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ECT Measurement System with Optical Detection for Quality Control of Flow Process

***Abstract**. Multi-phase flow measurement technologies are still built and improved. There is a clear trend in the industry to implement more optimum related functions, where the focus is put on an active control and the monitoring system. Control related active optimum functions can only be realised with a system that allows the electronic control. Electrical capacitance tomography (ECT) is a method of imaging cross-sections of vessels and pipelines containing dielectric material. Permittivity distribution is determined with a multi-electrode sensor and interpreted by software. This paper provides description of the device as well as results of exemplary measurements.*

***Streszczenie.** Technologie pomiarowe przepływu wielofazowego są wciąż budowane i ulepszane. Istnieje wyraźna tendencja w przemyśle do realizacji funkcji związanych z bardziej optymalnym sterowaniem, w którym nacisk kładziony jest na aktywną kontrolę i system monitoringu. Optymalizacja funkcji do aktywnej kontroli może być realizowana tylko w systemie, który umożliwia sterowanie elektroniczne. Elektryczna tomografia pojemnościowa (ETP) jest metodą obrazowania przekrojów naczyń i rurociągów zawierających materiał dielektryczny. Przenikalność elektryczna jest wyznaczana za pomocą czujnika wieloelektrodowego i interpretowana przez oprogramowanie. Niniejszy dokument zawiera opis urządzenia, jak również przykładowe wyniki pomiarów.*(**System pomiaru ETP z optyczna detekcją do kontroli jakości procesów przepływu**).

Keywords: Electrical Capacitance Tomography, Image Analysis, Sensors
Słowa kluczowe: elektryczna tomografia pojemnościowa, analiza obrazów, sensory

Introduction

Simple and low cost intrusive probes have been used in many operation systems to obtain flow information. Process tomography becomes even more appealing when nonintrusive sensors are used to obtain the cross-sectional images. Designed control system allows for correlative studies using sets of measuring electrodes (Fig. 1). The present arrangement is not only measurements for testing various types of multiphase flow, but also the development of the methods used in electrical capacitance tomography. One of the main goals of this research is to create a uniform system that will provide optimization and control of the production process [6-13, 15].

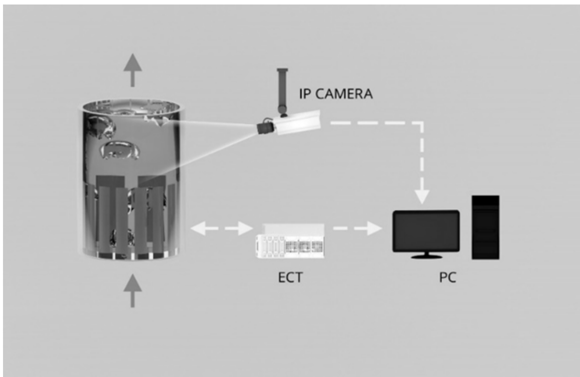

Fig. 1. The architecture of the quality control system

Electrical capacitance tomographs are devices capable of performing very fast analysis of pipeline fragment or a vessel filled with examined medium [1-5, 14]. Obtained cross-section's image reconstruction can be analysed further for an automated quality control system. However, existing industrial solutions are still of significant size and structurally complex. This fact greatly limits the number of actual deployments. Decision makers are afraid of electrical capacitance tomography implementation due to high costs of possible equipment failures and because of limited ability to support multiple elements in vast area of production lines. In response to the market demand and maintaining trend of complete automatic control, herein described system's project was created. It features some advantages of classic approach and meets the standards of modern industrial equipment at the same time. In this paper hardware issues and sample measurements are described.

Data acquisition

The most characteristic features of presented project are compact size of data acquisition module and its low energy demand. As in classic computerised solutions this part is connected with ECT sensor and computer which is processing measurements into image in real-time.

Fig. 2. Block diagram of data acquisition module

Small size is a result of using integrated circuits performing multiple functions simultaneously and limiting the number of electrodes to 16. The device is able to run in power saving mode and meets thermal requirements for industrial equipment (-40°C do 85°C). It is powered via stabilized AC/DC adapter. There is also a possibility of using external battery if necessary. Figure 2 presents block diagram of data acquisition module. Project of herein presented ECT system's prototype consists of 4 main elements: ECT sensor, data acquisition device, router and a computer (Fig. 3).

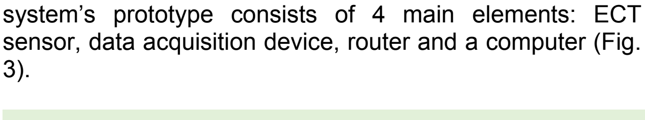

Fig. 3. Block diagram of system structure

System control

Virtual panels, the same as their physical counterparts, can be equipped with active elements (LEDs and audio controls, displays text and graphics, etc.), control and maintenance. Algorithms of the manual control and automatic cover issues are related to the processing of data obtained from various sensors (located at key nodes of the system). Supervision and control are in the range of acquired and processed data. Device parameters are implemented automation such as servo valves, pumps supply and rotary flow, etc. The main feature is to obtain important information about the process in real time by persons having strategic importance in the management and technical supervision. The solution of designed system is presented in Figure 4.

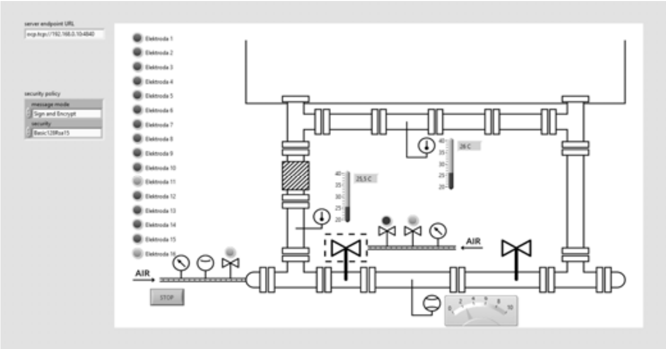

Fig. 4. User Control Panel

Scheme system for multiphase flows consist of:
- two-phase flow in horizontal and vertical,
- adjustable water flow,
- adjustable air flow,
- water flow measurement,
- water temperature measurement,
- sensor card valve (Fig. 5 and 6),
- registration flow method ECT,
- registration flow method image segmentation.

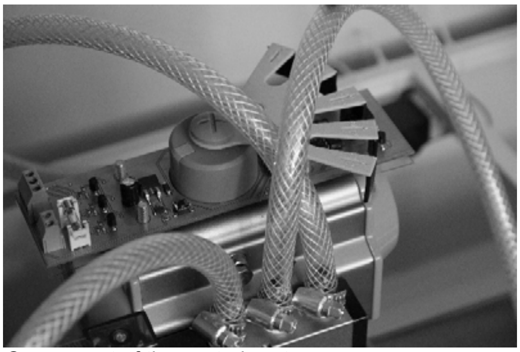
Fig. 5. Component of the control system

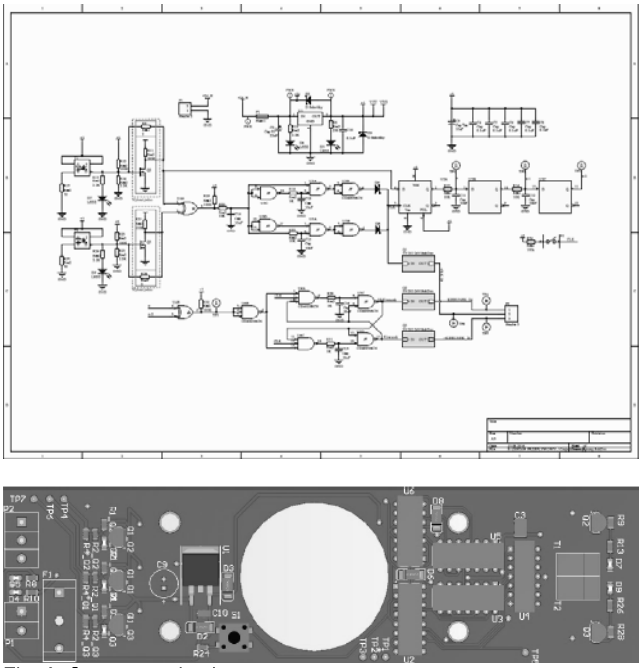
Fig. 6. Sensor card valve

The ECT sensor is built from a tube made of plexiglass with measuring electrodes mounted externally (Fig. 7). They are cut from equal stripes of 0.1 mm thick copper foil to which sockets are soldered via special 3D printed joints. Internal diameter of the tube is 94 mm, while the external one is 100 mm. Mounting the electrodes outside the dielectric tube protects them against damage or corrosion caused by examined medium. In order to reduce electric field disturbances inside the sensor. It is equipped with two grounded annular shielding electrodes. They are made of 25 mm wide and 0.1 mm thick stripes of copper foil fixed perpendicularly to measuring electrodes. All metal elements are covered with a layer of varnish protecting them against corrosion. Finally, there is an external electrostatic shield wrapped around the sensor tube in fixed distance from its surface. It is made of metal grid and it is connected to the sensor ground. The shield separates measuring electrodes from unwanted external factors. Data acquisition module is combined with ECT sensor with 16 coaxial cables RG174 type (Fig. 7). Obtained cross-section’s image reconstruction can be analysed further for an automated quality control system. However, existing industrial solutions are still significant size and structurally complex. System to inspect the air bubbles in water was presented in Figure 8.

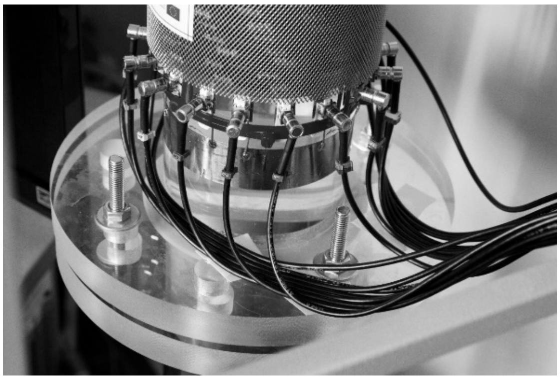
Fig. 7. ECT sensors


Fig.8. The laboratory model of the pipeline tomography system

Measurement Device

The figure 9 presents the electrical scheme of the smart ECT device. The electronic construction of the board is shown in Figure 10.

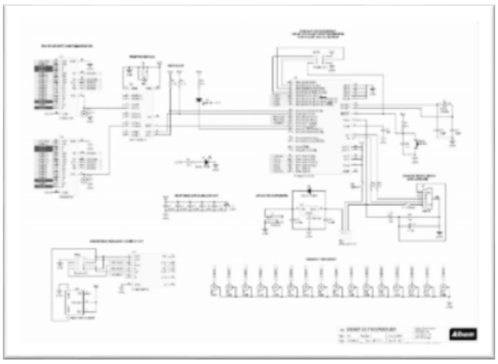

Fig. 9. The electrical scheme of the smart ECT

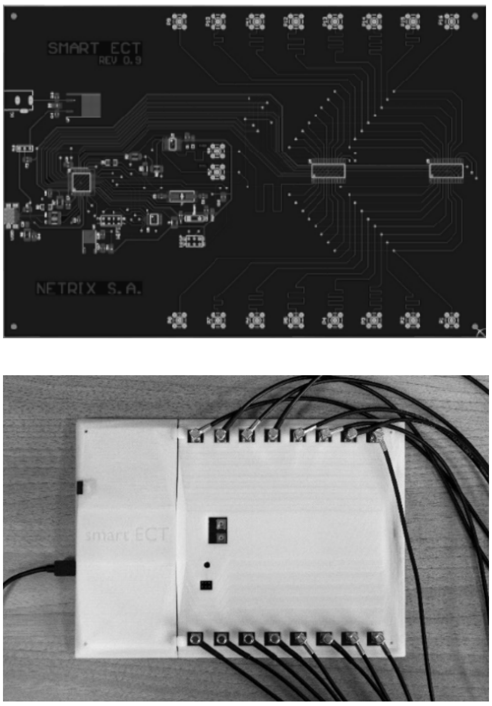

Fig. 10. Smart ECT device

Results

Parameters of the ECT sensor were tested with Analog Devices® AD7746 Evaluation Board.

1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10	1-11	1-12	1-13	1-14	1-15	1-16
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13	2-14	2-15	2-16
	1,300792	0,29461	0,103752	0,054347	0,035768	0,02778	0,02449	0,024136	0,024928	0,028441	0,036124	0,054454	0,106141	0,298625
		3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-11	3-12	3-13	3-14	3-15	3-16
		1,19821	0,291443	0,108005	0,057339	0,039368	0,031995	0,025439	0,023636	0,024958	0,028521	0,036241	0,054493	0,105197
			4-5	4-6	4-7	4-8	4-9	4-10	4-11	4-12	4-13	4-14	4-15	4-16
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				5-6	5-7	5-8	5-9	5-10	5-11	5-12	5-13	5-14	5-15	5-16
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					6-7	6-8	6-9	6-10	6-11	6-12	6-13	6-14	6-15	6-16
					1,282751	0,300581	0,105011	0,053531	0,032162	0,02672	0,023999	0,02309	0,025005	0,028175
						7-8	7-9	7-10	7-11	7-12	7-13	7-14	7-15	7-16
						1,29951	0,299647	0,1031	0,044787	0,032546	0,026414	0,024066	0,023627	0,024808
							8-9	8-10	8-11	8-12	8-13	8-14	8-15	8-16
							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
								9-10	9-11	9-12	9-13	9-14	9-15	9-16
								[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
									10-11	10-12	10-13	10-14	10-15	10-16
									1,227546	0,27241	0,081359	0,045919	0,033036	0,027212
										11-12	11-13	11-14	11-15	11-16
										1,321046	0,295933	0,103322	0,054006	0,036489
											12-13	12-14	12-15	12-16
											[illegible]	[illegible]	[illegible]	[illegible]
												13-14	13-15	13-16
												[illegible]	[illegible]	[illegible]
													14-15	14-16
													1,296803	0,301594
														15-16
														1,309177

Fig. 11. Matrix for measurement of mutual capacitance of electrodes – ECT sensor filled with air

First series of measurements were conducted on the sensor filled with air and the second one on sensor with a dielectric phantom inside. Phantom was an irregular, cylindrical vessel filled with water. The values were put into matrix (Fig. 11 and 13). and following classic characteristics presenting mutual capacitance of electrodes were created (Fig. 12 and 14). It can be observed clearly that the results match the theoretical assumptions. The measured values are between 1.357 pF and 0,023 pF and are arranged in a U shape. Moreover, their span fits into capacitance-to-digital converter input range. Results of the second test, with phantom inside the tube, also differ as suspected. Capacitance measured between electrodes located far away from each other is distinctly higher than during the previous test. Irregularity of the phantom can be noticed as well. The example of the image reconstruction by the ECT device measurement was shown in Figure 15. Figure 16 presents the image segmentation of gas in the water by the level set method. Using genetic algorithm with 5 classes, populations 8000, a filter for noise removal pepper and salt was shown in Figure 17.

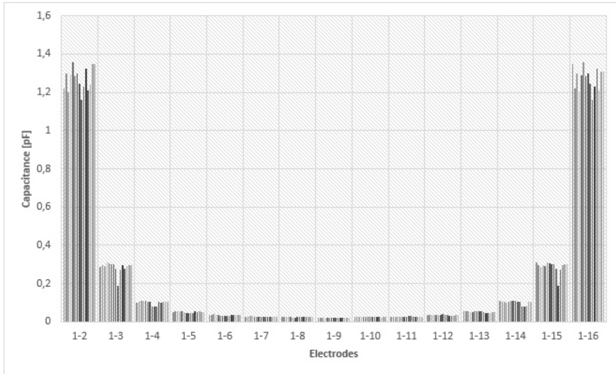

Fig. 12. Characteristics of mutual capacitance of electrodes – ECT sensor filled with air

1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10	1-11	1-12	1-13	1-14	1-15	1-16
0,516033	0,418777	0,417596	0,419062	0,426015	0,448461	0,445757	0,441114	0,437738	0,436976	0,432834	0,436789	0,434386	0,434091	0,567904
	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13	2-14	2-15	2-16
	0,56914	0,409552	0,410085	0,425169	0,444329	0,440247	0,435217	0,431729	0,431857	0,426516	0,433908	0,428514	0,431861	0,428329
		3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-11	3-12	3-13	3-14	3-15	3-16
		0,523745	0,405524	0,41865	0,431886	0,434989	0,428005	0,424858	0,426954	0,419568	0,424622	0,422249	0,424643	0,422183
			4-5	4-6	4-7	4-8	4-9	4-10	4-11	4-12	4-13	4-14	4-15	4-16
			0,541372	0,41675	0,427549	0,427532	0,423791	0,421543	0,41953	0,413508	0,421358	0,413746	0,417875	0,413661
				5-6	5-7	5-8	5-9	5-10	5-11	5-12	5-13	5-14	5-15	5-16
				0,531838	0,430803	0,429935	0,422634	0,422487	0,423712	0,418978	0,424005	0,418745	0,420768	0,418014
					6-7	6-8	6-9	6-10	6-11	6-12	6-13	6-14	6-15	6-16
					0,569126	0,442454	0,437766	0,433136	0,434291	0,427758	0,437248	0,430482	0,436131	0,431804
						7-8	7-9	7-10	7-11	7-12	7-13	7-14	7-15	7-16
						0,556544	0,452262	0,451119	0,448603	0,443031	0,450099	0,447033	0,448375	0,444465
							8-9	8-10	8-11	8-12	8-13	8-14	8-15	8-16
							0,579399	0,451443	0,450754	0,444328	0,451461	0,445698	0,449977	0,448443
								9-10	9-11	9-12	9-13	9-14	9-15	9-16
								0,548727	0,44475	0,439484	0,446927	0,441534	0,444517	0,439678
									10-11	10-12	10-13	10-14	10-15	10-16
									0,580652	0,437711	0,44372	0,437094	0,441323	0,437263
										11-12	11-13	11-14	11-15	11-16
										0,536426	0,44146	0,43678	0,438416	0,437597
											12-13	12-14	12-15	12-16
											0,578755	0,433222	0,434499	0,432514
												13-14	13-15	13-16
												0,563544	0,442436	0,43984
													14-15	14-16
													0,548261	0,43318
														15-16
														0,531992

Fig. 13. Matrix for measurement of mutual capacitance of electrodes – ECT sensor with air and water

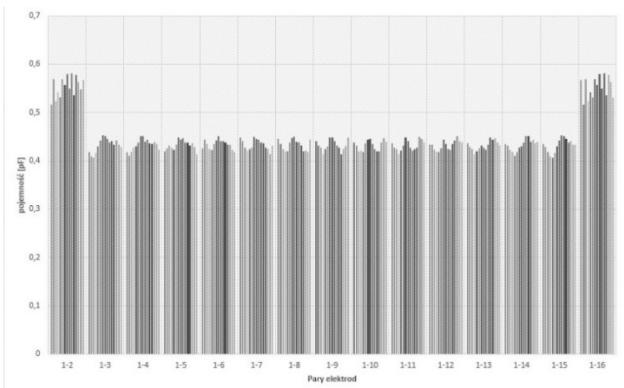

Fig. 14. Characteristics of mutual capacitance of electrodes – ECT sensor with air and water

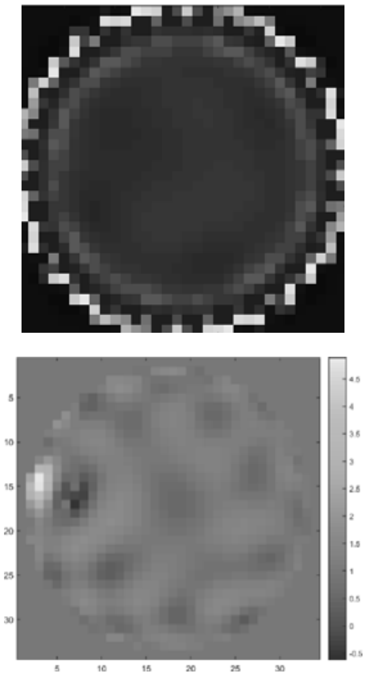

Fig. 15. The example of the image reconstruction by ECT device

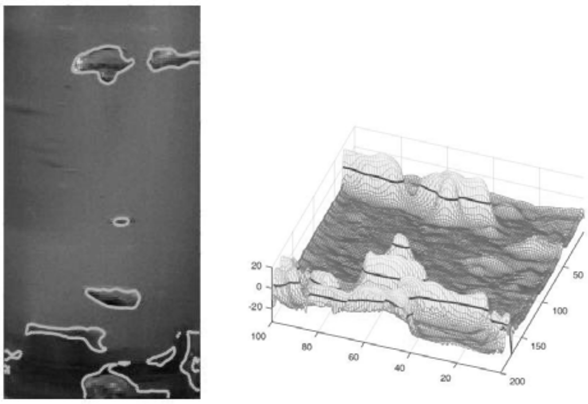

Fig. 16. Image segmentation of gas in the water by the level set method

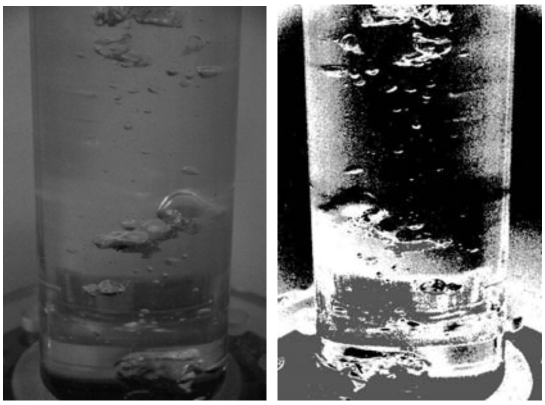

Fig. 17. Genetic algorithm: 5 classes, populations 8000, a filter for noise removal pepper and salt

Summary

In this work there was presented the control and steering system for testing flow. Optimization is a very important in the production process. There was designed system to control the flow process. They were made virtual arrays equipped with active elements, control algorithms of manual and automatic. Running an application for processing and data was obtained from various sensors disposed at key nodes installation. Supervision and control are in the range of acquired and processed data and parameters of devices. The development of new systems based on the technology of capacitive tomography and optical detection methods to a large degree can improve the production process at different stages. The challenge is to create a single optimal and efficient measurement system which ensures the easy application.

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