Real Implementation of Ultrasonic Phased Array Technology Using Advanced Signal Processing Algorithms

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ABSTRACT

Over the past few years, all improvements in the field of ultrasonic non-destructive testing have led to significant advances in ultrasonic signal processing and image construction techniques. The main focus in non-destructive testing area is to improve the resolution of defect detection and make the detection process as fast and accurate as possible. Many techniques have been proposed and implemented to improve the flaw and crack detection processes. In general, these techniques can be divided into two main parts. As first, many proposals consider the 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 presents our fully developed ultrasonic portable system with implemented phased array technology. All acquired ultrasonic signals are consequently processed using our proposed filtering algorithms.

Introduction

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 (2). In present, the most desired task is to detect the fault echo in ultrasonic signal; it means to locate the subsurface cracks or defects in 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 have to be 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 three 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 (3) and testing based on phased array ultrasonic technology (4). All these non-destructive methods were successfully implemented into one device called "DEFECTOBOOK DIO1000'. Except implemented ultrasonic non-destructive testing methods we were also 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 four years ago. The main objective of our development was to have the best phased array instrument with on-line measurement and visualization of material bulk. 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 16 up to 64 elements.

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 (2) 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. 1, there can be seen the example of using averaging by 64 acquired signals. The acquired signal (see Fig. 1a) is corrupted with relatively higher effective noise level amplitude. By using averaging (see Fig. 1b) of 64 signals, both flaw echo and back-wall echo are easily visible.
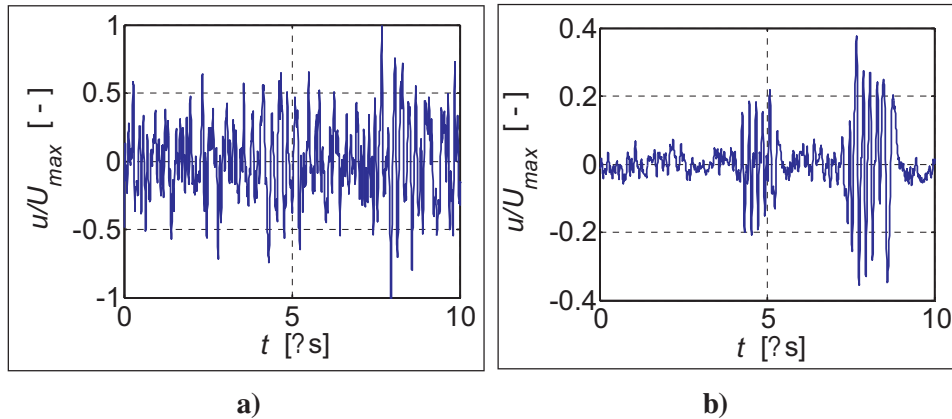
Fig. 1: Example of averaging: a) acquired ultrasonic signal - flaw 2 mm,
b) averaged signal by 64× signals

Digital filter - Finite Impulse Response (FIR) filter

Zero-phase digital filtering (2) 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.
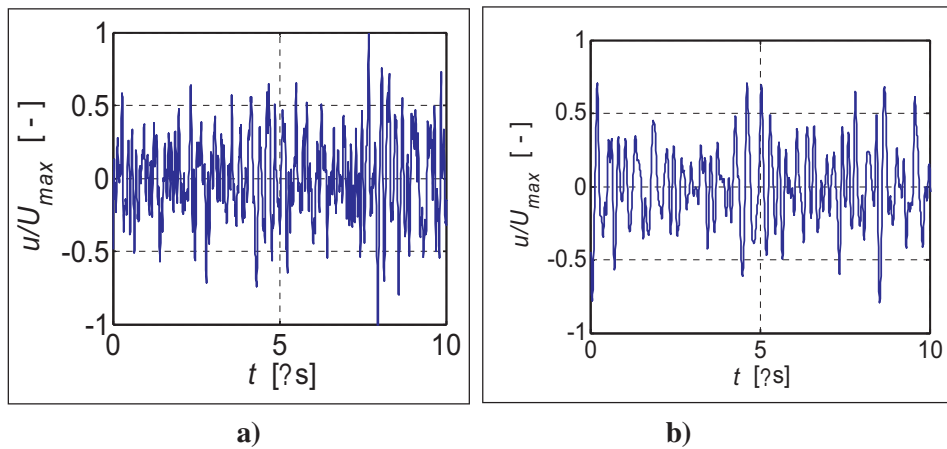

Fig. 2: Application of FIR: a) acquired ultrasonic signal - flaw 2 mm, b) filtered signal

As can be seen in previous Fig. 2, noise was successfully 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.2 we used the ultrasonic transducer with central frequency 4 MHz. The proposed and implemented anti-causal filter has bandwidth 4MHz.

Phased Array technology

Next step was to implement the advanced ultrasonic phased array technique (5) and visualize the internal bulk of 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 few 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 difficulties 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. We suppose, the transducer is located on the tested material and each element is transmitting signal with derived delay. The following Fig. 3 shows the curve of time delay based on each element location deviated from central position of phased array transducer (see central axis in Fig. 3)
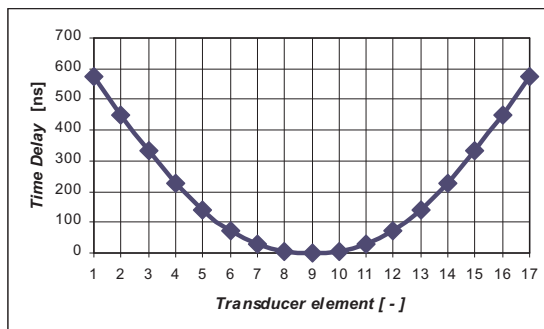
Fig. 3: Time delay of transmitted signals

As can be seen in Fig. 3, 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.

The mentioned idea was implemented into our designed ultrasonic system, called DEFECTOBOOK DIO1000. The following picture represents our full developed ultrasonic system with implemented phased array technology.

Fig. 4: Constructed system DIO1000, phased array - calibration gauge

As can be seen in Fig. 4., we have successfully constructed ultrasonic phased array instrument with implemented advanced signal processing algorithms. Using this system and phased array technique, we are able to easily detect flaws within the range of scanned angles. To verify the proposed system and properly configure all parameters we also constructed calibration gauge with defined flaws (see Fig. 4.). When we passed all tests and initial experiments we were able to see the flaws on calibration gauge. Using the predefined settings we use our system for industrial application, see below.

During the last few years we have been working on improvements in resolution. Based on special settings and configuration we have reached the resolution to recognize two flaws located 1 mm between each other. The main improvements were made in signal processing, the noise has been successfully suppressed and signal representing flaws and cracks are simply displays.

# Applications

Testing of railway rails

The following Fig. 5 presents one sector scan where we can see all side drilled holes.

Fig. 5: Testing of railway Rails
et.al., Real implementation of ultrasonic phased array technology

Using of phased array probe without adapter with ultrasonic signal deflection on both angle sides can be seen in Fig. 6. Our systéme visualizes all three side drilled holes (see Fig. 6b.).

a)   b)
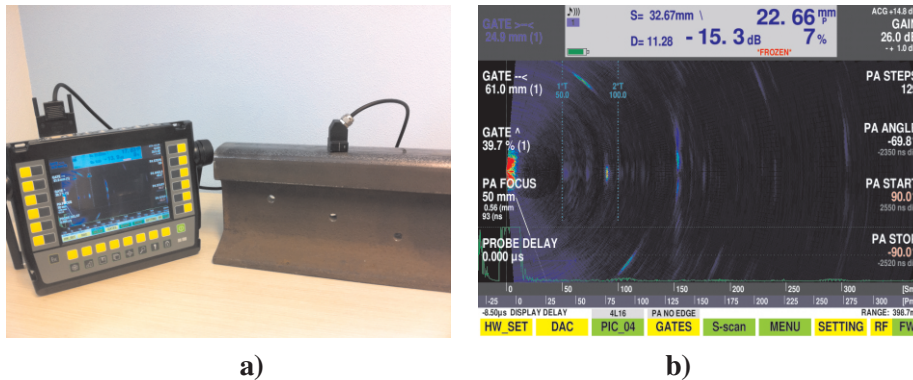
Fig. 6: Testing of railway rails, a) probe without adapter, b) detected flaws

Testing of railway axles

Testing of railway axles from side axis of the axle. It is possible to see the orientation of the cut of axle from one probe location.
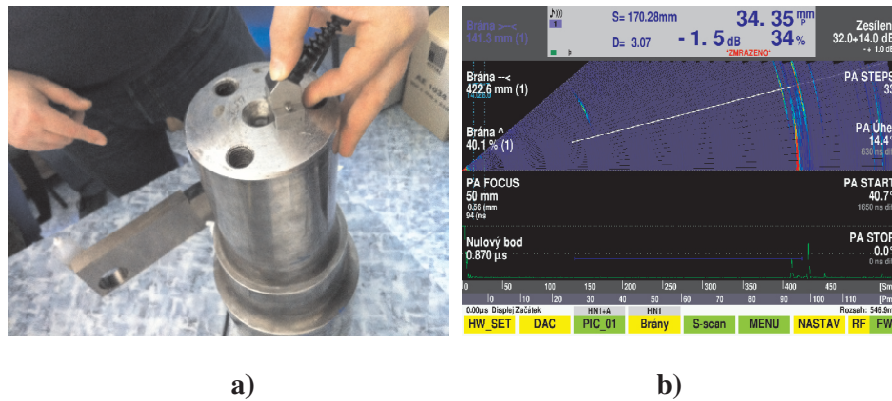
a)   b)

Fig. 7. Testing of railway axles, a) placed probe on the side of axle, b) detected flaws

Testing of welds

The testing of welds is a standard option in our proposed system, The following Fig. 8. shows the result of weld testing.
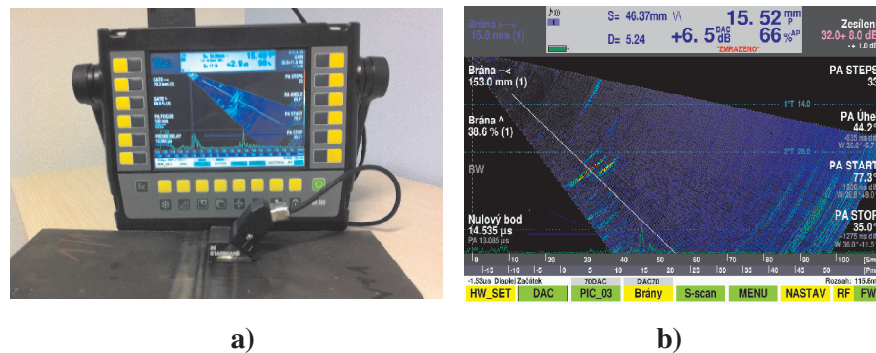

a)   b)

Fig. 8: Testing of welds, a) tested material with weld, b) detected cracks

During the weld testing, it is possible to set the deflection angle within 35-90°. Based on the advanced settings and automatic amplitude correction, it is possible to successfully detect cracks hidden in welds.

Conclusion

This paper presented our developed ultrasonic portable system with phased array technique and possible applications. 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 signals 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

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