Chirp Signal Based Pulse Compression Techniques for Non-Contact Ultrasonic Guided Wave Applications

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Abstract

Many engineering structures are made of composite materials. Non-contact ultrasonics is one of the most emerging NDE techniques for application in inspection of aerospace structures made of composite material. Non-contact ultrasonic system suffers from low signal-to-noise ratio due to attenuation in composite materials. To increase ultrasound signal levels and improve the ultrasound signal-to-noise ratio we can either reduce the noise level or increase the excitation signal level. Due to limitation of transducer construction excitation voltage level cannot be increased above a certain limit.

Pulse compression methods are widely used in radar imaging have been recently applied to medical ultrasound imaging for their ability to improve the signal to noise ratio (SNR) without increasing the amplitude of the excitation signal. The pulse compression approach applies a frequency-swept exciting signal into an object and the signal reflected from the target is decoded to compress the signal, therefore the signal to noise ratio (SNR) is increased and the resolution is enhanced.

The required complexity in electronics for generating an exciting signal for pulse compression techniques and implementation issues has hindered it use in the field of practical NDT applications. In the present experimental work, Lab View based programmable instrumentation and flexible hardware system for pulse compression technique system is proposed. This system is used to demonstrate Non-contact ultrasonic inspection on composite sample in through transmission. This technique is further extended and applied to guided wave non-contact ultrasonic application in pitch catch mode to improve the signal-to-noise ratio.

Keywords: Non-contact ultrasonics, Guided waves; Chirp Signal, Composite Material

Introduction

Many methods have been used in the past for the characterization and imaging of thin metal plates using air coupled ultrasonics, different chirp excitations and pulse compression technique [1,2]. Air coupled ultrasonics is one of the preeminent Non-destructive technique for inspecting composite materials because it overcomes the disadvantages of coupling materials like (Water, gel, oil etc.). On the other hand, Composite materials have found a wide range of applications in engineering due to their high strength to weight ratio, resistance to corrosion, low thermal expansion. Multilayer composites in form of plate like structures are being increasingly used in variety of structures because of the unique properties they offer. In particular they are often used for fabricating wings and other substructures of aircrafts. One of the commonly occurring defect in aircraft structure composite are barely visible impact damages are sub-surface damages, which are not detected through visual inspection and hence ultrasonic Non-Destructive Testing (NDT) methods have been used to inspect these damages. The conventional ultrasonic C-scan method is a point-by-point inspection that it is tedious and time consuming. Further, conventional NDT methods are difficult to use for inspection of inaccessible portions of structures.

Most NCU studies using air coupled transducers were conducted to detect damage in composite laminates by making use of separate transmitter and receiver on the either side of the test specimen and aligned to each other. Point by point scanning was done to image the damage. These studies mainly focused on evaluation of damage based on the amplitude variation of the received signal. Karthikeyan et. al. [2] and Ramadas et. al. [3] studied using the interaction of primary anti-symmetric Lamb mode with non-contact ultrasonic transducers.

Air coupled ultrasonic as NDT method fails to impress in fairly thick composites due to poor signal to noise ratio. Large no of signal averages during data collection is required to improve the signal to noise ratio, makes air-coupled a slow inspection process. To increase ultrasonic signal levels and improve the ultrasonic signal-to-noise ratio we can either reduce the noise level or increase the excitation signal level. Due to limitation of transducer construction excitation voltage level cannot be increased above a certain limit.

Pulse compression method are widely used in Sonar imaging have been recently applied to medical ultrasound imaging for their ability to improve the signal to noise (SNR) without increasing the amplitude of the excitation signal. The pulse compression approach applies a frequency-swept exciting signal into an object and the signal reflected from the target is decoded to compress the signal, therefore the signal to noise ratio (SNR) is increased and the resolution is enhanced.

H. Gan et. al. [4] applied Pulse compression method and used sinusoidal chirp based excitation to air coupled transducer for inspection of thin metallic plates. Garcia-
Rodriguez et al. [1] demonstrated the application of square chirp excitation to improve the signal to noise ratio on composite materials. The required complexity in electronics for generating an exciting signal for pulse compression techniques and implementation issues has hindered its use in the field of practical NDT applications.

Methodology

The pulse compression approach applies a relatively small voltage over a long period of time, resulting in a large overall amount of energy as opposed to the traditional ultrasound approach that provides a large voltage over a very short period of time. An excitation waveform was constructed to provide an optimized transmitted waveform to the transmitting transducer. A hamming window is used to modulate the amplitude of the signal $C(t)$ as shown in the figure below. If $y$ represents the output sequence Windowed $X$, the Hamming Window VI obtains the elements of $y$ from

$$y_i = \chi [0.54 - 0.46\cos(w)] - - - - - - \text{Eq.}(1)$$

For $i = 0, 1, 2 \ldots n - 1$, $w = 2\pi f$. Where $n$ is the number of elements in the input sequence $X$.

In this study we have used a linear chirp rate. The linear chirp is given by the relation

$$f(t) = f_0 + kt$$

Where $f_0$ is the starting frequency (at time $t = 0$), and $k$ is the rate of frequency increase or chirp rate. The corresponding time-domain function for a sinusoidal linear chirp is:

$$x(t) = \sin \left[ 2\pi \int_0^t f(t')dt' \right]$$

$$= \sin \left[ 2\pi \int_0^t (f_0 + kt')dt' \right]$$

$$= \sin \left[ 2\pi \left( f_0 + \frac{k}{2} t \right) \right]$$

The pulse compression can be described as

$$\xi(t) = \begin{cases} \frac{1}{T} \int_{t-T}^{t} \frac{\xi(t')}{T} dt' & 0 \leq t < T \\ 0 & \text{else} \end{cases}$$

Experimental Setup and Results

In order to generate the chirp waveform we have used a National Instruments (NI) arbitrary function generator, a NI data acquisition card for acquiring the data and sophisticated software is written in LabVIEW for filtering and signal processing. A RITEC Pulser receiver is used for exciting the transducer, a 40db amplifier is used for amplifying the signal. Ultrasonic air coupled ultrasonic transducers of 100kHz are used for generating guided waves and 200kHz are used for generating C-scan images of a composite plate.

The above figure shows the lamb waves on an 8mm thick composite plate. Figure 2(a) shows the raw chirp signal, Fig. 2(b) shows cross correlated signal of the same.
Above figures show the B-Scan of a section on a composite plate. Figure 3(a) shows the two defect regions at A and B locations.

The given images shows the C-scan of a 8mm thick composite plate, with two impact damages on it as shown in the photograph.

**Conclusion**

Chirp excitation and Pulse compression techniques were discussed. The application of ultrasonic chirp excitation on composite materials was discussed and experiments were carried out on composite plates. Chirp excited Lamb waves are generated on 8mm thick composite materials and B-scans were compared with the pulse excited B-Scan images, it is observed that chirp excited B-Scans have more information and sharp features than pulse excited B-scan images. The same was observed in C-Scans images using Chirp excitation.

**References**

1. Lamb Wave generation with an air-coupled piezoelectric array using square chirp excitation PACS: 43.35.Zc Garcia-Rodriguez, Mercedes; Yahez, Yago; Garcia-Hernandez, Miguel; Salazar, Jordi; Turo, Antoni; Chavez, Juan Antonio.