Electronic Solution to the QTUD Method for Materials Testing

Zoran Ebersold, Nebojša Mitrović, and Slobodan Đukić

***Abstract*—The method for defectoscopy of materials that uses separated ultrasonic heads for emitting and reception of signals i.e. ultrasonic transmission defectoscopy has not been much in use in science and engineering until now. This method consists of an ultrasonic head for emitting signal and only a single ultrasonic head for its reception. The method described in this paper is named quadraphonic transmission ultrasound defectoscopy (QTUD). It is an ultrasonic defectoscopy method for materials testing that uses a single ultrasonic head for emitting and four ultrasonic heads for receiving of ultrasonic signal. The advantage of this method is its suitability even with porous materials, all based on relatively low frequencies (about few tens of kHz). Therefore, electronic components are cheaper, so the wide application of this method, both in science and industry is possible.**

***Index Terms*—Defectoscopy, quadraphonic transmission method, ultrasonic transmission defectoscopy.**

I. Introduction

SOUND waves represent propagation of oscillations and can be spread out in solid, liquid and gaseous state [1]. Sound waves are also called ultrasonic waves or ultrasound if their frequency is higher than 20 kHz [2]. This frequency is often cited as the upper limit of the sensitivity range for human hearing. Defectoscopy is a scientific discipline concerned with finding errors i.e. defects in materials. When the ultrasound is used for testing, this method is named as ultrasonic defectoscopy. Samples that are undergoing ultrasound testing do not receive any damage, and therefore this method is listed as a non-destructive material testing method. This method can easily be integrated into technological process of production or as a final stage for control for semi-finished or finished products. Ultrasound defectoscopy is applied primarily in optical opaque materials, materials that strongly absorbs X-rays and in metals where application of electromagnetic signals is not possible due to the “skin effect” [3].

Various methods for the purpose of ultrasound defectoscopy of solid objects have been already developed [4, 5]. Properties of these methods depend on the application and objectives of the measurement. Propagation time and the intensity of ultrasonic waves are the parameters obtained by ultrasonic defectoscopy. These parameters can be applied in various mathematical algorithms [6, 7] for analyzing the condition of a given sample. Usually, applied technique of ultrasound defectoscopy is based on the same ultrasound head for emitting and reception, where the method uses the impulse echo technique. This is common method in the literature and in industry. The impulse echo method currently represents the main "trend" within the ultrasound defectoscopy [8]. However, the application of this method is under high frequencies (several GHz). This causes a huge absorption of ultrasonic waves in samples. Therefore, application of ultrasonic impulse echo method is not possible on very porous materials.

The procedure discussed in this paper has been neglected and developed as a method for using separate heads for ultrasonic emission and reception. The literature provides data on this method employing one head for emitting ultrasound signal and one single ultrasonic head (i.e. sensor) for receiving. The method with two separate heads is named the "transmission ultrasound method".

The aim of this study is to present a concept and technical solution developed for the improvement of transmitting ultrasonic method of defectoscopy for materials with one ultrasonic head(for emitting an ultrasound) and four heads (for the reception), i.e. quadraphonic transmission ultrasound defectoscopy (QTUD). It aims to provide a contribution to the development of science and technology, improving a transmission of ultrasonic method in an effective method for defectoscopy of materials, especially for porous materials. The main advantage of the QTUD method over previous ultrasound methods based on impulse echo methodology is the application of much lower frequencies (about a few tens of kHz, for example 45 kHz). Therefore, it can be successfully applied even on the extremely porous samples (for example various sintered polymers, sintered metals and various indirectly and directly laser-sintered materials).

The block diagram shown in the Fig. 1 represents an operating principle of the QTUD assembly. The components shown in the scheme are: function generator, an ultrasonic transmitter S1, ultrasonic sensors as receivers P1, P2, P3 and P4, adapters A1, A2, A3 and A4 as signal pre-amplifiers, four-channel analogue to digital (A/D) converters and a computer for digital signal processing with appropriate software. For

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signal control during measurement an oscilloscope and frequency meter were used.

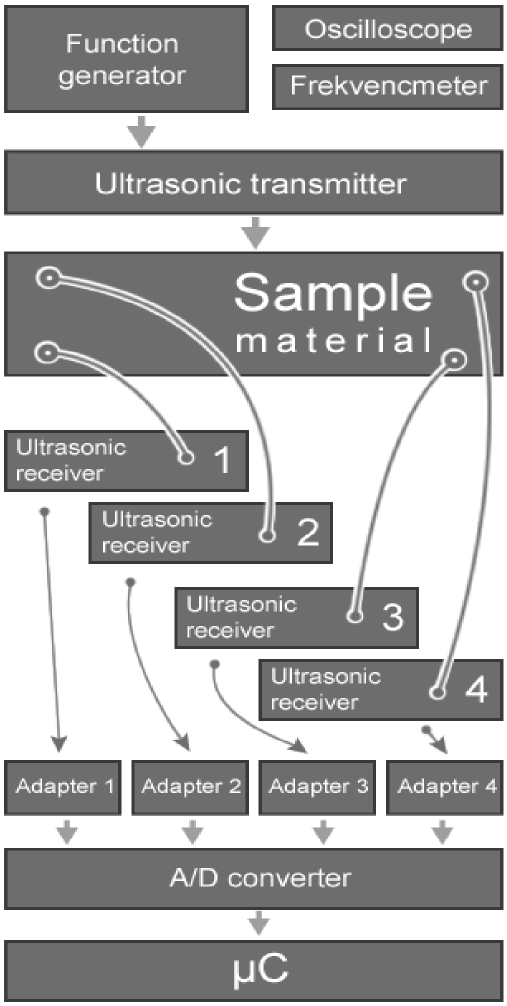

Fig. 1. Block scheme of the QTUD method.

II. Methodology

The sample material is mounted on the holder which keeps the sample stable i.e. the ultrasonic transmitter (S1) and four ultrasonic sensors (P1, P2, P3 and P4) can be positioned so as to ensure confidential contact with the sample. Fig. 2 shows part of the apparatus of the QTUD method, i.e. insert (a) shows the location of transmitter (S1), insert (b) shows the position of four ultrasonic sensors (P1, P2, P3 and P4) mounted on the sample material. Fig. 3 shows three-dimensional positions of all ultrasonic heads on the sample material. Point marked as S1, with coordinates (x_s, y_s, z_s) stands for the position of ultrasound head (transmitter) on the surface of the sample material provided at the bottom of the sample. Points marked as P1, P2, P3 and P4, have coordinates:

- P1 (x_1, y_1, z_1),
- P2 (x_2, y_2, z_2),
- P3 (x_3, y_3, z_3),
- P4 (x_4, y_4, z_4)

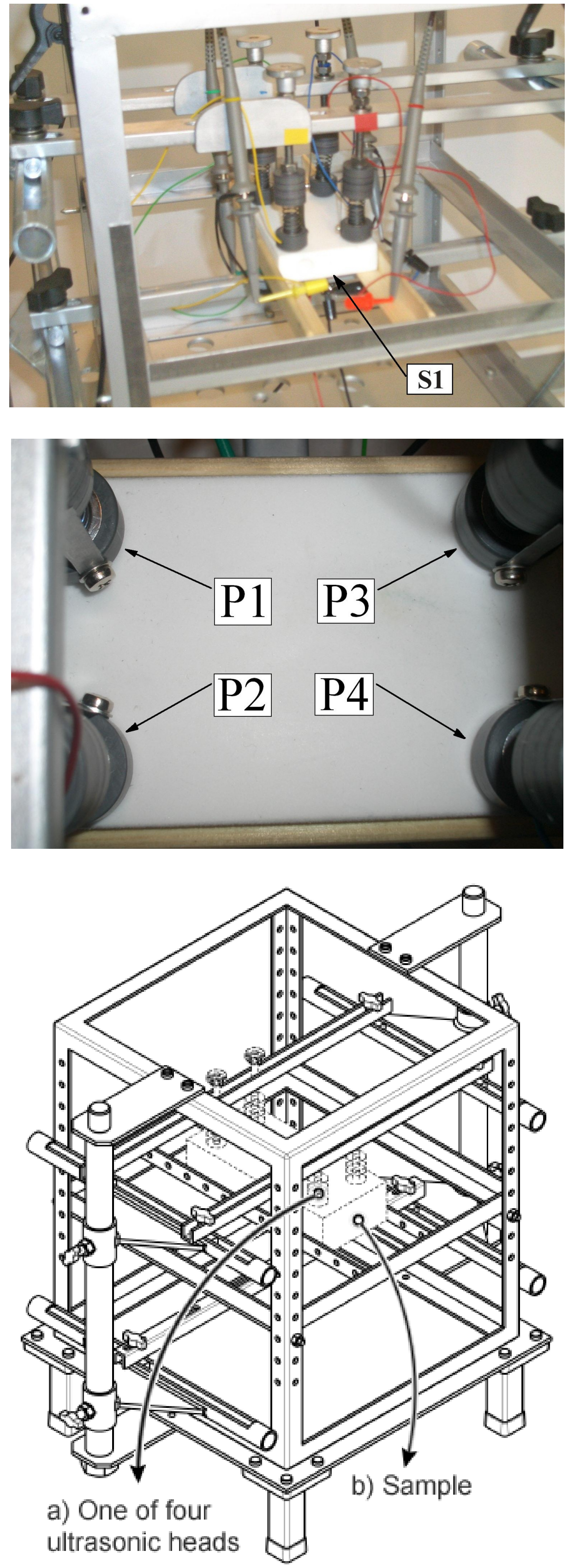

Fig. 2. Apparatus for the QTUD method.

as the positions of contact ultrasonic heads (which are ultrasound receivers) on the surface of the sample material. These positions are on the opposite, upper side of the sample material. The distance from coordinate zero value of xyz system to the point S1 is seen as a vector in three dimensions. It is analogue with the distances to the origin points P1, P2, P3 and P4. Fig. 3 presents the relationship among the vectors $\vec{r}_1$, $\vec{P}_1$ and $\vec{S}_1$. As it is situation for vector $\vec{r}_1$ we have similar relations for vectors $\vec{r}_2$, $\vec{r}_3$ and $\vec{r}_4$:

$$\vec{r}_2 = \vec{P}_2 - \vec{S}_1$$
$$\vec{r}_3 = \vec{P}_3 - \vec{S}_1$$
$$\vec{r}_4 = \vec{P}_4 - \vec{S}_1$$

Given these coordinates and using mathematical algorithms that can be applied for the purpose of analyzing the signal, the conclusions about the state within the sample material can be made. These conclusions can be derived on the basis of delay time of ultrasonic waves as well as on the differences in the amplitudes received by the ultrasonic receiver heads.

The ultrasound head S1 (transmitter), emits ultrasonic wave that passes through the sample. If the receiving ultrasound heads P1, P2, P3 and P4 are placed symmetrically in relation to the transmitter S1 and if it is assumed that the structure of the tested sample does not contain any material defect, the ultrasonic waves emitted from S1 arrive in the same time at any of the receiving heads P1, P2, P3 and P4. Furthermore, the signals received by P1, P2, P3 and P4 have the same amplitude. This is of particular importance for the employed experimental circuit.

In the case when an investigated sample contains material defect, the largest delay of ultrasonic signals will be at the ultrasonic head closest to the defect. The value of this delay is proportional to the speed of ultrasound through the material from which the sample was made.

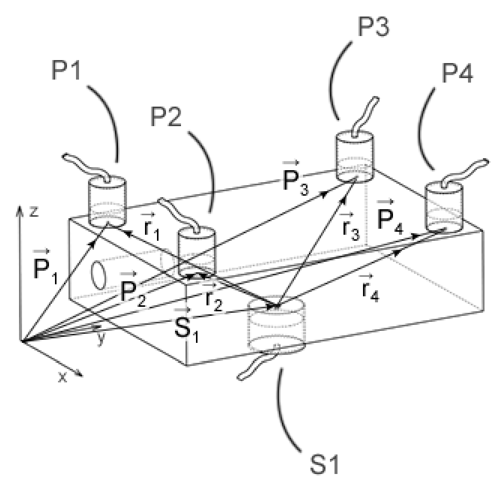

Fig. 3. Relationships for vectors $\vec{S}_1, \vec{r}_1, \vec{r}_2, \vec{r}_3, \vec{r}_4, \vec{P}_1, \vec{P}_2, \vec{P}_3, \vec{P}_4$.

For a given material it is a physical constant that must be already known in order to be able to perform a calculation. The ability of the system to provide sufficient precision and register the delay of ultrasound signals substantially depends on the resolution of analog digital converters used. It should be noted that the high-quality A/D converters with high resolution are a significant investment.

In the case when a sample contains a material defect, the attenuation of ultrasonic signal amplitude is strongest in the ultrasonic head closest to the defect. This amplitude is really smaller than other amplitudes and it can be registered by relatively simple and cheap A/D converters.

The method presented here, offers a possibility of using both principles, i.e. signal delay and amplitude attenuation. Based on the above said, the conclusion can be made about defect existence within the investigated sample.

III. Electronic Design

Fig. 4 shows the electronic design scheme. It includes the following components: function generator G1, ultrasonic emitter S1, ultrasonic sensors as receivers P1, P2, P3 and P4. There are also preamplifiers of the signal N1, N2, N3 and N4 as well as analogue digital (A/D) converters B1, B2, B3 and B4. Additionally, there are some instruments for electronic control: oscilloscope A1 and frequency meter A2. The electronic design of QTUD methods contains four electronic measurement channels consisting of incentives from the physical processes in the form of transmission of ultrasonic signal, the sensor, adapter and A/D converter. At the end of these measuring channels is the computer which performs further signal processing. Connections between the displayed electronic devices and the computer are presented as d1, d2, d3 and d4.

The function generator G1, powered by the 220V/50 Hz (voltage u_p), generates a signal frequency of 45 kHz (voltage u_s). This signals u_s is fed to the ultrasonic transmitter S1, which is an ultrasonic head with the voltage-controlled crystal. The ultrasound signal transmitter and reception sensors are piezoelectric devices made of lead zirconium titanate (PbZrTiO).

Ultrasound was transmitted through the sample material and was received more or less attenuated, i.e. more or less delayed in receiving ultrasonic sensors P1, P2, P3 and P4. Over piezoelectric effect these receivers convert mechanical vibrations into analog electrical voltages. Voltages from the receivers P1, P2, P3 and P4 are brought to preamplifiers of the signal N1, N2, N3 and N4, and subsequently to A/D converters B1, B2, B3 and B4.

By analyzing delay times of individual signals, or respectively differences in amplitudes of individual signals and using the appropriate mathematical algorithm, the state of examined samples i.e. the existence of defects in the material can be foreseen.

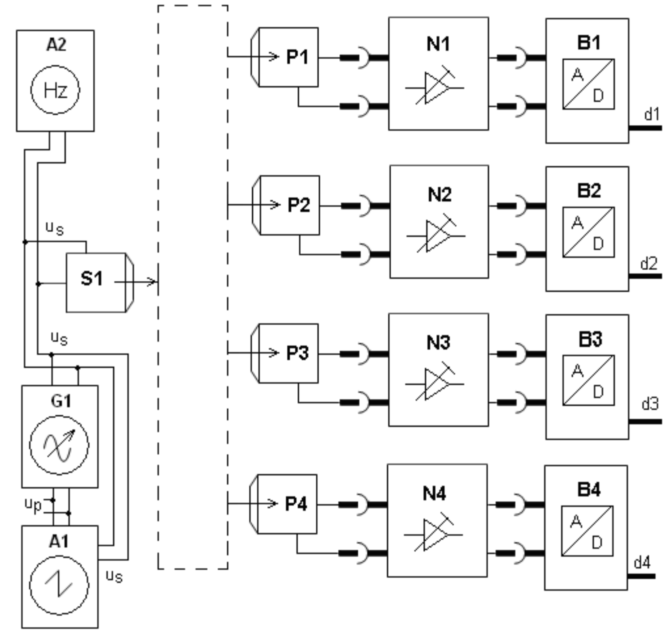

Fig. 4. Electronic design of QTUD method.

IV. Coordinates Determination System

Coordinates determination system is a sub-system inside experimental set, comprising the following electronic components: transmitters of infrared signals E11, E21, E31, E41 and E51; receivers of infrared signals E12, E21, E32, E42 and E52 along with signal handlers E13, E23, E33, E43 and E53.

Components E51, E52 and E53 are used in case when ultrasonic head S1 (the transmitter of ultrasonic signal provide at the bottom of the sample) can be moved, i.e. spatial position of S1 can be changed. During the experiment, head S1 is firmly fixed. It can be assumed that spatial coordinates are already known and constant.

Fig. 5 shows a block scheme of the coordinates determining system consisting of distributor A3 for powering the transmitters E11, E21, E31, E41 and E51 by voltage u_3. These transmitters emit infrared signals by photo cells so that the photo transistors inside the receivers E12, E22, E32, E42 and E52 react on precisely directed infrared signal. The signal handlers E13, E23, E33, E43 and E53 generate individual voltages u_{12}, u_{22}, u_{32}, u_{42} and u_{52}. This voltages turn on signal handling photo diodes D15, D25, D35, D45 and D55. Specified voltages generated by the signal handlers are grounded over the A4 module, inside which the signal handling photo diodes are placed. This A4 module is used as distributor of voltage u_3 for the signal handlers. Receivers of infrared signals are mounted on mechanical rails so they can be moved on the outer part of the mechanical experimental set. After the sample material is placed and fixed and the ultrasonic heads are mounted, every individual receiver of infrared light (E12, E22, E32, and E42) is moved along the rails, until individual signaling photo diodes (D15, D25, D35, and D45) are lit up and the position taken.

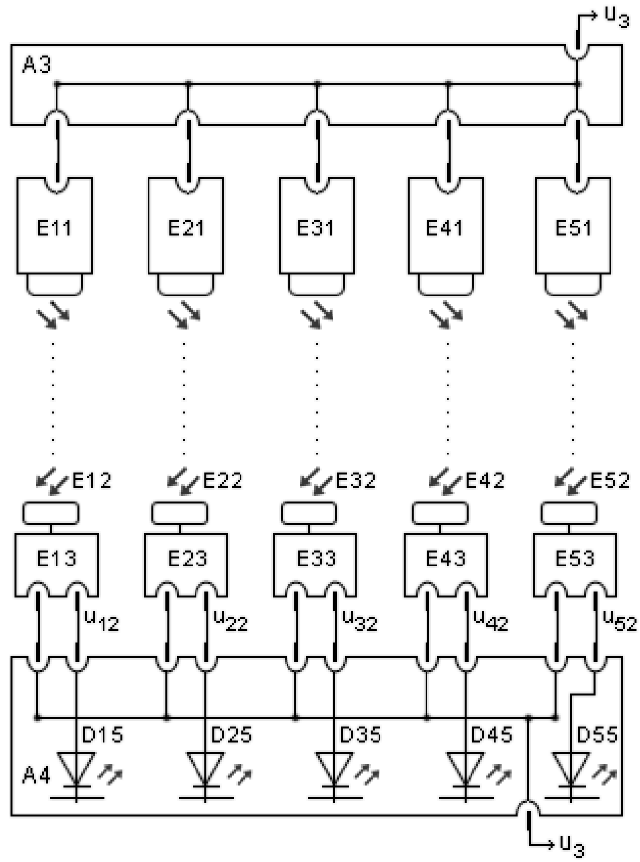

Fig. 5. Block scheme of system for determining coordinates.

Fig. 6 shows electric circuit of the transmitter E11, where the output degree presents the diode D12 which, when directly polarized, emits infrared light. To ensure proper functioning of the diode D12 it is necessary to provide dc constant current, where the purpose of T11 transistor comes in. To provide dc current constant through the output diode, it is necessary to keep T11 at an optimal operating point. For that purpose we use diodes D13 and D14 which maintain constant base voltage of 1.2 V. Diode D11 sends a signal that indicates that transmitter E11 is operational. Fig. 6 shows a circuit for the created receiver of infrared light E12 and E13. Input stage is photo-resistor F0 whose electrical resistance decreases from 10 MΩ to 3 MΩ when illuminated.

Following the changes of resistance of diode D11 there is also a change in relationship between input voltages of operational amplifier LM741 i.e. V_{op-} where the value going under the value of the V_{op+}, and in that case voltage from V_{iz} increase from 1.2V to around 9V (close to the u_3 voltage). This switches on the output transistor T1 which powers LED diode D15 over module A4. Led diode D15 notifies that the optical connection between receiver and transmitter of infra red signal is established and indicates that the read-out position of individual receiver can be performed. This creates an easy and accurate procedure of determining the coordinates of ultrasonic receiver sensors.

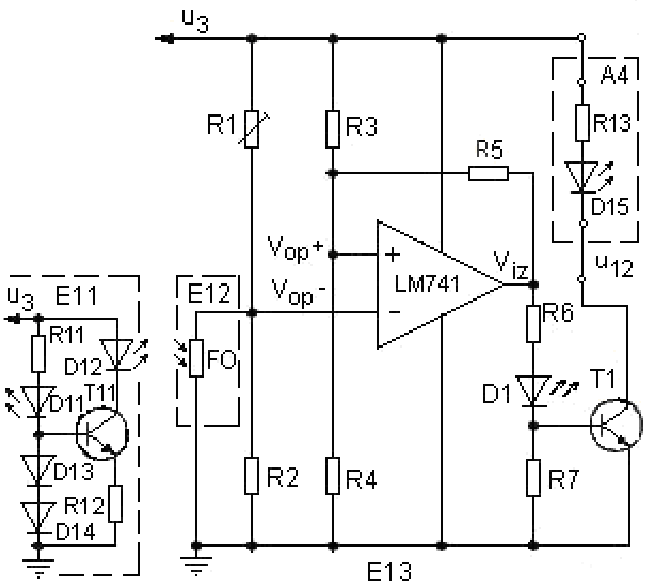

Fig. 6. Circuits of transmitter E11 and receiver E12/E13.

V. RESULTS

In the experimental procedure the investigated sample contains embedded defect. The measurement was conducted over a sample made of a piece of "PORPOLAST" plate [9]. It is made of sintered polyethylene with a few additives, for various industrial fluidizing floors and filter applications. These plates are manufactured in different thicknesses and formats to be further processed to disks, or weld constructions, and they are highly porous material. This sample is shown in Fig. 7 (high H = 19.8 mm, width W = 66 mm, length L = 104 mm). The built-in defect is located near the ultrasonic head P1, in the form of hole (cal1) with a diameter of 11.5 mm and depth of 46 mm. During the performed measurement, the variant of recording attenuation of amplitude of ultrasonic signal was chosen. The attenuation of the received amplitude is largest in the ultrasound receiver that is closest to the defect. For these performed experiments instead of the A/D converters B1, B2, B3 and B4 and computer (see Fig. 1 and Fig. 4), digital signals are measured with a digital oscilloscope Owon PDS 5022S. Results of the measurement with digital oscilloscope are shown in Fig. 8.

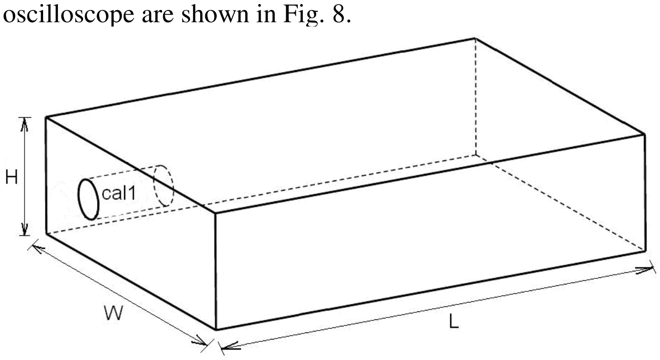

Fig. 7. Sketch of the sample used for the measurement.

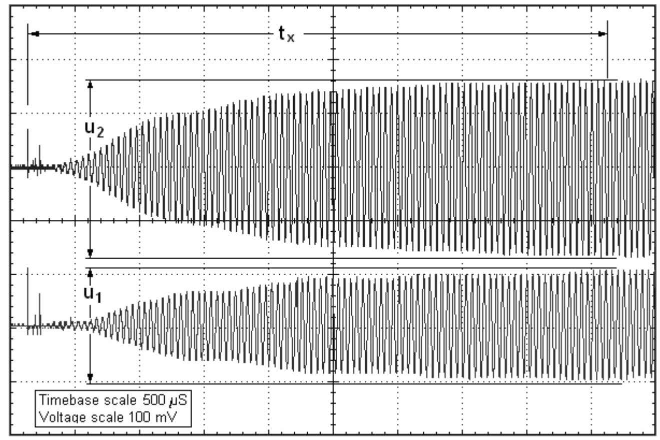

Fig. 8. Results of the measurement from the digital oscilloscope.

The upper part of the diagram corresponds to the recorded signal from the ultrasonic receiving head P2, whereas the bottom part of the diagram shows recorded signal of head P1. Voltage levels of u_1 and u_2 represent the particular maximums of the received amplitudes. Voltage u_1 in this case is 330 mV peak-to-peak while voltage u_2 is 200 mV. Recognition of persistently received amplitude is not automated. For this reason issue with automation the dimensions are graphically marked in the diagram.

Fig. 8 shows time t_x, which stands for the distance between voltages u_1 and u_2 on the horizontal time axis. This distance is characterized by time after which it comes to persisting voltages of receiving heads and when loading of values for those voltages for further calculations can be executed. After time t_x, a signal with permanently lower amplitude can be observed at the receiving head P1 (located above the defect).

In order to obtain a series of measured values, further measurements using the pattern above can be repeated with the same dimensions of samples but with difference in the radius and depth of built-in defect. Then, groups of obtained data will enable the formation of tables that provide information about the existence of defects within the sample. As a next step, the samples with actual defects (occurring as a result of an error within the production cycle) can be performed.

VI. CONCLUSION

Ultrasonic defectoscopy is a scientific discipline that deals with finding errors i.e. defects in materials, especially in optically opaque materials that strongly absorb X-rays or in metals in which application of electromagnetic signals due to the skin effect is not possible. A method that uses ultrasonic pulse echo technique, which includes only a single head used for emitting and reception of ultrasonic waves, used to be preferred in engineering and science. The impulse echo method currently represents the main "trend" within the ultrasound defectoscopy, but application of this method with high frequencies (order of several GHz) causes excessive absorption of ultrasonic waves within sample. Therefore, on very porous materials defectoscopy by ultrasonic impulse echo method is not possible. The procedure presented in this paper represents a further development of a method with separate ultrasound heads for emitting and reception of ultrasonic waves. The QTUD method comprises a single head as a transmitter of ultrasound signal and four ultrasonic sensors as the receivers of ultrasound.

Electronic solution contains function generator, one ultrasonic emitter, and four ultrasonic sensors as receptors, and components for signal amplification, analogue digital converters and a microcontroller unit or optionally a computer for processing digital signals. If the investigated sample contains material defect, the largest delay of ultrasonic signals will be at the ultrasonic head closest to the defect. Also, the attenuation of ultrasonic signal amplitude is the strongest in the ultrasonic head closest to the defect. The observed amplitude is substantially lower than other amplitudes and registration can be performed by relatively simple and cheap A/D converters. The presented method enables using both principles: signal delay and amplitude attenuation.

Therefore, the conclusion can be made about defects in the sample. In the experimental procedure, the measurement was conducted on a sample made from sintered polyethylene plate which is a highly porous material. For the QTUD method, the application for European patent in the Central German Patent Office was made in October 2010 [10].

REFERENCES

[1] G. Sorge, Faszination Ultraschall, Stuttgart: Teubner Verlag, 2002.

[2] E. Schrüfer, Elektrische Meßtechnik: Messung elektrischer und nichtelektrischer Größen, Leipzig: Hanser Fachbuchverlag, 2007.

[3] H. Kuttruff, Physik und Technik des Ultraschalls, Stuttgart: S. Hirtzel Verlag, 1988.

[4] C. Cooke, An Introduction to Experimental Physics, Florida: CRC Press, 1996.

[5] G. Simpson, J. Blitz, Ultrasonic Methods of Non destructive Testing, Dordrecht: Springer, 1996.

[6] C. Weissmantel, C. Hamann, Grundlagen der Festkörperphysik Berlin: Springer Verlag, 1997.

[7] K. Jänich, Vektoranalysis, Berlin: Springer, 2008.

[8] J. Gobrecht, Werkstofftechnik - Metalle, München, Oldenbourg Wissenschaftsverlag, 2006.

[9] Durst Filtertechnik GmbH, D-74354 Besigheim-Ottmarsheim, Germany.

[10] Deutsches Patent- und Markenamt (DPMA) (“German patent office“), München.