TR based microwave NDE of composites in far field reflection mode

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Glass fiber Reinforced Polymer (GFRP) have been increasingly used in the aerospace, automobile and civil industries to replace metals, fully or partially due to their unique properties such as light weight, corrosion resistance and high mechanical strength [1]. The wide application of such structures demand a reliable, robust and efficient NDE system that can be used to rapidly inspect large areas of these structures, and accurately detect potential anomalies. Among several NDE modalities, the microwave NDE technique is particularly fitted for defect detection in dielectric materials due to their potential to penetrate inside such structures, without suffering much attenuation [2]. Some of the recent applications of Microwave NDE are corrosion detection in painted aluminum and steel substrates, flaw detection in Sprayed on Foam Insulation (SOFI) of space shuttles, disbond detection in CFRP strengthened cement based structure [3]. This research investigates the feasibility of microwave NDE of composite materials using a microwave TRM processing. Experimental results obtained using a pulsed time domain laboratory system are coupled with a model based TR back-propagation in order to detect important damage modes in real GFRP composite structures. High imaging quality achieved in experimental studies lay the foundation for a robust microwave imaging system for NDE of composites.

TR is a consequence of the reciprocal property of the wave equation. In the scalar case we have [4]:

$$\left(\nabla^2 - \frac{n^2(r)}{c^2}\right)\varphi(r,t) = 0 \tag{1}$$

It can be easily observed that if $\varphi(r,t)$ is a solution of (1), $\varphi(r,-t)$ is also the solution of the same equation. Thus fields diverging from a point source can be reversed in time and back-propagated in a model to focus back at the source. Since defects behave as secondary sources for the scattered field, this property can be exploited for imaging defects in composites:

- a short pulse is transmitted from an antenna to the sample.
- the scattered signals due to the defective sample and a healthy (reference) sample are measured by a receiver array and subtracted to obtain the defect contribution;
- the defect contribution is reversed in time and numerically back propagated through a healthy sample to achieve spatio-temporal focusing around the defects.

The numerical model for back-propagation is based on a 2D TMz mode excitation based finite-difference time-domain method. The time integrated energy of the time reversed fields is capable of providing a focal spot around the defect [5].

The experimental setup for measuring the scattered fields from the composite samples is shown in Fig. 1. A pair of 2-18 GHz TEM horn antennas serve as the transmitter and receiver are used in an arch range of radius 3.5 m, with the samples located at the center of the arch range. A digital sampling is utilized to measure and display the back-scattered fields, along with a pulse generator, which generates a pseudo gaussian pulse of pulse width 45 ps, which corresponds to an ultra-wide bandwidth of around 20 GHz. The samples along with the far field images are shown in Fig. 2. The perturbation signals are time reversed in the numerical model to obtain the far field images. A GFRP laminate with fibers woven at 0° and 90° is used as the sample.

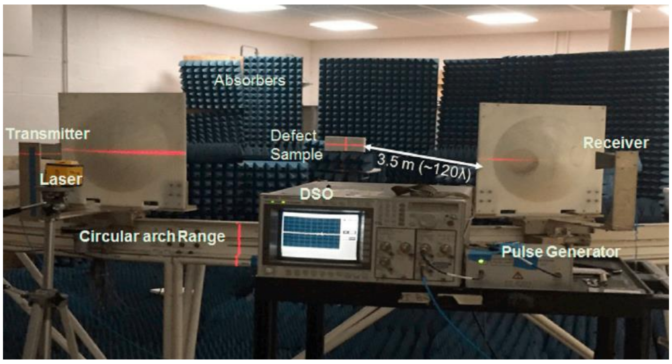

Fig. 1. Time domain scattering experiment setup, with the sample placed at the center.

(a) Sample I (b) Sample I TR image (c) Sample II (d) Sample II TR image

Figure 2: GFRP samples with defects and their corresponding TR images

Two different defects are investigated in this research. Carbite tip drills were used to create the first defect (Sample I) which consists of 3 drilled holes of diameter 8 mm (D1), 4 mm (D2), and 2 mm (D3), separated by 2.5 cm. The TR integrated energy image shows the energy localized around the defect region corresponding to D1 and D2. However D3 is not detected since its dimensions are much smaller than the corresponding wavelength. A drop weight impact test was used to create the second defect (Sample II), which is an impact damage of size 20 mm approximately. The TR integrated energy image obtained shows the energy localized around the impact damage.

This research presents TR based far field microwave imaging experiments for NDE of composites. Benefits of the far field system involve single side access, large stand-off distance, for rapid inspection. Accurate results and high imaging resolution obtained from the experiments demonstrate the efficacy of the methodology and the potential for a rapid and reliant microwave NDE system.

References

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