EXPERIMENTAL DETERMINATION OF THE TRANSFER FUNCTION FOR PRESSURE SENSORS

SORIN EUGEN POPA [*1], TOMA CONDRUT[2]

[1] *"Vasile Alecsandri" University of Bacau, Calea Marasesti 157, Bacau, 600115, Romania*

[2]*Syncraft Engineering GmbH, Münchner Str. 22, 6130 Schwaz, Austria*

Abstract: Although the manufacturers of various electronic components, including pressure sensors, provide us with their operating characteristic, it is necessary to establish it accurately. In this context, the paper presents the results obtained following the design and construction of an experimental laboratory stand intended for the experimental determination of the operating characteristics of differential pressure sensors.

Keywords: pressure sensor, Arduino, operating characteristic

1. INTRODUCTION

Today's world is full of all kinds of sensors, which determine different parameters of the surrounding environment. Barometric, atmospheric pressure, humidity and temperature sensors represent one of the broadest categories, with multiple uses in the medical field (blood pressure measurement [1], apnea detection [2], human health status [3], and normal breathing detection [4].

In the paper we will analyze the real operating characteristic [5] of a differential pressure sensor, which can be used in biomedical applications. The idea started from studying and analyzing the operation of artificial ventilation devices, so necessary in the COVID-19 pandemic [4, 6].

Analyzing several works in the field of determining the operating characteristic of pressure sensors, [5, 7, 8], a strategy was developed to analyze the operation of the equipped sensor.

The paper presents the results obtained as a result of the research carried out in order to raise the actual operating characteristic of the atmospheric pressure sensor from the MPS20N0040D series. In order to achieve this, a laboratory stand was designed and built. To monitor and change the pressure to which the sensor is exposed, the use of a tube pressure gauge was chosen. These devices are characterized by simple construction and high precision, being used in laboratories and industry as reference devices.

The sensors used, MPS20N0040D [9], piezo resistive type, are differential pressure sensors with a stated measurement range of +/- 20kPa. They measure pressure relative to atmospheric pressure.

The work had two main objectives. The first, the creation of an experimental stand, which will allow the realization of the second objective, namely, tracing the performance characteristic of the chosen differential pressure sensor.

[*] Corresponding author, email: sorinpopa@ub.ro doi.org/10.29081/jesr.v28i4.013

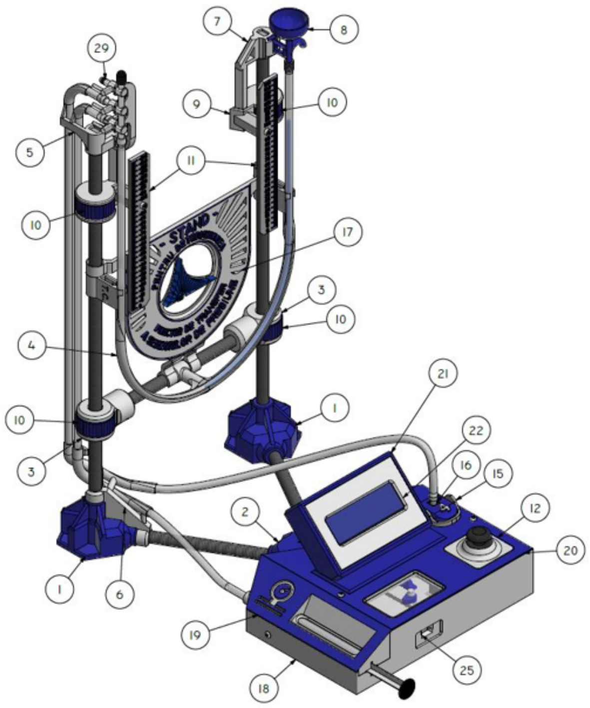
2. EXPERIMENTAL SETUP

2.1. Experimental stand presentation

In order to check the sensitivity of the sensors and the accuracy of the measurements obtained, it was necessary to design and build a multifunctional stand, shown in Figure 1, which would allow:

- The possibility of applying positive and negative pressures;
- Retrieving the data provided by the sensor through the IIC (Inter-Integrated Circuit) interface;
- Data processing to determine the pressure measured in Pascal and mm H_2O;
- Data display on a built-in LCD screen;
- Modification of operating parameters and conversion factor by the user.

In order to be able to determine and modify the pressure to which the sensor is exposed, it was chosen to create a liquid instrument that expresses the pressure through the length of a vertical liquid column.



No.	Description
1	Internal rod holder
2	Connector
3	Transverse rod holder
4	Hose holder
5	Distributor holder
6	Lower hose holder
7	Funnel holder with hose guide
8	Funnel, drain connection
9	Ruler holder
10	Height adjustment wheel with M10 nut
11	Ruler
12	Joystick holder
13	Joystick
14	Sensor housing
15	Sensor holder
16	Hose adapter
17	Descriptive plate
18	Lower case
19	Syringe compartment cover
20	Case cover
21	Display holder
22	Display cover
23	Polycarbonate plate
24	Polycarbonate plate frame
25	USB connector cover
26	Plate fixing element
27	Safety nut
28	Cable fixing element
29	Dispenser with 3 taps

Fig. 1. Stand for pressure change applied to atmospheric pressure sensors: 1-Internal rod holder; 2-Connector; 3-Transverse rod holder; 4-Hose holder; 5-Distributor holder; 6-Lower hose holder; 7-Funnel holder with hose guide; 8-Funnel, drain connection; 9-Ruler holder; 10-Height adjustment wheel with M10 nut; 11-Ruler; 12-Joystick holder; 13-Joystick; 14-Sensor housing; 15-Sensor holder; 16-Hose adapter; 17-Descriptive plate; 18-Lower case; 19-Syringe compartment cover; 20-Case cover; 21-Display holder; 22-Display cover; 23-Polycarbonate plate; 24-Polycarbonate plate frame; 25-USB connector cover; 26-Plate fixing element; 27-Safety nut; 28-Cable fixing element; 29-Dispenser with 3 taps.

To process the data transmitted by the sensor through the IIC protocol, the Arduino Nano development board with the ATmega 328p microcontroller was chosen. To process the data transmitted by the sensor via the IIC protocol, the Arduino Nano development board with the ATmega 328p microcontroller was chosen, which is present in numerous scientific researches, such as [10-13]. In the stand designed configuration, communication with the sensor is via digital pins 2 (SCK) and 3 (DOUT). Figure 2 shows a simplified circuit diagram, highlighting the sensor connection.

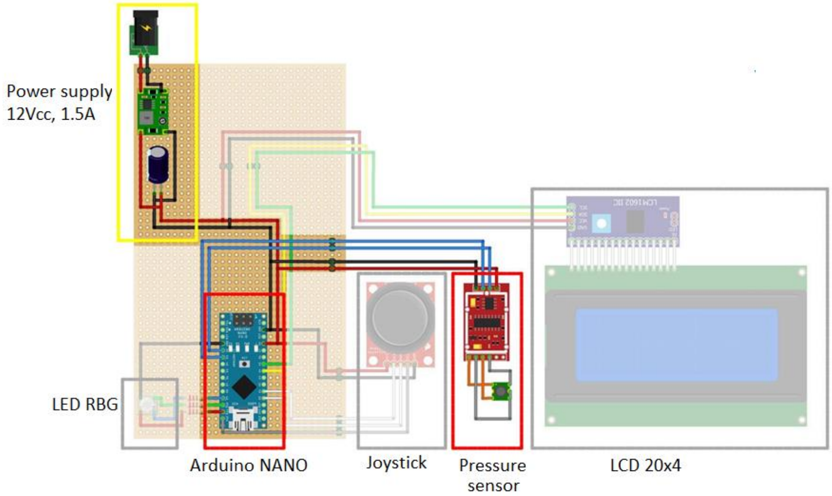


Fig. 2. Simplified circuit diagram.

2.2. Data processing

For the chosen sensor model, Arduino has developed a specific function library, named Q2HX7111.h [14, 15]. According to the description of this book, we need to determine two quantities, namely:

- The offset or zero point - the numerical value corresponding to the atmospheric pressure (hereinafter *Pnul*);
- The slope of the line depending on the chosen measurement unit.

Starting from the assumption that the sensors correspond without deviations to the technical specifications [9, 16], the slope of the transfer function can be determined as follows:

- Assigning the zero-point value 8388.61 the pressure of 0 kPa;
- Assigning the maximum numerical value 16777.22 the maximum pressure of 20kPa;
- Determining the slope with the equation:

$$\frac{20}{16777.22-8388.61} = 0.0023842 \quad (1)$$

- The transfer function therefore becomes:

$$y = (x - 8388.61) \times 0.0023842 \quad (2)$$

The graphic representation of this ideal function is shown in the Figure 3.

The described function represents the correspondence between the values determined by the sensor and the unit of measure kPa. For equating in other measurement units, one of the following conversion factors is added to the function:

- millibar: x 10;
- Pascal: x 1000;
- mmH_2O: x 101.9716.

The logic diagram of the operation of the pressure measurement process is briefly shown in Figure 4, and Figure 5 shows the menus and information displayed on the LCD screen.

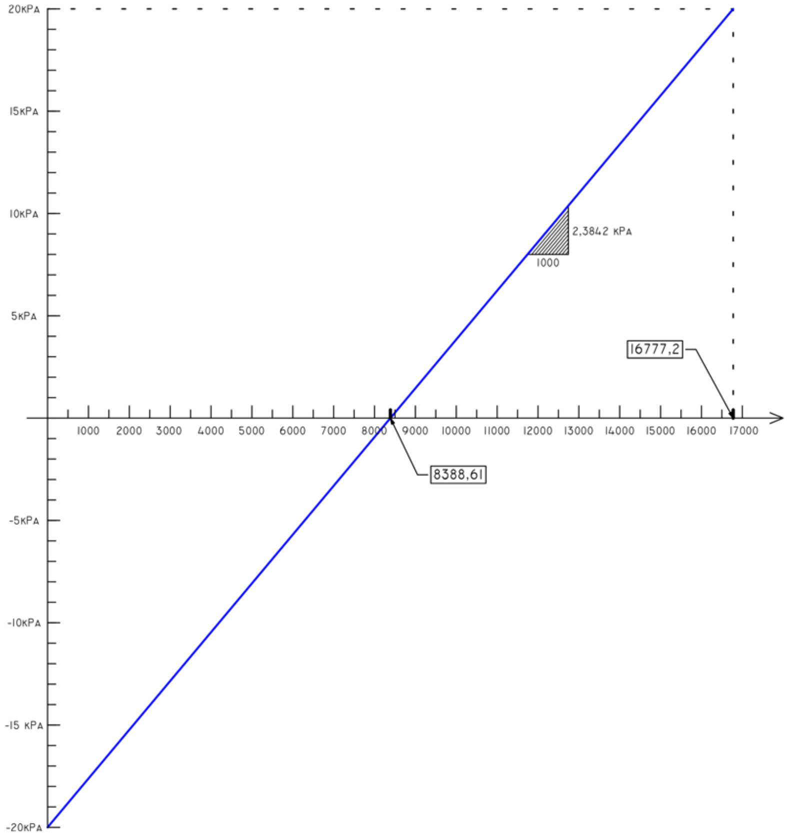


Fig. 3. Transfer function according to the manufacturer's data sheet.

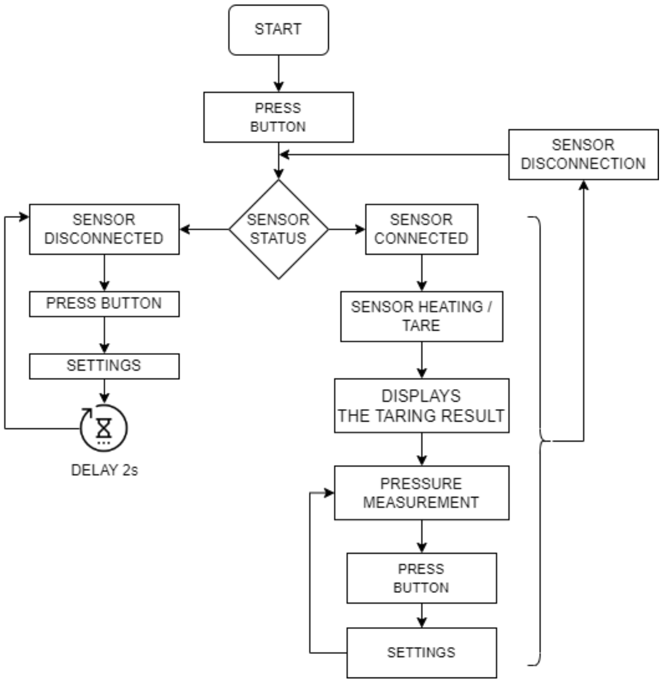


Fig. 4. Logical diagram of the transfer function determination booth menus.

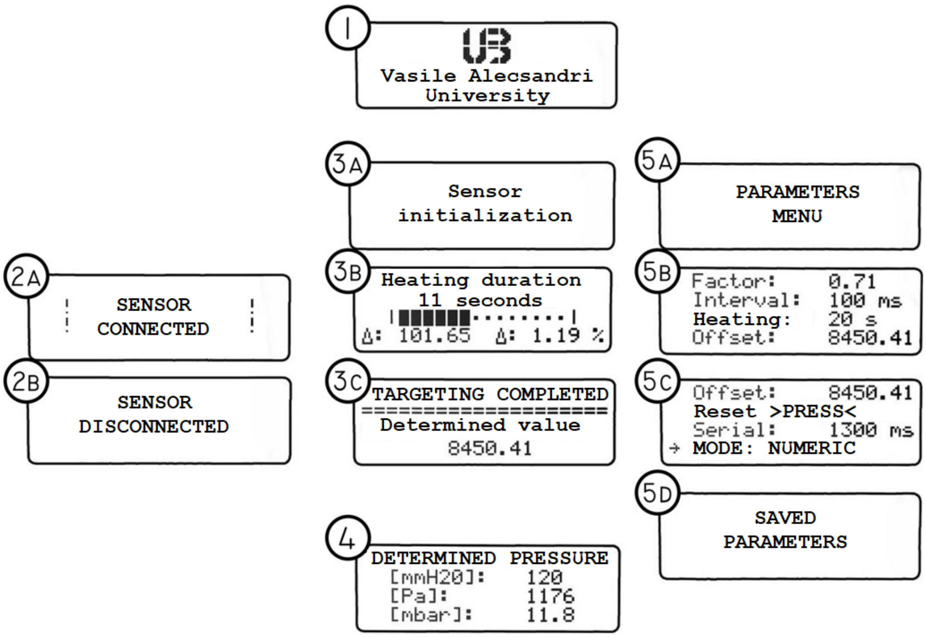


Fig. 5. Transfer function determination booth menus.

2.3. Sensor stabilization feature

Experimental modeling (also called identification) involves performing direct tests on the physical system, allowing either the global identification of the system (the case of black box systems), or only the determination of the value of some parameters of the model, when the structure and shape of the model are known (from analytical modeling) [17].

During the information acquisition process, an ideal relationship can be established between the primary information *inf* and the output signal S:

$$S = f(inf) \tag{3}$$

The ideal function can be stated in the form of a table of values, a graph, or a mathematical function. In the specialized literature, this dependence is used, in static and dynamic mode, for the analysis and design of the sensory element [18, 19].

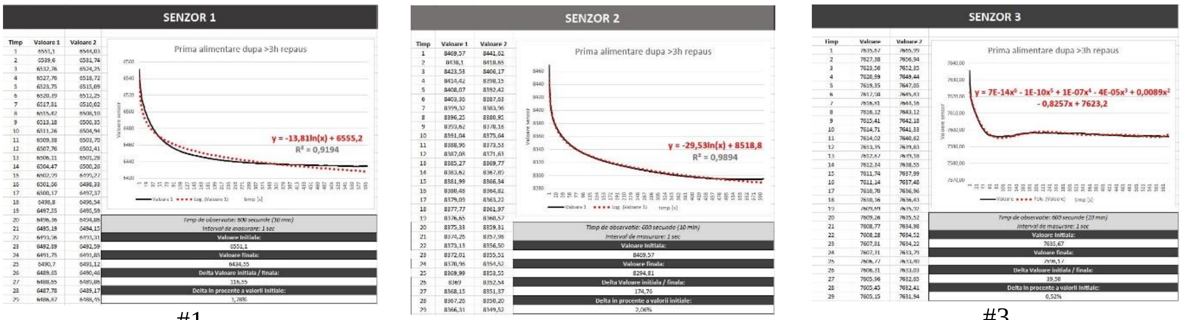
2.4. Measurement uncertainty

For the three transducers (two working, one spare) the heating characteristic was determined experimentally. The values transmitted by the transducers from the moment of the first power-up after a period of non-operation of at least 3 hours were taken. They were not exposed to a differential pressure, the values therefore representing the equivalent of the numerical conversion of the voltage difference in the Wheatstone bridge of the sensors when no force other than gravity is exerted on the diaphragm.

A stabilization phenomenon with a negative logarithmic characteristic is observed. A monitoring period of 10 minutes was chosen for each pressure transducer, the graphs shown in Figure 6, each resulting from 600 individual measurements.

It is found that the values transmitted at the end of the observation period show a difference between 0.5 and 2% compared to the first value transmitted.

In the first minute of heating, the values approach between 71.5% (transducer #2) and >90% (transducer #3) of the final values, considered stabilized.



#1 #2 #3

Fig. 6. The stabilization characteristic of the three analyzed transducers.

2.5. Experimental determination of the transfer function of pressure transducers.

The resulting graphs display major differences both between the individual functions and, especially, the transfer function declared by the manufacturer (Figure 7).

The transfer function is determined using the stand in the range -120 ÷ +120 mm H_2O (or -1.17kPa to 1.17kPa), for a number of 14 measurements performed for each transducer.

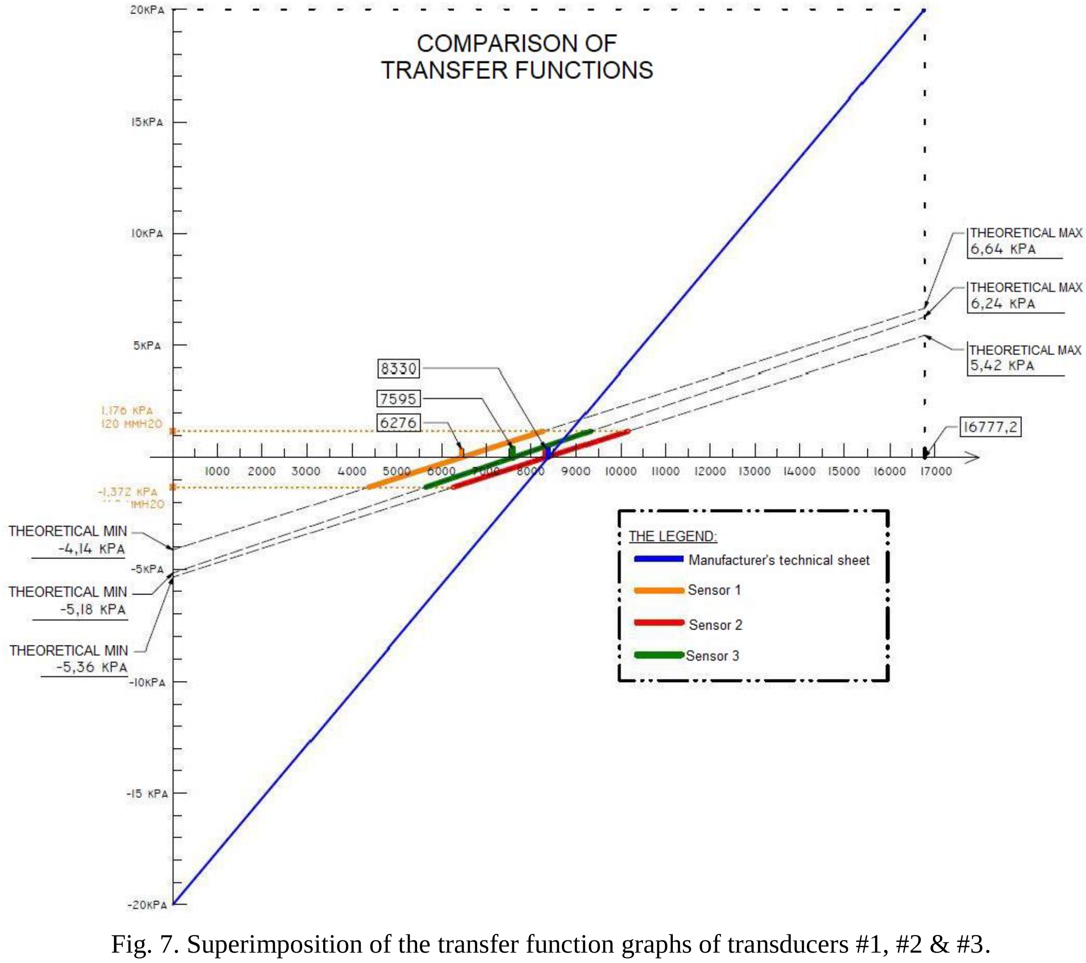


Fig. 7. Superimposition of the transfer function graphs of transducers #1, #2 & #3.

3. RESULTS AND DISCUSSION

The conversion factors being approximately 3.7 times lower, respectively the slopes of the functions being flatter than the manufacturer's specifications present advantages for the intended application. Even though the maximum and minimum pressures that fall within the transducer conversion threshold are lower by the same factor, the resolution in the measurement range increases in the same proportion.

This feature is advantageous in order to obtain high precision measurements, considering that the pressure differences between the primary pressure pickup point and the point of local reduction of the flow section of the Venturi depressurize will not exceed 1-2 mm column H_2O. The static characteristic depends on the analyzed sensory element. A typical static characteristic for a force sensor is illustrated in Figure 8. The characteristic highlights aspects related to nonlinearities of the sensor element.

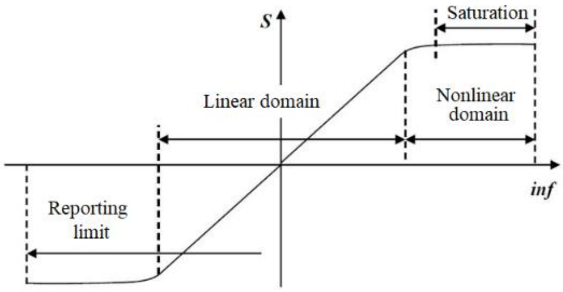


Fig. 8. Static characteristic and non-linearity aspects [18, 19].

A system is linear if it meets the following two criteria [20]:

• If the input signal x will determine the output signal X, then an input signal 2x will produce an output signal 2X. In other words, in a linear system the amplitude of the output signal is directly proportional to the amplitude of the input signal.

• If an input signal x produces an output signal X, and an input signal y produces an output signal Y, then the resulting input signal x + y will produce an output X + Y. In other words, for the linear system the input signals are independent, so they do not interact within the system.

In the present case, the results of the performed measurements show that the limits of the linear domain were not exceeded, according to Figure 8. Table 1 shows the transfer functions determined according to the methodology presented in the previous chapter.

Table 1. The transfer functions of the transducers examined.

	Zero point	Conversion factor	Transfer function
transmitter #1	4374	0.643	y = (x – 4374) * 0.643
transmitter #2	6272	0.643	y = (x – 6272) * 0.643
transmitter #3	5655	0.681	y = (x – 5655) * 0.681

4. CONCLUSIONS

The paper presents the achievements obtained by the authors in the field of raising the operating characteristic (determining the transfer function) of differential atmospheric pressure sensors. To achieve the proposed goal, the authors created an experimental stand, designed entirely by them in Autodesk Invertor, and printed on a 3D printer. The minimum/maximum pressures the stand can create are -120mmH_2O and +120mmH_2O (ie ± 1,176 kPa).

Measurements were made on three sensors of the same type, from which we can conclude:

• All three have a linear characteristic, with the same slope (conversion factor) of about 0.6xx but different offset;

• All three sensors have different slopes than the one provided by the manufacturer, so they can measure much lower pressures (from about -5 kPa to about 6kPa versus ± 20kPa);

• The smaller slope will give us greater precision;

• After determining the actual transfer function (operating characteristic) the sensors can be used in other experimental setups, providing a suitable measurement.

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