Pulse-echo Measurement Systems - A Mini Review

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***Abstract*—Pulse-echo measurement systems using optical, radio frequency, and acoustic sources have been widely used to detect the fault and crack of the desired target materials because of repair and condition of the materials. Recently, some pulse-echo measurement systems have been widely used combined with several sensor devices. Especially, the pulse-echo measurement systems with acoustic sources could provide real-time, non-invasive, and cost-effective solutions. In this review paper, several commercial pulse-echo measurement systems were introduced. Therefore, this review paper could provide some guidance how to handle and utilize the acoustic-based pulse-echo measurement systems and to optimize the performances of the pulse-echo measurement system electronics.**

Keywords—pulse-echo response; fault and crack; measurement system

I. INTRODUCTION

Among the medical imaging instruments, X-ray, magnetic resonance imaging (MRI), optical imaging, single photon emission computed tomography (SPECT), positron emission tomography (PET), X-ray based computed tomography (CT), and ultrasound imaging are most common imaging solutions [1-16]. These medical diagnostic, therapeutic, and imaging instruments are commercialized over 60 years [7, 17-25]. Especially, the MRI, CT, PET, and ultrasound imaging are commonly used in the hospitals and their market shares are still increasing especially in the Asia because of the recent semiconductor integrated circuit technology and deep learning technology [26-42].

Compared to optical imaging, ultrasound imaging techniques could obtain the images from deep area due to the characteristics of the acoustic signals which can penetrate to the materials [43-51]. Because most optical lights could be scattered in the surfaces and only some lights could be penetrated into the target, the optical imaging could provide functional information with high contrast [52-56]. The optical absorption characteristics need to utilize the light beam due to different light wavelengths [57-61]. The penetration depth of the materials is related with absorption coefficient such as oxy-hemoglobin, lipid, melanin, collagen, and elastin. The optical beam needs to be passed through several optical components and delivered to the target [62-66]. Compared to optical imaging, the ultrasound imaging could provide structural information with high spatial resolution and low contrast [67-70]. Therefore, the photoacoustic instruments combined with optical and ultrasound techniques were developed to use mutual advantages of the optical and ultrasound imaging such as high contrast and spatial resolutions [71-75].

Ultrasound instruments have been widely accepted because they provide real-time image processing capability, relatively low cost, non-ionized, and non-invasive functions [76-78]. For ultrasound imaging systems, portable or mobile type medical ultrasound imaging machines are widely used in the industry and hospitals [79-83]. For such small size mobile imaging machines, synthetic aperture imaging methods are supported to be utilized for array type transducers [84-86]. The acoustic signals are transmitted to the soft tissues in the human body and reflected or refracted from the materials which have different acoustic impedances [87-92].

The received acoustic signals are reconstructed to obtain the images. Basically, this concept was developed from radar system of the communication instruments or sonar from submarine [93-96]. The medical ultrasound imaging adopted this concept. The essential devices in the ultrasound imaging systems are ultrasonic array transducers so the scanning techniques are used [97-99].

The scanning techniques are utilized in the medical ultrasound diagnostic instruments [100-102]. The scanning methods are composed of the electrical and mechanical scanning methods. The electrical scanning methods are composed of linear, sector, and phase methods. Mechanical scanning methods are also composed of liner and sector scanning methods. These scanning methods are coming from radar system techniques [103-105]. To test the performances of developed imaging solutions like ultrasound imaging, the pulse-echo measurement systems are utilized accordingly [106-108].

Section II describes the main devices of the pulse-echo measurement system. In section II, the beamforming techniques using array transducer is described because the pulse-echo measurement systems utilize the beamforming techniques. Section III describes the electronics for the pulse-echo measurement systems. Section IV describes the commercial pulse-echo measurement systems. In section IV, the specific process and operating mechanisms of the pulse-echo measurement systems with some commercial instruments are described. Section V is the conclusion of the paper.

II. DEVICES FOR PULSE-ECHO MEASUREMENT SYSTEMS

The main devices of the pulse-echo measurement system are fundamental array transducer [109-111]. The linear, convex, curvilinear, phased, and sector array type transducers are categorized depending on the structures and applications [112-114]. In the array transducers used in the medical ultrasound systems, a linear array transducer is mainly used for shallow areas, convex array transducer is used for human abdomen, and phase array transducer is used for deep heart area [115-117].

The theory of the beam-forming measurement method is briefly introduced with respect to the electrical scanning, focusing, steering, and transmission principles [118-120]. The ultrasonic beam transmitted from one ultrasonic array transducer element in medical ultrasonic diagnostic instruments spreads over a fairly wide ranges so the resolution of the instruments can hardly be obtained with only one element [121-123]. When forming the ultrasonic beam on an arbitrary point, the ultrasonic beam radiated from each element at the focal point or focal distance must be constructive interference [124-126].

The ultrasonic waves from each element at the focal point must have the same phase and reach the desired targets at the same time [41, 127, 128]. At the focal points or focal distances, the amplitudes of the beam will be maximized compared to the surrounding areas out of the focal points so the amplitudes of the ultrasonic beam are relatively reduced due to beam cancellation or interference [129-131]. Therefore, the signal transmission generated from each ultrasonic transducer array element must have appropriately different delay time which we call focusing delay [132-134].

In the beam-forming measurement technique, a beam is made into the desired beam shape to be focused, thus improving the spatial resolution of the ultrasonic instruments [135-137]. In the medical ultrasound diagnostic instruments, beam-forming techniques are important because they can determine the ultrasound image resolutions [138-140]. The performances of the array transducers have also great influences of the ultrasound image resolutions [141-143]. When transmitting ultrasonic signals, each array transducer element produces the transmit pulse [144-146]. The beam generated from each transducer element could be reached to the focal point at the same time, resulting in focusing the ultrasonic beam in the desired focal points [147-149]. On the other hand, the time delay is applied to the ultrasonic echo signal received by each element to unify the time delay when ultrasonic echo signal is received [150-153]. When all the received signals are added together, they become coherent summation which we called delay-and-sum receiving focusing [154-156]. In the pulse-echo measurement system, ultrasound beam needs to be focused.

III. ELECTRONICS FOR PULSE-ECHO MEASUREMENT SYSTEMS

The fundamental pulse-echo measurement instruments except several beam-forming and control electronics will be described [157-160]. The electronics for pulse-echo measurement systems are transmitter, receiver, and control electronics [161-163]. The transmitter needs to produce the single unipolar pulse or multi-cycle pulse. We called a pulser which can produce the uni-polar pulse and a power amplifier which can produce the multi-cycle pulse [164-166]. The transmitter can be used to trigger the ultrasonic transducer which generates the acoustic signals [166]. The transmitted acoustic signals are delivered to the target in the water tank. The returned acoustic echo signal is converted to the electrical echo signal through the ultrasonic transducer. The obtained electrical echo signal is processed through the receiver electronics.

The receiver needs to filter out the noise signals or amplify the weak echo signals generated from the ultrasonic transducers [167-171]. The analog-to-digital converter (ADC) or digital-to-analog converter (DAC) are used to support the transmitter or receiver, respectively [172-176]. The DAC is used to convert the digital signal controlled by the computer to the analog signal. This analog signal is the input of the transmitter. The ADC is used to convert the received analog echo signal to the digital echo signal. The control electronics are simply called beam-forming electronics [177-179]. The beam-forming electronics are transmitting and receiving beam-forming electronics which control the transmitter and receiver electronics, respectively [180-182]. These beam-forming electronics control the whole transmitter and receiver electronics with proper timing control because the pulse generation and echo generation time should not be merged. Otherwise, the received acoustic echo signal waveforms in the pulse-echo measurement system could not be properly obtained.

The most commercial transmitters/receivers are called pulse-echo or pulser-receiver made from Olympus Inc., Verasonics Inc., and Imaginant Inc., The companies of the Olympus Inc. and Imagniant Inc. usually provide the positive or negative uni-plor single pulser combined with receiver. The pulser-receiver made from the Olympus Inc. and Imagniant Inc., is composed of the pulser and receiver. The receiver is composed of the preamplifier and filter. The Vantage system made from Verasonic Inc., is composed of the pulser, power amplifier, and receiver including imaging processing electronics. The Vantage system utilizes the pulser and power amplifier which can generate the single uni-polar pulse and multiple pulse together. In the Vantage system, there are beam-forming electronics including ADC and DAC electronics to plot the ultrasound images in the computer.

IV. PULSE-ECHO MEASUREMENT SYSTEMS

This section will describe the commercial pulse-echo measurement systems. Genesis Inc. recently developed the automatic pulse-echo ultrasound measurement system with robotic arm for other applications such as transportation and aerospace applications. The developed pulse-echo system could be used to detect the flaws of the structures in the materials or pipelines using ultrasonic array transducers [183]. In 2016, real-time mobile scanning function supported pulse-echo laser-ultrasonic transmission imaging instrumentation was developed [183]. That system could be used as in-situ and in-process non-destructive testing equipment.

Onda Corporation provides the pulse-echo measurement system which they called acoustic intensity measurement system (AIMS). AIMS is one of the pulse-echo systems for ultrasound transducers and system evaluation tool. The AIMS system follow the internationally recognized guidelines which are standard procedure for diagnostic ultrasound systems such as AIUM-NEMA, UD-2/UD-3, IEC 60601-2-37, IEC 62127-1, and IEC 62359 [184]. Acertara Corporation also provided similar system which they called acoustic measurement system (AMS). The AMS system follow the internationally recognized guidelines such as NEMA UD 2, NEMA UD 3, IEC 60601-2-37, EN 45502-1, IEC 61847, and ISO 147081-1.

In the pulse-echo measurement system, the ultrasound array transducers and fixtures support the x, y, and z axes with tilt, azimuth, and elevation directions which are five axes directions [185-187]. In these systems, users could use the programs from the personal computer to control the ultrasonic array transducers with LM guide structure and supporting position indicators [188-191]. When testing the materials in the pulse-echo measurement system, the ultrasonic array transducer and hydrophone need to be aligned. The control boxes could provide the alignment process. In the pulse-echo measurement system, the holder needs to move from left to right and top to bottom. The transmitted acoustic signals generated from the ultrasonic transducers are approached into the ultrasound hydrophone sensor located in the bottom of the pulse-echo system. The motor controller, digital oscilloscope, arbitrary function generator or signal generator are also used. The temperature monitoring sensor with control motion board is also included because the water temperature need to be controlled all the time for accurate performance measurement with ultrasonic transducer and ultrasound system. The received acoustic signals are extracted using MATLAB or Microsoft EXCEL programs in the computer.

V. CONCLUSION

This review paper briefly provide the information of the pulse-echo measurement system with electronics information of the system. The pulse-echo measurement system is recently widely used to estimate the performances of the developed ultrasonic transducers or ultrasound system electronics or find the flaws or cracks of the materials. The pulse-echo measurement system is composed of the transmitter, receiver, control electronics, and ultrasonic transducers with some beam-forming algorithms.

In the pulse-echo measurement system, the transmitter and receiver electronics with beam-forming techniques are utilized to align the ultrasonic transducers and hydrophone with target materials. This alignment process is performed with control box electronics in the water tank. After alignment process, the received echo signals could be processed to obtain the crack or fault images of the materials. Therefore, customers could analyze the material status.

Several companies commercialize the pulse-echo measurement system for research and industry purpose. However, there are no detail information about the concept, construction methods, and beam-forming algorithms which are useful for the ultrasonic transducer engineers because customers just utilize to evaluate the performances with the regulations of the ultrasonic transducers. The commercial pulse-echo measurement systems include some internally recognized guidelines with manual as mentioned before.

In this review paper, the descriptions and guidelines of the special ultrasound system could be provided with evaluation tools in the pulse-echo measurement system so the customers or users could provide some useful reports about various ultrasound data. However, these companies do not provide the detail construction methods. Therefore, this review paper could be useful guidance for the engineers who developed the pulse-echo measurement system commercialization.

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