REAL IMPLEMENTATION OF ULTRASONIC PHASED ARRAY TECHNOLOGY USING ADVANCED SIGNAL PROCESSING ALGORITHMS

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Abstract:
Over the past few years, the improvement in the field of ultrasonic non-destructive testing has led to significant advances in ultrasonic signal processing and image construction techniques. Many techniques have been proposed to improve the flaw and crack detection processes. In general, these techniques can be divided into two main parts. As first, many proposals have been focused on construction of ultrasonic transducers and systems. The second part is mainly focused on proposal of efficient signal processing algorithms that improve sensitivity (noise reduction) during ultrasonic signal acquisition. This paper combine both parts. We present our developed ultrasonic portable system with implemented phased array technology. All acquired ultrasonic signals using commercial phased array transducer are consequently processed using our proposed filtering algorithms. These algorithms are necessary to obtain unambiguous information about detected flaws and cracks. The detected flaws can be than easily visualize. For material bulk visualization we use phased array technology.

Introduction – Ultrasonic Non-destructive testing

Ultrasonic non-destructive testing (UT) is commonly used for flaw detection in materials. Ultrasound uses the transmission of high-frequency sound waves in a material to detect a discontinuity or to locate changes in material properties [1]. Ultrasonic wave propagation in tested materials is essentially influenced by the tested material structure. In general, due to material structure the acquired ultrasonic signal can be corrupted with relatively high noise level, commonly called backscattering noise. In present, the most desired task is to detect the fault echo in ultrasonic signal; it means to locate the cracks or defects in tested materials. The flaw detection efficiency is mainly influenced by the noise level and on this account the efficient signal processing techniques used for noise reduction are proposed. As all acquired signals are processed with our implemented signal processing methods than all signals are reconstructed to create flaw visualization using phased array technology.

Ultrasonic portable system with implemented phased array technology

During the last two years, we have been developing a completely new ultrasonic non-destructive testing portable instrument. The main goal was to develop the highly robustness ultrasonic portable instrument including conventional ultrasonic testing [1], EMAT testing [2, 3] and testing based on phased array ultrasonic technology [3]. All these non-destructive methods were successfully implemented into one device called “DEFECTOBOOK DIO1000’. Except implemented ultrasonic non-destructive testing methods we were focused on proposal of efficient signal processing algorithms that contribute for flaw detection and efficiently suppress noise. Conventional ultrasonic testing and EMAT testing have been already implemented in DIO2000 system three years ago. The main objective of our new instrument was to have implemented phased array technology as well. This makes our system universal in many industrial applications. Our phased array technology is based on transmitting of ultrasonic waves from all elements simultaneously and consequently receiving of all reflected signals back to phased array transducer. For our experiments we use commercial phased array transducer including sixteen elements. As we are still in developing stage, we plan to implement sampling phased array technology [5] based on gradual transition of each element with consequent receiving using all elements.

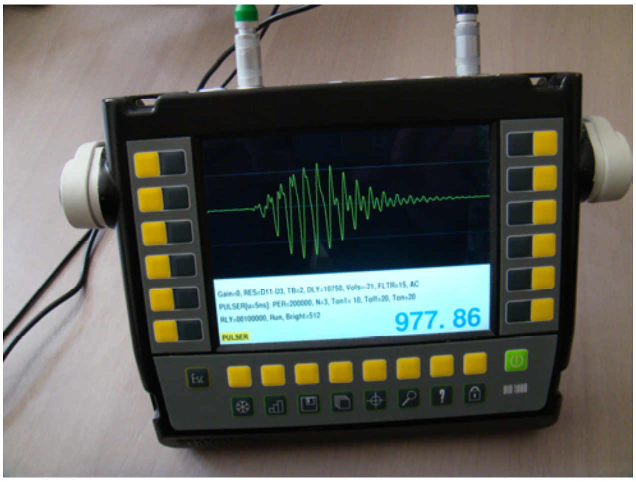


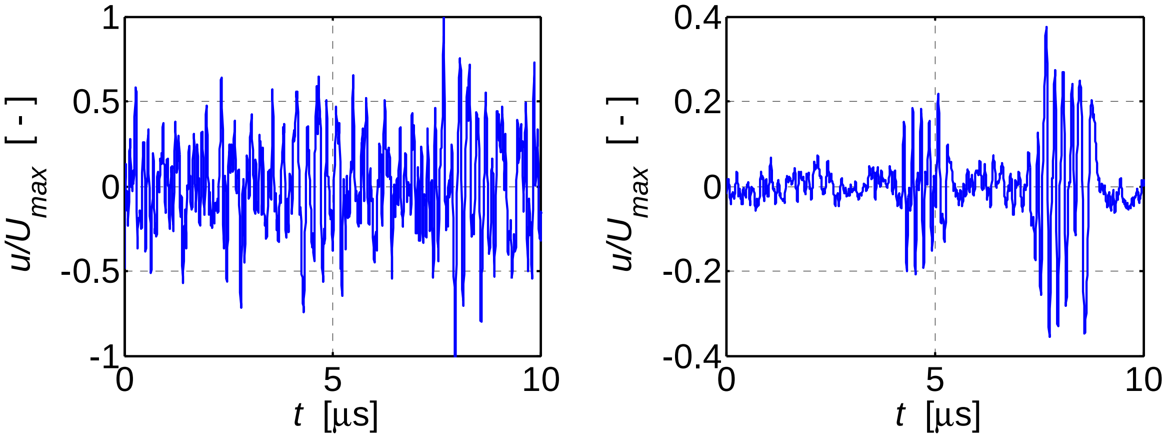
Fig. 1. Ultrasonic portable instrument DEFECTOBOOK DIO1000

All mentioned non-destructive testing methods were implemented based on previous research. First of all, we have implemented conventional ultrasonic method and EMAT testing method. As all acquired ultrasonic signals are corrupted with relatively higher noise level, methods used for effective noise reduction were searched. During the research we have tested many algorithms used for noise reduction but the main goal was to find efficient noise reduction and simple methods that could be easily implemented as algorithm processing the signals in real time. This goal was successfully achieved and averaging, digital filters and correlation methods were implemented into DIO1000 signal processor.

Signal processing algorithms – Averaging and Digital filters

Averaging

Averaging [6] the ultrasonic signal is a common method of enhancing the signal-to-noise (S/N) ratio. This method slows down data acquisition, because the pulse repetition rate of ultrasonic instruments is orders of magnitudes slower than the processing time needed to perform averaging. In general, many (e.g. 64) signals are acquired and these are averaged over all signals. The main advantage of averaging is that this method is relatively easier to implement. On the other hand, the main disadvantage is that number of acquired signals and consequent averaging of these signals essentially makes the processing time much higher. But, of course with used digital signal processor it can be used for real time application. On the following Fig. 2, there can be seen the example of using averaging by 64 acquired signals. The acquired signal (see Fig. 2a) is corrupted with relatively higher effective noise level amplitude. By using averaging (see Fig. 2b) of 64 signals, both flaw echo and back-wall echo are easily visible.



a) b)

Fig. 2: Example of averaging: a) acquired ultrasonic signal – flaw 2 mm, b) averaged signal by 64× signals

Digital filter – Finite Impulse Response (FIR) filter

Zero-phase digital filtering [6] can be realized using non-casual filtering method. This method is based on processing the input data in both the forward and reverse directions. After filtering in the forward direction, the filtered sequence is reversed and fed back through the filter. The resulting sequence has precisely zero-phase distortion and double the original filter order.

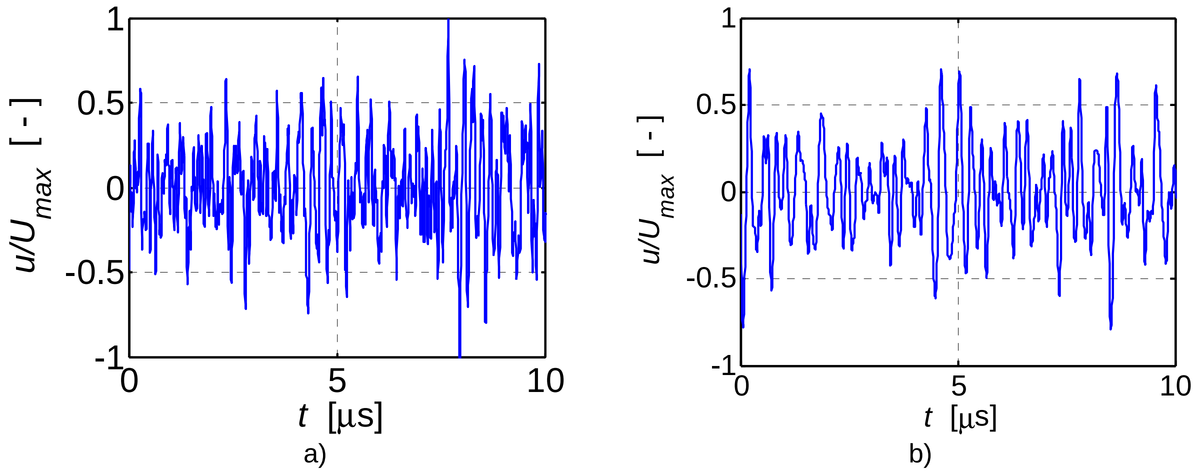


Fig. 3: Example using FIR filter: a) acquired ultrasonic signal – flaw 2 mm, b) filtered signal

As can be seen in previous Fig. 3, noise was succesfully suppressed. The main objective is to detect the flaw. This as well as a frequency band of proposed filter depends used ultrasonic transducer. In the previous Fig.3 we used the ultrasonic transducer with central frequency 4 MHz. The proposed and implememnted anti-causal filter has bandwidth 4MHz.

Phased Array technology

Next step was to implement the advanced ultrasonic phased array technology [4] to visualize tested material in detail. Phased array holds the promise of being able to efficiently detect all significant flaws by combining many angles and focus depths into one probe and image the resulting reflections in an understandable way. Flaw acceptance still requires the comparison of flaw reflections represented as an A-scan with the A-scan of a known artificial reflector such as a side-drilled or flat-bottomed hole. The use of special signal processing and image reconstruction algorithms allows generating A-scans of several angles and/or sector-scans, which can be implemented in real time. With parallel computing structures, this principle is used for automatic testing systems at very high inspection speed.

Over the past years, many companies have introduced systems making use of phased array technology. Phased array training courses for operators usually address general principles and only few examples of real applications. One of the major difficulty often omitted during training and in practice is the actual coverage of phased arrays. It is easy to say that a sector scan will detect all defects in a material as it passes through a large range of probe angles. Although a high probability of detection can be achieved – certainly a lot higher than manual UT – it is by no means guaranteed that all defects will be detected. The resolution in terms of the step width between angles and the focus depth range are of major importance to detect defects and discriminate between adjacent flaws. The angle at which an ultrasonic reflector is detected is not only dependent upon the angle of incidence of the transducer array, but is also dependent upon the position of the transducer relative to the weld axis. When these parameters are not adequately addressed, these factors can seriously affect the degree of success of phased array inspection.

As we mentioned before, the first implemented phased array technology is based in synchronous transmitting of signals from all elements followed by receiving of reflected signals, we are working on improvements. These improvements are based on transmitting of each element independently with some delay based on focused point. Other elements transmit ultrasonic signals with derived delay. The following drawing represents our calculation of time delay of each element.

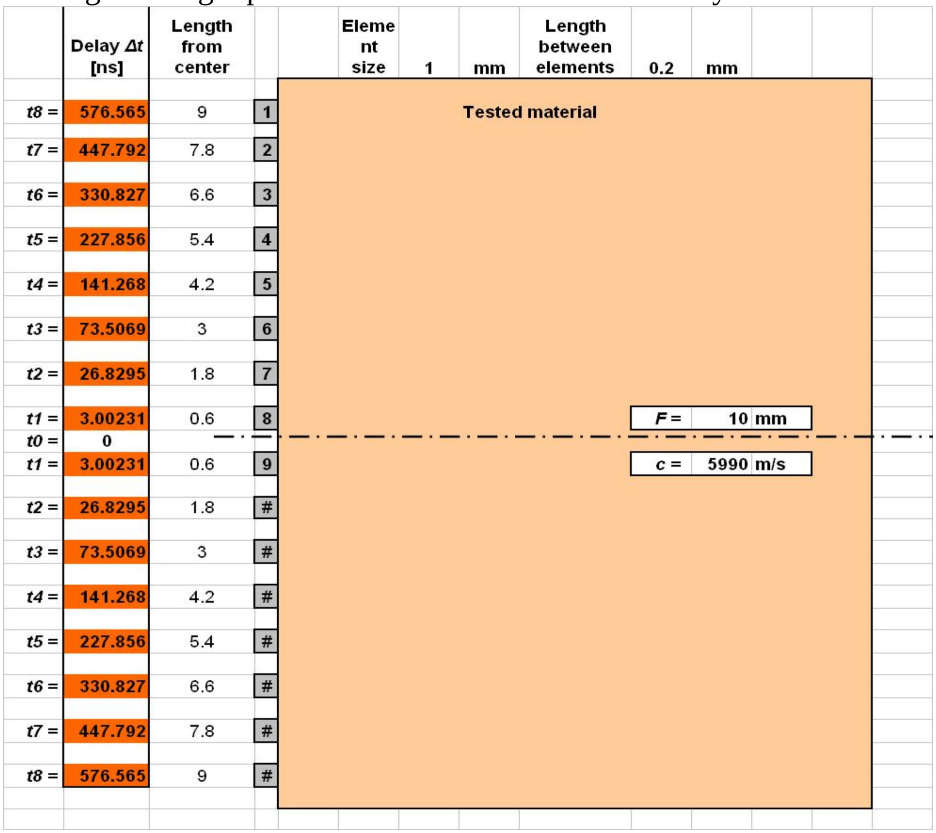


Fig. 4: Calculation of time delay

We suppose, the transducer is located on the tested material and each element is transmitting signal with derived delay. The following Fig. 5 shows the curve of time delay based on each element location deviated from central position of phased array transducer (see central axis in Fig. 4).

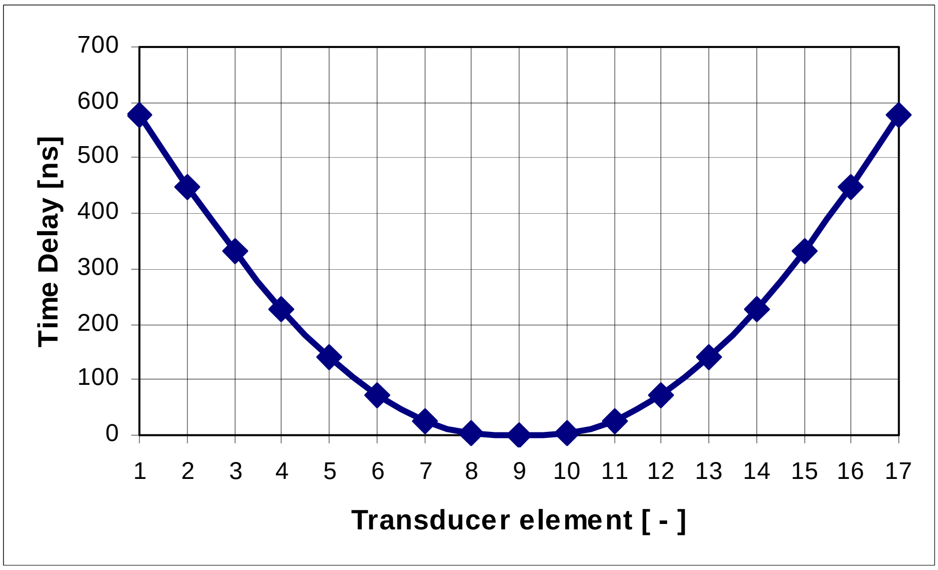


Fig. 5: Time delay of transmitted signals

As can be seen in Fig. 5 the transmitting of all elements has semicircle curve shape. By calculated time delay we are able to receive signals with unique information about flaw location during manual testing. Our analysis supposes there is circled flaw in the center of the material under the phased array transducer.
As we are at the beginning of our experiments, we have implemented only simple phased array technique. All signals are transmitted at the same time and at the same time received. This we have working well in our DEFECTOBOOK DIO1000 ultrasonic instrument. The following picture represents our full developed ultrasonic system with implemented phased array technology.

Fig. 6. Material scanning using phased array technology

Conclusion

This paper presented our developed ultrasonic portable system. The developed system contains implemented conventional ultrasonic testing, EMAT testing and phased array testing. As all signals are corrupted with relatively higher amplitude noise level, our system contains signal processing methods based on averaging and digital filters. The presented system is equipped with phased array technology. As we are at the beginning of our experiments we are able to scan flaws using transmitting and receiving signal s at the same time. The presented paper describes phased array technique using transmitting the signals with derived time delay based on distance from focused point.

Acknowledgement

This research work has received support from research program No. 2A—1TP1/092 " Research of piezoelectric laminated nanoforms for high-temperature ultrasonic transducers" of the Ministry of Industry and Trade.

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