thickness. EMAT system generates ultrasonic signals with frequency 4 MHz but

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with shear waves with speed of sound is 3320 m/s waves. With this setup there is no direct information for thickness evaluation. As it is described in [10] pulse echo time measurement technique is not the only way to measure distance. For this data acquisition was used experimental EMAT system developed and described in [11].

Fig. 2 Pulse echo signal on left, EMAT signal on right

Studied EMAT signal is different to a common ultrasonic signal. In [12] is described standing wave which came up as a result of tested plate and used EMAT system. We evaluated the interference principle. We expect that till half of the wavelength we can extract material thickness from the level of wave superposed from the direct wave and reflected wave from backwall of the material. The first step in verification interference model was to scan plate scratches. From received datasets the amplitude, frequency and phase was extracted with sine-fitting [5]. We used hybrid median filtering and spline cubic interpolation to suppress noise. Some of the results are in the Fig. 3.

Fig. 3 Scan with EMAT probe

4. Conclusion

The main objective of the study which is described in this paper is to present a combination of recent signal processing methods with non-contact non-destructive methods. Systems used for this evaluation were novel / experimental and industrial. Both industrial based systems proved to have higher sensitivity and resolution than their laboratory counterparts. This difference on the other hands helped in verification of the importance and robustness of proposed signal processing methods.

The most suitable method proved to be eddy current inspection. Recently developed eddy current systems even with GMR sensors didn’t meet the sensitivity of industrial systems. We identified that our focus will be in development of the probe shielding and testing new GMR sensors series. While we work on development of non-contact evaluation techniques we proposed simple model with EMAT probe which we verified with measurement. These results are closely bonded with signal processing methods. In the first place using the 7-parameter sine fitting algorithm to obtain the amplitude and phase of the output voltage of each sensing coil leads to more accurate results than the application of cross-correlation. For flaw description with eddy current systems simple evaluation of the signal is inaccurate and complex descriptors are crucial.

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