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Development of virtual instrument for piezoelectrical sensor signal transformation using the transfer function

Z. Lukosius, M. Kurmis, A. Andziulis, J. Venskus
Klaipeda University, Department of Informatics Engineering
Lithuania

Z. Lukosius
Vilnius University, Faculty of Natural Sciences,
Lithuania

***Abstract*— at the moment determining of the pulse wave main parameters using a piezo sensor is performing using the RC adjustments in the circuit. With the increasing adaptation of the virtual instrumentation it is possible to reduce the RC complexity. The purpose of this work was to determine the piezo-electric actuator transfer function according to the signal of the air pressure sensor using virtual instruments. In this works it was created a virtual piezo-electric sensor transfer function measurement model which proved that in order to change the sensor frequency amplitude we do not need to use electronics components.**

***Keywords*— Piezo sensors, transfer function, virtual instruments**

I. Introduction

Sensors that convert one form of energy to another are widely used in biomedicine. Piezoelectric sensors convert mechanical energy into electrical energy and vice versa, therefore they are widely used for various applications. Piezo sensors are used for the detection of biomedical signals [1-4]. They can be employed to register the pulse wave of the carotid artery [5]. The main issue here is that piezoelectric sensors in their physical nature show a nonlinear transfer performance when affected by different pressure values, frequencies, directions of impact on crystal, etc [6]. Therefore every piezo sensor must be tested and adjusted. The adjustment can be performed by implementing a scheme of integral and differential elements. Nowadays, as digital technologies and various modeling methods (especially for piezo sensors [7]) are developing, the adjustment is possible by implementing digital methods. The goal of the adjustment is to adjust the performance of piezo sensor to a “standard” sensor (e.g. pressure sensor). Thus we can simplify the device by abandoning complex circuits and their elements. Therefore the main goal of our work is to estimate the transfer function of piezo actuator by comparing a “standard” (pressure sensor) with a piezoelectric sensor.

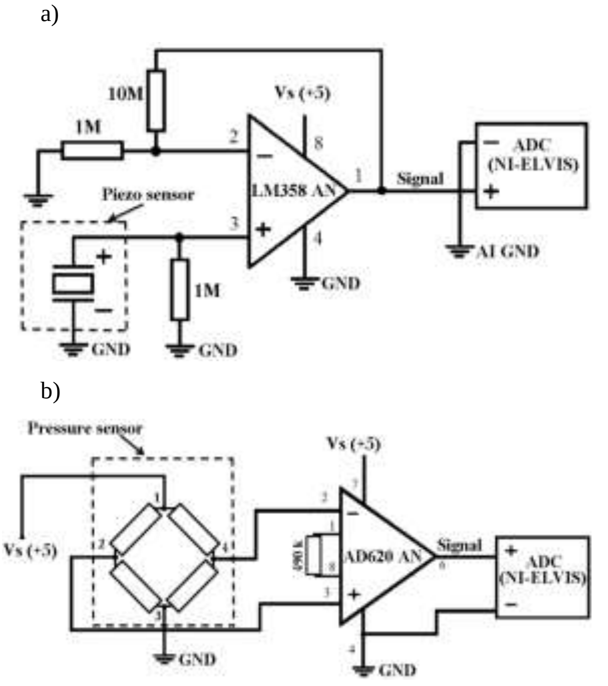

Figure 1. Scheme of amplification of piezoelectric sensor signal (a) and scheme of amplification of pressure sensor signal (b)

II. Related Works

Zhang et al. reveals the influence of multiple piezoelectric effects (MPE) on piezoelectric sensors/actuators. Thei try to improve the performance using the general theoretical models to calculate MPE under a stress and an electric field are established and validated experimentally. Authors use a piezostack as sensors and actuators for MPE experiments. The results show that the piezoelectrics dielectric, piezoelectric property and even stiffness can be enhanced in view of MPE. Both theoretical analysis and experiment by the authors prove that multiple direct and multiple converse piezoelectric effects have the equal piezoelectric coefficients [8]. Venugopal et al. analyzes performance of piezoelectric and differential pressure sensor for vortex flowmeters. As these sensors are two among the most widely employed sensors for vortex flowmeter application authors present evaluation of the performance of piezoelectric and transient differential pressure sensors under fully developed and disturbed flow conditions. Firstly, they optimize the location of the transient differential pressure sensor to obtain high amplitude signals and good linearity in Strouhal number. The empirical mode decomposition method in combination with autocorrelation decay is employed at high Reynolds numbers to identify the vortex shedding frequency in presence of hydrodynamic noise. The output signals of the

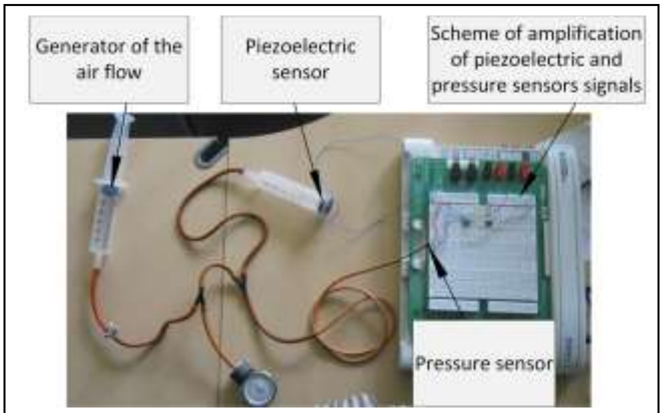

Figure 2. Scheme of amplification of pressure sensor signal

piezoelectric sensor and differential pressure sensor under no flow condition are compared to obtain the background noise due to piping vibrations and electrical interferences [9]. There is increasing number of research addressing the application of the piezoelectric sensors however most of researches using the RC adjustments in the circuit. In our presented solution it is shown that that in order to change the sensor frequency amplitude we do not need to use electronics components.

III. Methods

Amplifying schemes for the pressure and piezo sensors signals were designed using the NI ELVIS mounting panel to estimate the transfer function of a piezoelectric sensor. The schemes were designed considering the specifications of the sensors. The constructed experimental scheme is showed in figure 1 (a and b).

The signal of piezoelectric sensor Piezo element LD-BZPN-2730 was amplified 10 times, whereas the signal of pressure sensor Honeywell -26PC SMT was amplified 100 times. The signals of these sensors were acquired using a 16-bit NI ELVIS analogue to digital converter. The discretization frequency was 1 kHz. In this case it is crucial to know the amplitude and frequency transfer characteristics of the sensor and of the whole electrical circuit. For the assurance of equal conditions of the pressure it was created a system in which a vacuum cylinder was constructed that had a piezoelectric sensor installed at one end. The sensor was actuated by the pressure of the airflow. During the next stage of research, an impulse pressure signal was generated and synchronically sent to both sensors (see Fig. 2).

For the signals registration from the above mentioned sensors and processing it was developed virtual instruments application using LabVIEW (Laboratory Virtual Instrument Engineering Workbench) 2012. LabVIEW ties the creation of user interfaces (called front panels) into the development cycle. LabVIEW programs/subroutines are called virtual instruments (VIs). Each VI has three components: a block diagram, a front panel and a connector panel. The last is used to represent the VI in the block diagrams of other, calling VIs. The front panel is built using controls and indicators. Controls are inputs – they allow a user to supply information to the VI. Indicators are outputs – they indicate, or display, the results based on the inputs given to the VI. The back panel, which is a block diagram, contains the graphical source code. All of the objects placed on the front panel will appear on the back panel as terminals. The back panel also contains structures and functions which perform operations on controls and supply data to indicators. The structures and functions are found on the Functions palette and can be placed on the back panel. Collectively controls, indicators, structures and functions will be referred to as nodes. Nodes are connected to one another using wires – e.g. two controls and an indicator can be wired to the addition function so that the indicator displays the sum of the two controls. Thus a virtual instrument can either be run as a program, with the front panel serving as a user interface, or, when dropped as a node onto the block diagram, the front panel defines the inputs and outputs for the given node through the connector panel. This implies each VI can be easily tested before being embedded as a subroutine into a larger program. The created program consists of two parts: block diagram and visual data scope window (front panel). The block diagram consists of signal acquisition modules, infinite impulse response (IIR) filter modules, calculation of the transfer function modules and data storage in the NI TDMS format modules. Using the developed program it was acquired signals of both sensors and the filter was disabled. The signals were represented graphically (see Fig. 3 and Fig. 4).

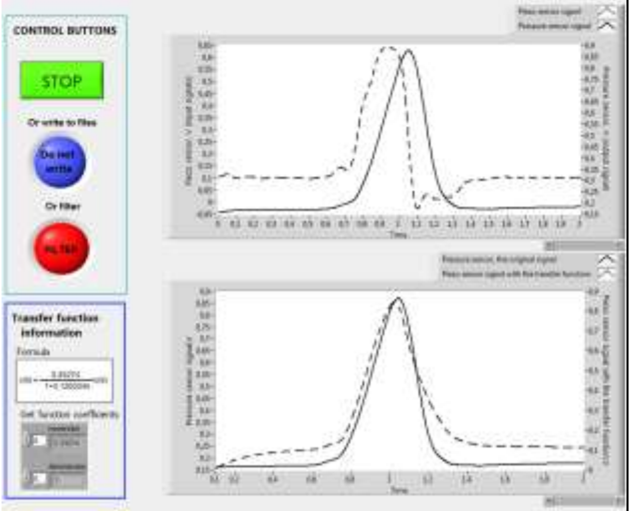

Figure 3. Fragment of the front panel of the developed virtual instrument

The signal detection modules were used to create a virtual channel and to add it to a task. The instances of this polymorphic VI correspond to the I/O type of the channel. It was configured the number of samples to acquire. The instances of this polymorphic VI correspond to the type of timing to use for the task. The samples were read from the specified virtual channel.

Also it was used the LabVIEW System Identification Toolkit which assisted in identifying large multivariable models of high-order systems from large amounts of data. The System Identification Toolkit provides two tools, an assistant and a library of VIs, for identifying these discrete single-input single-output (SISO) and multiple-input and multiple-output (MIMO) linear systems, respectively. Both tools enabled to

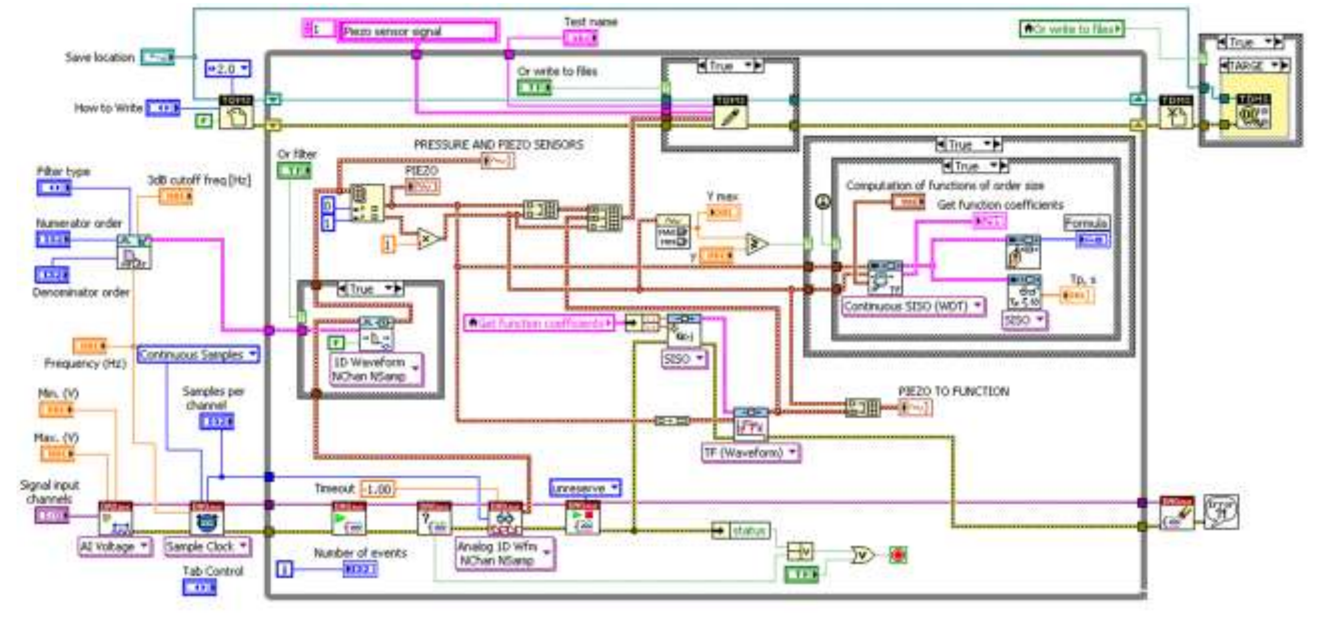

Figure 4. Fragment of the program block diagram of the developed virtual instrument

complete the entire system identification process from analyzing the raw data to validating the identified model.

IV. Results and discussion

Diagrammatic signal-registering form shows that the signal of piezoelectric sensor differs from that of a standard air pressure sensor (Fig. 5). The equation model was used to identify the differences and to determine the transfer function of the system (first order). We used the Single-Input Single-Output (SISO) Model. The dynamic system model contains different numbers of inputs and outputs.

$$Y(s) = G(s) \cdot u(s) \tag{1}$$

Where: Y(s) – signal of piezo-actuator (output), G(s) – transfer function between input and output signals (2), u(s) – pressure sensor signal (input).

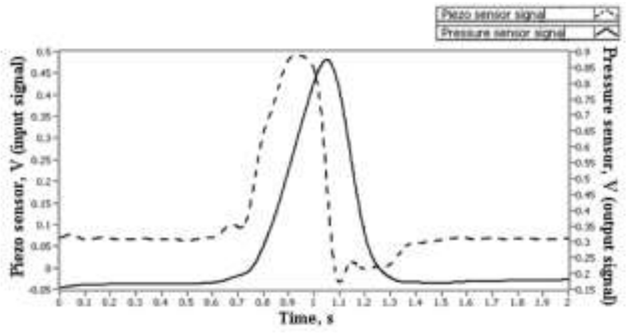

Figure 5. Piezoelectric and pressure sensors signals without transfer function operation (1 period)

$$G(s) = \frac{b_0}{a_0 + \tau s} \tag{2}$$

where: b_0 – stationary gain coefficient of the numerat

or polynomial function, a_0 - the coefficients of the denominator polynomial function, s - is the Laplace variable and continuous time, τ- time constant of the lag.

Thus, as the transfer function of the system and the output signal are known, it is possible to adjust the input signal. It was calculated by employing the (3). In this case the determined feedback function was used to adopt piezo-electric sensor signal to pressure sensor signal.

$$Y_1(s) = G(s) \cdot Y(s) \tag{3}$$

Where: Y1(s) - the signal of piezo-actuator after using the transfer function (output signal), G(s) – calculated transfer function, Y(s) – piezo-actuator signal after first operation

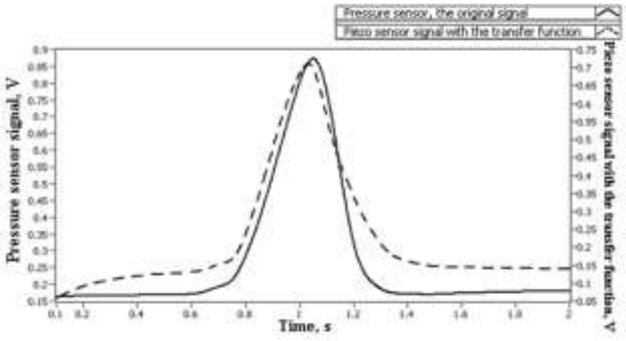

Figure 6. Pressure sensors (dotted) and piezoelectric sensor after processing with transfer function (solid) signals (1 period)

(input signal).

After calculations were done, a new signal was obtained that could be compared with that of pressure sensor (Fig. 6). It is evident that the newly obtained signal is not equal to the original one. However the differences remained merely in a constant constituent and in the ending part of the signal. The front and the peaks of the signals are almost identical.

The goal of the application of piezo actuator is to register the pulse wave at carotid artery. The most important information collected from registering the pulse wave is found at the front and the peak of the wave. Therefore it is assumed that such piezo sensor with an adjustment system is suitable for this task. Having performed the experiment using the designed system of measurement, the first order transfer function between the input and the output signals of piezoelectric sensor and pressure sensor was assessed. The transfer function derived is as follows (4):

$$G(s) = \frac{0{,}33274}{1 + 0{,}125024 \cdot s} \tag{4}$$

The amplification degree of designed system is equal to 0,33, time constant – 0,13 sec. By applying the transfer-function ratios it is possible, considering a standard signal, to design amplitude and frequency characteristics of the sensor for a desired goal. The designed virtual model for assessment of the transfer function of piezoelectric sensor shows that the usage of electronic elements is not always necessary to achieve the modification of amplitude and the frequency characteristics of the sensor. The amplitude and frequency-characteristics of the sensor can be modified using an RC circuit, however, in this case, in the first instance, it is also necessary to determine the values of the transfer function between original sensor signal and the signal of a standard sensor in order to choose necessary electronic elements. It is performed using various calculating applications. Therefore, in our opinion, the method suggested simplifies the electronic part of the adjustment system by transferring its functions into virtual environment.

V. Conclusions

It was designed the virtual model for assessment of the transfer function of piezoelectric sensor. The results shows that determining of the pulse wave main parameters using a piezo sensor makes it possible to develop it without RC adjustments in the circuit. The transfer function ratios were calculated: the degree of amplification is equal to 0,33; time constant – 0,13 sec. The obtained difference between the signals of pressure and piezo sensors shows that adjusted piezo actuator can be applied in measuring key parameters of pulse wave (the front and the peak of the wave).

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About Author (s):

Zydrunas LUKOSIUS is PhD student at Faculty of Faculty of Natural Sciences, Vilnius University (Lithuania). He graduated MSc degree in Informatics Engineering, Klaipeda University in 2011. He is lecturer at the Department of Informatics engineering of the Faculty of Marine Engineering of the Klaipeda University (Lithuania). His research interests include sensor technologies, biomedical systems engineering, graphical programming languages.

Mindaugas KURMIS is PhD student at Institute of Mathematics and Informatics, Vilnius University (Lithuania). He graduated MSc degree in Informatics Engineering, Klaipeda University in 2011. He is lecturer at the Department of Informatics engineering of the Faculty of Marine Engineering of the Klaipeda University (Lithuania). His research interests include service support in mobile systems, mobile technologies, computer networks, distributed systems, intelligent transport systems.

Arunas ANDZIULIS is professor, doctor, head of the Department of Informatics engineering of the Faculty of Marine Engineering of the Klaipeda University (Lithuania). He holds a diploma with honour of physics in 1968 of Vilnius University, PhD in electronic engineering in 1968 of Kaunas Institute of Technology, habilitation doctor procedure in the field of transport engineering sciences in 2007, and long time works as a head, designer and project manager. His research interests include operation research, nanotechnology and modelling, optimization of technical systems, intelligent transportation/logistic systems.

Julius VENSKUS is master student at Faculty of Marine engineering, Klaipeda University. He graduated BSc degree in Informatics Engineering at Klaipeda University in 2014. He is a highly experienced chief engineer at security and sensors company in Lithuania. His research interests include sensor technologies, adaptive systems, mobile technologies.