**46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA**

QNDE2019-1234

EVALUATION OF THE EFFECT OF MOTION ON ULTRASONIC SIGNALS ACQUIRED USING CODED EXCITATION

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ABSTRACT

Coded excitation is often used to improve signal to noise ratio (SNR) when ultrasound signals are acquired. A sequence of pulses is sent to increase the energy that is inserted into the medium. At the receiver the signals are pulse compressed so that a temporally short output with high SNR results. Commonly the technique only employs relatively short codes. This limitation is a result of the need to receive signals from relatively closely located reflectors. The author and his co-workers have recently presented an encoding method that overcomes that limitation. In the author's implementation very long codes are transmitted. With this a large improvement in SNR can be achieved but it also raises the question of how the technique performs in a dynamic environment where the probe is scanned over a surface. In this work the effect of motion on the acquisition process with long coded excitations is investigated. It was found that the process is affected by motion, but it remains robust at low speeds (a few m/s). For example, when a particular scenario was investigated that analysed signal reflections from a specimen containing a non-uniform inclined (17degrees) surface, the SNR dropped by 6dB when the probe moved at 1 m/s.

Keywords: ultrasound, coded excitation, acquisition speed

1. INTRODUCTION

Coded excitation is a well-known method to improve signal to noise ratio (SNR) in the ultrasound acquisition process [1]. Higher SNR results because the coded signal is temporally longer and, therefore contains more energy. The signals are pulse compressed after reception so that short signals with high SNR result. The technique has been successfully used in biomedical ultrasound systems over the last 20 years [1], but there are relatively few applications in NDE, an example being [2]. The common implementations of the technique also only employ relatively short codes, due to the need to receive signals from relatively closely located reflectors. The author and his co-workers have recently presented an encoding method that can employs very long codes for excitation [3]. Because of their length these codes dramatically improve SNR and it was shown that a low power (<10W) EMAT system could be built. It is unknown how these long, coded excitations perform when the transducer is moving during the acquisition process. Therefore, the effect of motion while acquiring data with long coded sequences is investigated in this work.

Figure 1a) illustrates the difference between pulsed excitation and coded excitation. If the same amount of energy (area of the rectangle) is injected into the material, then the same SNR should result. In coded excitation the shorter timescales are recovered via the pulse compression procedure after signal reception. The above example makes it clear that, if the maximum input amplitude is limited, coded excitation and pulse compression can help to improve the overall SNR by injecting more energy over time. Nonetheless, conventionally the maximum code length is also limited. This is because the travel time to reflectors within the inspected medium can be short and one needs to be able to receive the return reflections. Figure 1b) illustrates the maximum conventional code length that can be used. However, Isla et al. have recently shown that the code length can be arbitrarily extended if reception intervals are inserted into the excitation coded at random times [3]. This is illustrated in figure 1c). It makes it possible to increase the code length indefinitely until the system no longer is stationary. Stationarity, being one of the key assumptions required to perform the pulse compression operation.

In this work the long, coded excitation technique is used to measure the thickness of an object. The thickness of the object is not uniform and changes along its length. Simulations are performed to estimate how the SNR of the acquired signals changes as the measurement probe is moved over the object at different speeds. Figure 2 shows the setup that is being investigated. Without motion the SNR post pulse compression for the coded excitations that will be used in this work can be predicted by equation 1:

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$$SNR_{CE} = p_1(1-p_1)\, N \,/\, (p_1+1/(p_1\, SNR_{in})) \qquad (1)$$

where N is the total number of code symbols of equal length in the code and p_1 is the probability of a particular symbol in the code being a receive or transmit interval and SNR_{in} is the input SNR of the signal prior to pulse compression. The reader is referred to [3] for a derivation of this equation.

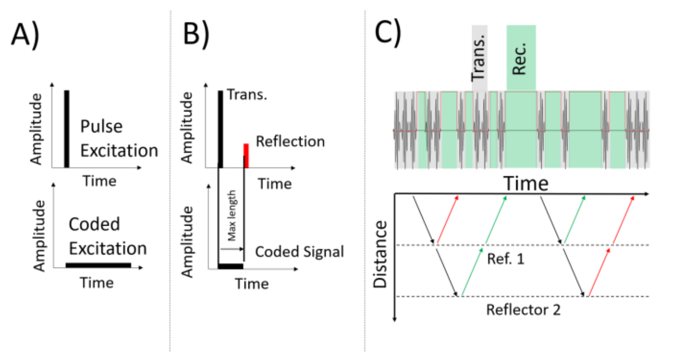

FIGURE 1: ILLUSTRATIONS OF A) PULSED AND CODED EXCITATION. B) THE CONVENTIONAL MAX. CODE LENGTH DUE TO PRESENCE OF REFLECTOR. C) EXCITATION CODE WITH RANDOM RECEPTION INTERVALS FOR LONG CODED EXCITATION WITH LARGE SNR INCREASE.

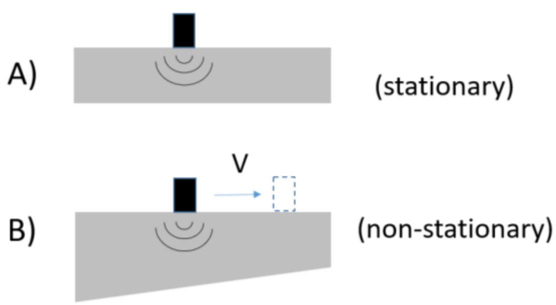

FIGURE 2: ILLUSTRATION OF THE MEASUREMENT SETUPS THAT ARE INVESTIGATED IN THIS STUDY A) STATIONARY PROBE ON OBJECT OF UNIFORM THICKNESS. B) MOVING PROBE ON OBJECT OF NON-UNIFORM THICKNESS.

2. MATERIALS AND METHODS

For the purpose of this study SNR was chosen as a key performance indicator. Simulations were performed to assess SNR with and without probe motion on an object of non-uniform thickness. For simplicity's sake an object with linearly varying thickness was chosen. For the stationary setup the received signal was simulated by creating three time-shifted copies of the coded excitation signal. The time shifts that were used were dt, 2dt and 3dt, dt corresponding to the transit time of the ultrasonic wave through the specimen and back again. The time shifted copies were summed with the signals with increasing time shift having diminished amplitudes. The values of 1, 0.6 and 0.3 were used for the first, second and third copy. The reduced amplitude was used to simulate attenuation and beam spread of the ultrasonic signal in the specimen. The resulting signal was then set to zero in the periods where transmission of the original signal was taking place. This resulted in a simulated acquired signal. This signal could then be pulse compressed by cross-correlating it with the input coded signal. The process to simulate the acquire signal is illustrated in figure 3.

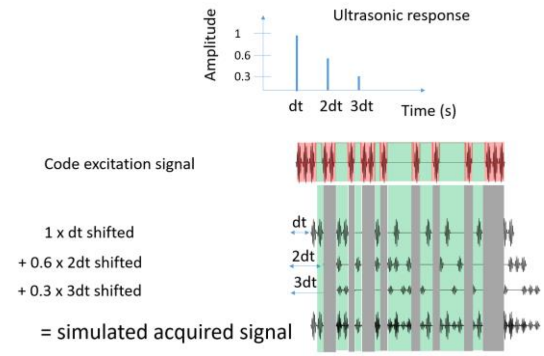

FIGURE 3: ILLUSTRATIONS OF THE METHOD THAT WAS USED TO SIMULATE THE RECEIVED SIGNALS.

It was necessary to introduce more complexity to simulate signals that were acquired while the transducer was moving. In order to do that each symbol or transmission interval was considered to be stationary. The coded signal was chopped up into *k* segments, one for each transmission period. For the period of that transmission the ultrasonic transit time *dt(k)* was evaluated and the simulated acquired signal was then created by adding time shifted copies of decreasing amplitude for each *kth* sub-segment of the code. The process was repeated *k* times to produce a complete signal. *dt(k)* could be adjusted for each *k* to account for a reduction of ultrasonic travel time as the transducer moved and the thickness of the object became thinner. The final signal was set to zero during the transmission periods of the original excitation signal and it could then be used for pulse compression. This process is shown in figure 4.

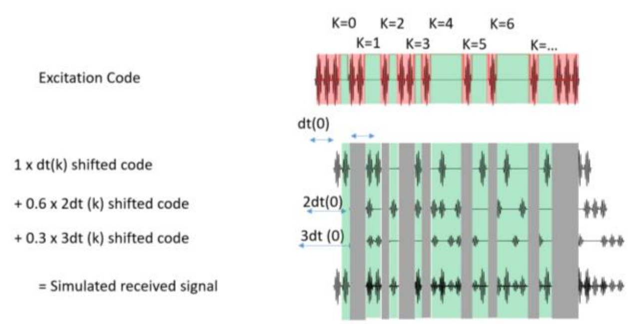

FIGURE 4: ILLUSTRATIONS OF THE METHOD THAT WAS USED TO SIMULATE THE RECEIVED SIGNALS WHEN THE TRANSDUCER WAS MOVING.

3. RESULTS AND DISCUSSION

Figure 5 shows simulated acquisition signals for acquisitions at different probe speeds. To make the result independent of slope and speed, they are shown as total vertical thickness change during the acquisition time. The geometry is as shown in Figure 2B with a linearly decreasing thickness starting from 15mm thickness. It was assumed that the object is made of steel (3260m/s). Coded excitation with 2^{10} symbols of 5 cycle 2MHz Hann windowed tonebursts was employed in every case.

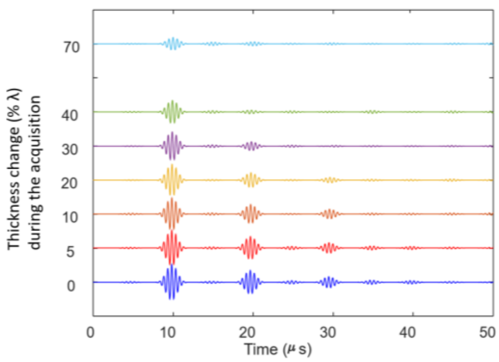

FIGURE 5: SIMULATED TIMETRACES WHEN THE PRESENTED CODED EXCITATION APPROACH IS USED TO ACQUIRE DATA FROM MOVING OBJECTS.

4. CONCLUSION

This work simulates the effect of motion on data acquired with long coded excitation signals. It can be concluded that the approach remains robust unless the thickness varies by a considerable fraction (>30% of the ultrasonic wavelength) during the acquisition process. A more detailed analysis of the SNR in the signals and experimental validation measurements for the simulations will be presented at the conference.

ACKNOWLEDGEMENTS

The author would like to thank Balint Herdovics for useful discussion on the content of this paper. The author would like to acknowledge the EPSRC for funding under the Grant EP/K033565/1.

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