Tomasz RYMARCZYK[1,2], Michał GOŁĄBEK[1], Piotr BOŻEK[1], Przemysław ADAMKIEWICZ[1], Michał MAJ[1], Jan SIKORA[1]

Research & Development Centre Netrix S.A.(1), University of Economics and Innovation (2)

doi:10.15199/48.2019.03.26

Ultrasound tomography measuring system for acquisition and analysis data

***Abstract**. Ultrasound tomography provides the ability to analyse processes occurring inside the facility without interfering with the production, analysis and detection of obstacles, defects and various anomalies. The presented measuring system has a specially designed measuring structure (including electrodes, thanks to which it is an innovative solution in the field, particularly effective in the analysis). Knowledge of the characteristics of each tomographic technique solution, the application allows you to choose the appropriate method of image reconstruction. A reverse problem is the process of identifying optimization or synthesis, in which the goal is to determine the parameters describing the data field.*

***Streszczenie.** Tomografia ultradźwiękowa daje możliwość analizowania procesów zachodzących wewnątrz obiektu bez zakłócania produkcji, analizy i wykrywania przeszkód, wad i różnych anomalii. Prezentowany układ pomiarowy ma specjalnie zaprojektowaną strukturę pomiarową (w tym elektrody, dzięki czemu jest innowacyjnym rozwiązaniem w terenie, szczególnie skutecznym w analizie). Znajomość charakterystyki każdego rozwiązania techniki tomograficznej, aplikacja pozwala wybrać odpowiednią metodę rekonstrukcji obrazu. Odwrotnym problemem jest proces identyfikacji optymalizacji lub syntezy, w którym celem jest określenie parametrów opisujących pole danych (**System pomiarowy tomografii ultradźwiękowej do pozyskiwania i analizy danych**).*

Keywords: Ultrasound Tomography, Sensors, Inverse Problem.
Słowa kluczowe: tomografia ultradźwiękowa; sensory, zagadnienie odwrotne.

Introduction

The main purpose of this work is to design a system for data acquisition and data analysis. Control methods include issues related to the processing of data obtained from various sensors located in nodes. Monitoring takes place as part of data processing and parameters obtained and processed (Fig. 1). The device has been designed for tomographic measurements of the properties of processes occurring in reservoirs.

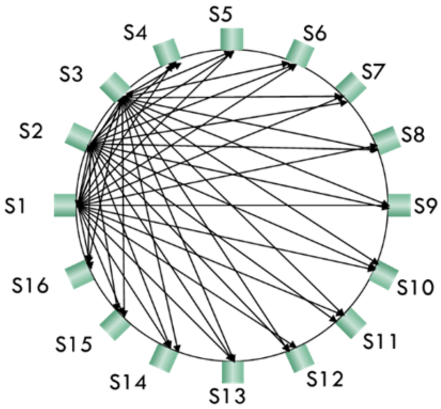

Fig. 1 Principle of ultrasonic measurement using the transmission method

Measurement technologies are still being built and improved. There is a clear tendency in the industry to implement more optimal related functions with an emphasis on active inspection and monitoring [24-26,18-22]. There are many optimization methods [1,8-15], but to solve the inverse problem in the ultrasound tomography can use [2-7,16,17,23].

Measurement system

One of the active probes sends an ultrasonic signal (the number of sent signal periods will depend on the type / size of the tested object, in the case of the container being tested, 4 periods were sufficient), the rest of the probes are in the listening mode. Active probes measure the time individually from the moment the signal is sent until it is picked up by individual transducers. We assume that this is the time in which ultrasounds overcome the distance between the probes.

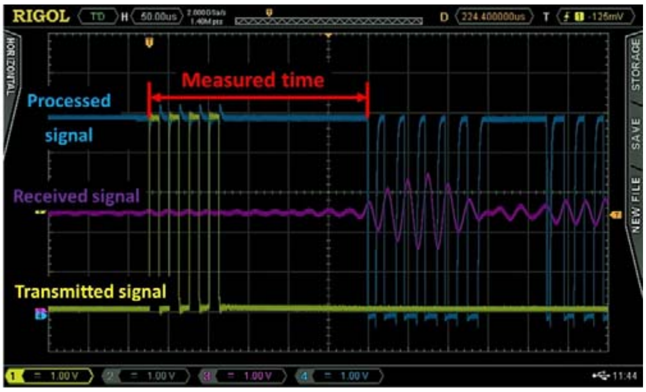

Fig.2 Signal waveforms in the measurement probe

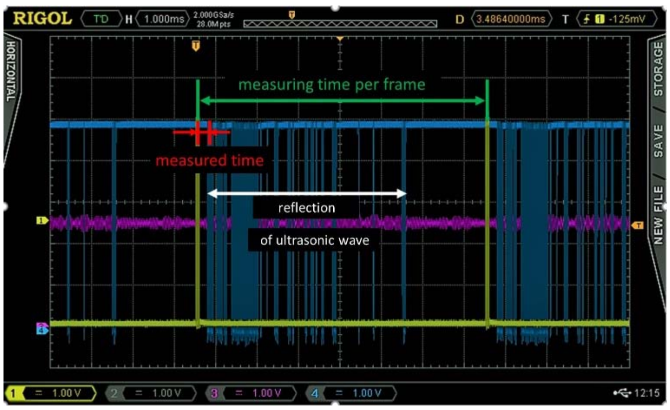

Fig.3. Measurement time of one measuring frame

After receiving the signal by all sensors, one measuring frame is terminated, the signal from the next probe is transmitted, the remaining probes receive the signal again. The sequence repeats until each probe gives a signal and all times are collected. Figure 2 shows the signal waveform for one pair of transducers. The signal is fed into a rectangular signal fed to the ultrasound transducer in order to force transmission (probe). The obtained signal is the shape of the signal wave at the transducer output, which is then transformed into a rectangular signal (processed signal) so that it can be read by the digital input of the microcontroller. The red segment is the measured time that is sent to the control unit.

Thanks to the active measuring probes, the analog signal path has been reduced to a minimum, which reduces the level of interference. The probes communicate with the main unit via the digital CAN bus. The concept of an active probe enables the switching system to be switched off from the system - a multiplexer that would introduce additional delays.

The measurement time of one measuring frame depends on the ultrasonic reflections inside the tested object, the next measurement can be made only after the reflected signals disappear. Figure 3 shows the recorded reflections. This is a serious problem because these reflections prolong the time of a single measurement many times. For example, the times to be measured are of the order of hundreds of microseconds, while the reflections of ultrasonic waves last several milliseconds. Depending on the number of measuring probes, the time needed to collect the data needed to create one image will be a multiple of the time of a single measurement and the number of measurement probes. In the case of the test container for 16 measurement probes, obtaining data for one image would theoretically last about 120 ms.

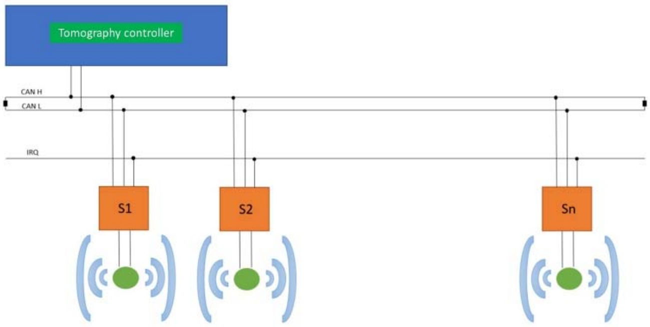

Fig. 4. Block diagram of the ultrasound tomograph

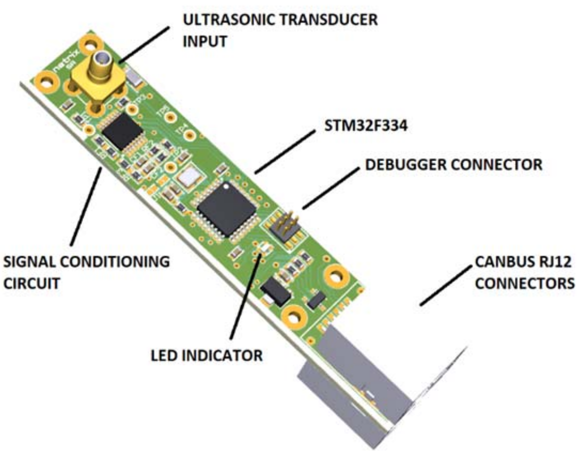

Fig. 5 3D design of the active measuring probe

The concept of construction of an ultrasound tomograph assumes the construction of active measurement probes controlled by an external module via a CAN bus (Fig.4). Active measuring probes are divided into digital and analog parts. The digital part is responsible for sending ready measurement results to the tomography controller via the bus. The analog part has been adapted to work with a piezoelectric transducer operating at 40 kHz (Fig. 5).

The active ultrasound tomograph measuring probe performs measurements using one piezoelectric transducer using the absorption method. The transducer can work as both a transmitter and an ultrasonic wave receiver. Its resonant frequency is 40kHz. In the PCB, it is possible to connect an external transducer by means of SMB socket (submersible devices immersed in medium or permanently mounted in the tested object). The probe has an integrated signal processing system and a microcontroller with a built-in A / C converter. By using a programmable digital potentiometer, each probe can regulate the gain of the received signal. The probe PCB also provides the option of filtering out the signal using an active filter. In the current version, this filter is not used. A small RGB diode is used to signal the operating status of the device. The probe control and reading of the measurements made by it takes place via CAN 2.0A buses.

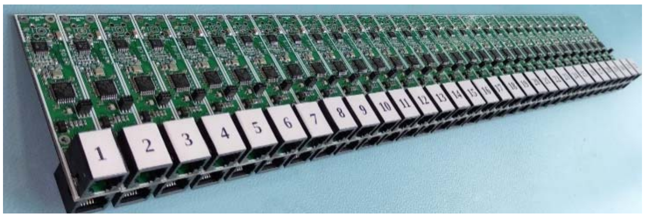

Fig. 6.View of composite 32 PCBs of ultrasound probes.

Fig.7. View of attached ultrasonic probes on the test object.

Fig.8. View of the test object with placed phantoms.

The probes are designed so that they can be placed very close to each other. Power lines, communication bus and break lines necessary for the correct implementation of the time measurement from the moment of sending to receiving the signal on other probes were carried out using RJ-12 cables (Fig. 6-8).

The casing of the device was laser cut out of acrylic glass. PCB assembly inside the housing is done by inserting a ready plate with a soldered ultrasound transducer and blocking it with plastic screws. Under the ultrasonic transducer there is an elastic rubber pad that allows its movement, thanks to which it can adjust to the curvature of the tested object. Installation of probes on the tested object takes place through flexible strips threaded through holes located in the upper part of the housing.

Each probe is assigned a number from 1 - 32. The probe number is assigned based on the microcontroller serial number. Therefore, after all serial numbers have been written down, it is possible to update the probe software with the same batch file. The measurement of ultrasonic wave transition time from one probe to the other was achieved by connecting all probes to an additional communication line (Fig. 9). When the low state occurs on this line, all probes outside the transmit probe start the time measurement and end it when the ultrasonic wave is received. Then, each receiving probe sends the measurement result to the CT controller. On the basis of information about which probe was a transmitter and which probe sent the result, the measurement value is recorded in the appropriate cell of the measurement matrix. The analog signal is processed by means of an A/C converter or by means of a comparator with a programmable threshold. Due to better accuracy in the current version, the measurements are sampled and the exact time of appearance of the acoustic wave is determined on the basis of the samples. This method is much more accurate but unfortunately it requires more processing power of the processor, which means that the measurement lasts longer than the previously used method.

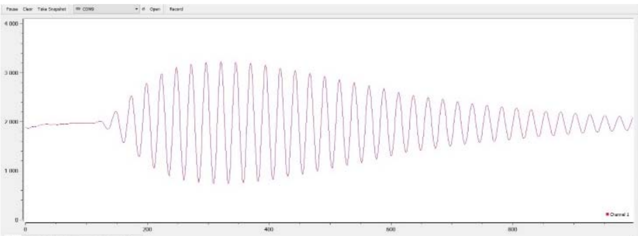

Fig. 9. Captured and amplified signal from a piezoelectric transducer at the time of receiving a 40 kHz acoustic wave.

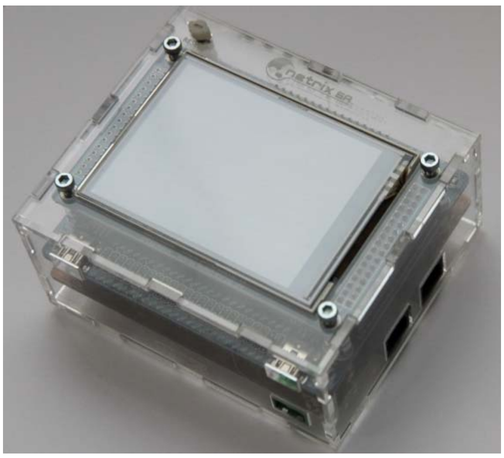

Fig. 10. Ultrasound tomograph controller.

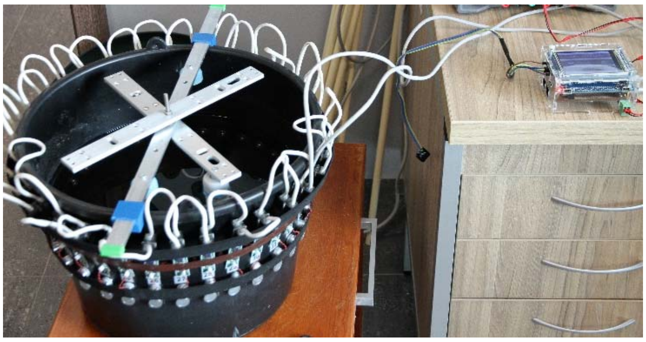

Fig. 11. Measuring system with ultrasound tomograph.

The main controller of the tomograph is responsible for managing the measurement sequence, setting the active probes in transmit / receive mode, and saving the results on the SD card (Fig. 10.11). The controller interface was made in Polish and English (Fig.12). This is an early version that will be further improved with additional features:

- the ability to change the gain on individual probes,
- the ability to send results via a USB port to external imaging devices,
- displaying graphics illustrating changes in values in individual cells of the result matrix.

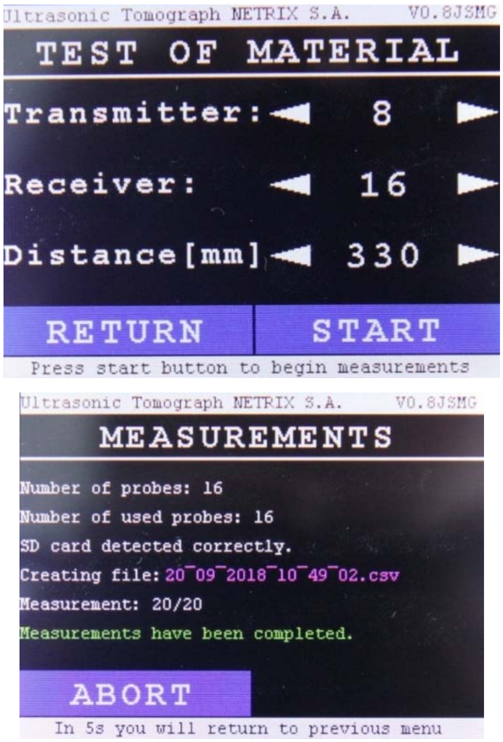

Fig. 12. View of the configuration screen and when the measurements are taken.

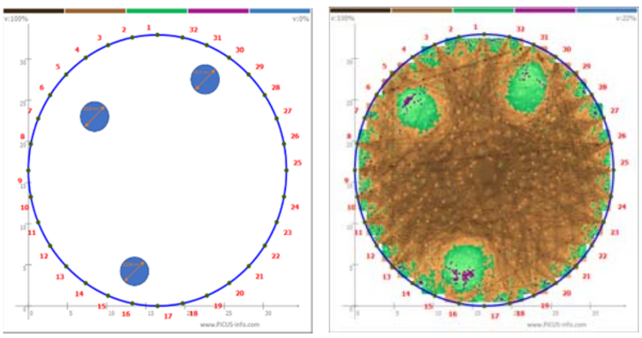

Fig. 13. Model and image reconstruction - 32 measurement points 40 khz transducers - 3 phantoms.

Results

Figure 13 shows the example of the model and the image reconstruction 32 measurement points at 40 khz transducers for 3 phantoms.

Conclusion

This article presents a data acquisition system. The ultrasound tomography enables the analysis of processes taking place in the facility without interfering with the production, analysis and detection of obstacles, defects and various anomalies. The presented measuring system has a specially designed measuring structure (including electrodes, thanks to which it is an innovative solution in the field, particularly effective in the analysis).

***Authors**: Tomasz Rymarczyk, Ph.D. Eng., University of Economics and Innovation, Projektowa 4, Lublin, Poland / Research & Development Centre Netrix S.A. E-mail: tomasz@rymarczyk.com; Michał Gołąbek, Piotr Bożek, Przemysław Adamkiewicz, Michał Maj, Jan Sikora, Research & Development Centre Netrix S.A.*

REFERENCES

[1] Rymarczyk T., Gołąbek M., Bożek P., Adamkiewicz P., Maj M. and Sikora J., The prototype ultrasound tomography device to analyze the properties of processes, PTZE — 2018 Applications of Electromagnetic in Modern Techniques and Medicine, 09-12 September 2018, Racławice, Poland..

[2] Banasiak R., Wajman R., Jaworski T., Fiderek P., Kapusta P., Sankowski D., Two-phase flow regime three-dimensional visualization using electrical capacitance tomography – algorithms and software". Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska - IAPGOS,1 (2017), 11–16.

[3] Das Y., Boerner W.M., On Radar Target Shape Estimation Using Algorithms for Reconstruction from Projections", IEEE Transactions on Antennas and Propagation, AP–26(2), 1978.

[4] Gudra T., Opieliński K.J., The multi–element probes for ultrasound transmission tomography", Journal de Physique 4, 137 (2006), 79–86.

[5] Herman G.T., Image Reconstruction from Projections: The Fundamentals of Computerized Tomography", Academic Press, New York, 1980.

[6] Kaczmarz S., Angenäherte Auflösung von Systemen Linearer Gleichungen, Bull. Acad. Polon. Sci. Lett. A, 6–8A, 1937, 355–357.

[7] Kak A.C., Slaney M., Principles of Computerized Tomographic Imaging", IEEE Press, New York, 1999.

[8] Kłosowski G., Kozłowski E., Gola A., Integer linear programming in optimization of waste after cutting in the furniture manufacturing, Advances in Intelligent Systems and Computing 2018; 637 (2018), 260-270.

[9] Kosicka E., Kozłowski E., and. Mazurkiewicz D., Intelligent Systems of Forecasting the Failure of Machinery Park and Supporting Fulfilment of Orders of Spare Parts," 2018, 54–63.

[10] Krawczyk A., Korzeniewska E., Łada-Tondyra E., Magnetophosphenes –History and contemporary implications", Przeglad Elektrotechniczny, 94 (2018), No. 1, 61-64.

[11] Korzeniewska E., Szczesny A., Krawczyk A., Murawski P., Mroz J. Seme M, S., Temperature distribution around thin electroconductive layers created on composite textile substrates", Open Physics, 16 (2018), No. 1, 37-41.

[12] Kryszyn J., Wróblewski P., Stosio M., Olszewski T., Smolik W., Architecture of EVT4 data acquisition system for electrical capacitance tomography", Measurement: Journal of the International Measurement Confederation, 101 (2017), 28-39.

[13] Lopato, T. Chady, R. Sikora, S., M. Ziolkowski, Full wave numerical modelling of terahertz systems for nondestructive evaluation of dielectric structures", 32 (2013), No. 3, 736 – 749.

[14] Majchrowicz M., Kapusta P., Jackowska-Strumiłło L.,. Sankowski D., Optimization of Distributed Multi-node, Multi-GPU, Heterogeneous System for 3D Image Reconstruction in Electrical Capacitance Tomography", Image processing & communications, 21 (2016), No. 3, 81-90.

[15] Majchrowicz M., Kapusta P., Jackowska-Strumiłło L., Sankowski D., Acceleration of image reconstruction process in the electrical capacitance tomography 3d in heterogeneous, multi-gpu system", Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska, 7 (2017), No. 1, 37-41

[16] Polakowski K., Filipowicz S.F., Sikora J., Rymarczyk T., Quality of imaging in multipath tomography", Przeglad Elektrotechniczny, 85 (2009), No. 12, 134-136.

[17] Polakowski K., Filipowicz S.F., Sikora J., Rymarczyk T., Tomography technology application for Workflows of Gases Monitoring in The Automotive Systems, Przeglad Elektrotechniczny, 84 (2008), No. 12, 227-229.

[18] Psuj G. Multi-Sensor Data Integration Using Deep Learning for Characterization of Defects in Steel Elements, Sensors, 1, (2018), 292; https://doi.org/10.3390/s18010292

[19] Rymarczyk T., Sikora J., Applying industrial tomography to control and optimization flow systems, Open Physics, 16, (2018); 332–345, DOI: https://doi.org/10.1515/phys-2018-0046

[20] Rymarczyk T., Kłosowski G., Application of neural reconstruction of tomographic images in the problem of reliability of flood protection facilities, Eksploatacja i Niezawodnosc – Maintenance and Reliability 20 (2018), No. 3, 425–434, http://dx.doi.org/10.17531/ein.2018.3.11

[21] Rymarczyk T., Kłosowski G., Kozłowski E., Non-Destructive System Based on Electrical Tomography and Machine Learning to Analyze Moisture of Buildings, Sensors, 7 (2018), 2285.

[22] Soleimani M., Mitchell CN, Banasiak R., Wajman R., Adler A., Four-dimensional electrical capacitance tomography imaging using experimental data", Progress In Electromagnetics Research, 90 (2009), 171-186.

[23] Wang M., Industrial Tomography: Systems and Applications", Elsevier, 2015.

[24] Ye Z.., Banasiak R., Soleimani M., Planar array 3D electrical capacitance tomography, Insight: Non-Destructive Testing and Condition Monitoring, 55 (2013), No. 12, 675-680

[25] Zhang Z., A review of rising damp in masonry buildings. Advanced Polymer and Composite Research, (2010).

[26] Ziolkowski M., Gratkowski S., and Zywica A. R., Analytical and numerical models of the magnetoacoustic tomography with magnetic induction," COMPEL - Int. J. Comput. Math. Electr. Electron. Eng., 37 (2018), No. 2, 538–548.