A Software Application for Automatic Characterization of Piezoresistive MEMS Pressure Sensors

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***Abstract*—In order to improve the efficiency of the pressure sensors characterization process at the Center of Microelectronic Technologies (CMT), a new measurement setup is developed that enables fully automatic characterization of multiple silicon piezoresistive MEMS pressure sensors. The whole experiment, including high-performance measurement of sensors output signals at several temperature and pressure values, and storage of the measured results in a computer file, requires only a minimum of operator action. The setup consists of both hardware and software modules. The hardware is partly based on equipment designed and built at CMT for this purpose, and the software is entirely developed at CMT. This paper is focused on the software aspects of the developed experimental setup. The main objective of the presented work is to make the small series production of industrial pressure transmitters at CMT more efficient. The results are also very useful for research and development of pressure sensors and instrumentation.**

***Index Terms*—Sensor; pressure; software; measurement.**

I. Introduction

A majority of research and development activities of the Center of Microelectronic Technologies (CMT) belongs to the field of sensors. Among all the different sensors in various stages of research at CMT, silicon piezoresistive MEMS pressure sensors stand out as the most successful commercialized devices so far [1–9]. Based on them, a range of industrial measurement instruments (pressure transmitters) has been developed, and is in small series production at CMT. Several types of these transmitters are in regular use in many industrial plants in Serbia. The latest generation of industrial transmitters developed at CMT is a series of intelligent transmitters that utilize digital signal processing for achieving high measurement performance, and have the capability of two-way digital communication with a measurement and control system [10–13].

Before a pressure sensor can be used as a part of a measurement instrument, it has to undergo several test and measurement procedures. The final stage of that process is the characterization of the sensor, which enables the calculation of calibration parameters for the instrument. In general, the way in which the characterization is performed depends on the required measurement performance, and it can be very involving if a sensor is intended for a high performance instrument. This is the case with sensors for intelligent industrial pressure transmitters, especially because such instruments have to operate within their specifications in a wide temperature range typical for industrial environments.

The pressure sensor characterization experiment is performed as follows. A sensor is placed in a temperature chamber in order to be subjected to a series of temperature values across its specified temperature range. Its pressure port is connected to a pressure calibrator that enables setting a series of pressure values within the sensor's nominal pressure range. The sensor's electrical ports are connected to a dedicated signal acquisition system that provides sensor excitation and measures the sensor's output signals with high measurement performance. A separate temperature sensor is attached to the pressure sensor under test, in order to measure the sensor's temperature (the temperature reading provided by the temperature chamber is not adequate for this purpose). The temperature values are set in a decreasing order (typically from 70°C to -20°C), so to avoid water condensation inside the temperature chamber. After a certain temperature has been settled, which is confirmed by monitoring the temperature sensor reading, a series of pressure values is set. For each pressure value, the corresponding values of the sensor output signals are acquired and then saved in a computer file. The total number of temperature and pressure values depends on the target measurement uncertainty for the sensor under test. For sensors intended to be used within intelligent transmitters, a typical number of temperatures is at least 5, and the number

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of pressure values is 11 in both the ascending and descending direction, resulting in a total of 110 measurements. As the time needed for each temperature to settle is at least 45 minutes, the experiment lasts more than 6 hours.

II. Method

In order for the sensor characterization experiment to be efficient and therefore economical for the purposes of small series production of industrial pressure transmitters, it has to be performed on several sensors simultaneously. Furthermore, the influence of the number of sensors on the experiment duration must be minimized. For these requirements to be fulfilled, a measurement setup was realized at CMT, which, apart from some commercially available devices, includes a signal acquisition unit [9] and a channel selector [14], both developed at CMT, as well as a software application that controls the instruments, enabling the experiment to be executed automatically. The focus of this paper is on the software application, entirely developed at CMT.

The best insight into the problem to be solved can be obtained by observing a block diagram of the measurement setup, shown in Fig. 1.

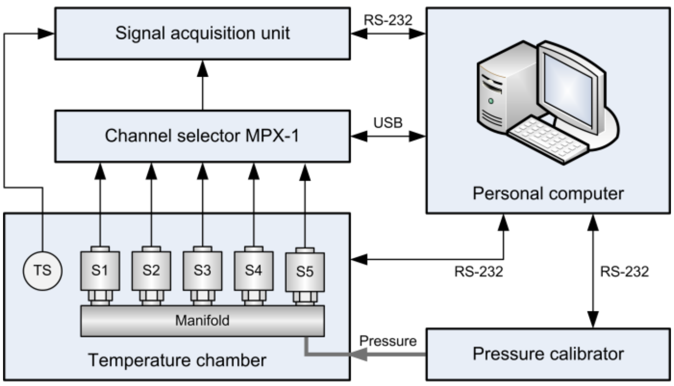

Fig. 1. Block diagram of the measurement setup for automatic pressure sensors characterization (S1 to S5 are the pressure sensors under test, TS is the temperature sensor).

It can be seen from the block diagram that there are four different devices that must be controlled by the computer and the developed software application in order to perform the experiment. The pressure calibrator, the temperature chamber and the signal acquisition unit are connected to the computer via the RS-232 interface, while the channel selector MPX-1 is connected via the USB interface. Since modern desktop, as well as portable personal computers, typically lack RS-232 ports, an additional card with such ports had to be added to the computer. This has proven to be a more reliable solution compared to the use of serial-to-USB adaptors, which are more common today.

The first step in the software development was to define the main functions the software application has to perform. They can be divided in 4 groups: 1) communication with external equipment comprising the measurement setup, 2) control of the measurement procedure, 3) storage of the acquired measurement data on the computer's hard disk, and 4) graphical user interface.

The next step was to choose both the programming language and the programming environment most suitable for the task. In this case the LabWindows/CVI programming environment was chosen, which is well proven in both scientific and industrial applications. In addition to the built-in standard C compiler, it offers a good choice of library functions needed for communication with peripherals, and all the prerequisites for efficient user interface creation.

The visual appearance of the graphical user interface window is shown in Fig. 2. The window is divided into 5 parts that will be described in the following paragraphs.

The part in the top-left corner of the window is dedicated to the pressure calibrator (Mensor APC600). The pressure value measured by the calibrator is indicated at the top-left corner whenever there is an active communication with the instrument. The controls below the pressure indicator enable all the adjustments pertinent to setting of the required pressure values in a chosen sequence. All the controls needed for the communication with the calibrator are located to the right of the indicator.

The part on the middle left side of the window is dedicated to the signal acquisition unit. The two indications titled "Sensor" are for the two sensor output signals, which are expressed as resistances, R_{out} and R_{br}, according to the explanation given in [13]. Below, there is also the indication of the temperature of the sensors under test. To the right of the indicators, the limits can be set of the allowed resistance and temperature values, so that the application can detect malfunctions during the measurement process. To the right there are all the controls needed for the communication with the signal acquisition unit.

The part in the top-right corner of the window is dedicated to the channel selector MPX-1. The software application enables the selector to be operated in the manual mode (the channel corresponding to the desired sensor is selected by marking the corresponding control box) or automatically, following a predefined sequence. As the communication with the MPX-1 is realized using a virtual COM port, the controls needed for setting the port are also implemented.

The part in the bottom-right corner of the window is dedicated to the temperature chamber. The controls enable setting of the temperature, and are realized in a similar way to those for the pressure calibrator. The indication of both the current temperature and the set temperature is provided whenever there is an active communication with the temperature chamber controller.

Finally, the part in the bottom-left corner of the window enables the operator to control the measurement process.

Before any measurement can be performed, all the necessary connections (electrical and pneumatic) with sensors must be established, the measurement setup must be fully functional, and all the settings in the software application must be correct. If that is not the case, an attempt to start the measurement will not be successful, and an error message will be displayed, stating the problem that prevented the execution.

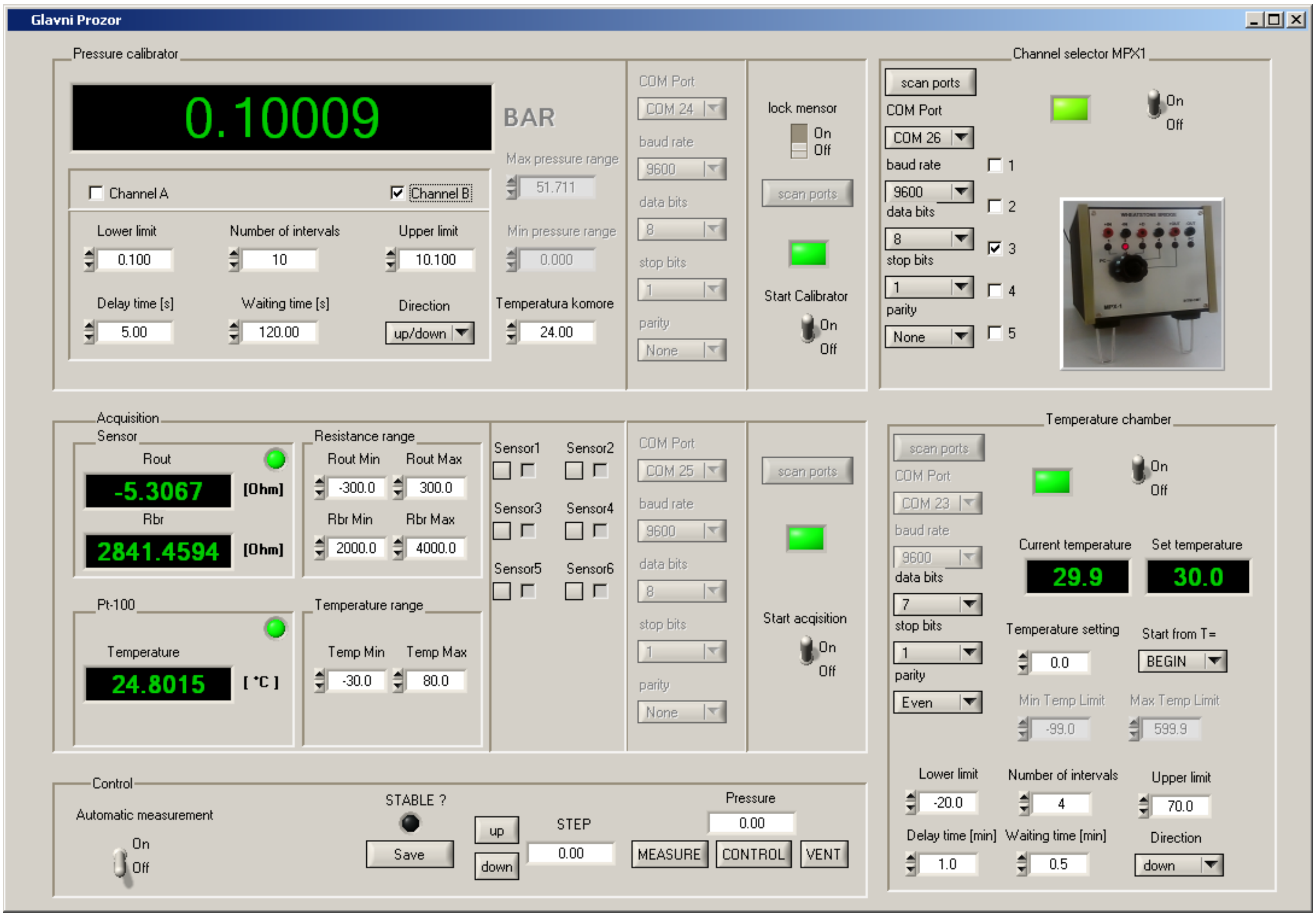

Fig. 2. Visual appearance of the graphical user interface.

Two modes of operation are supported: the manual and the automatic mode. In the manual mode the operator can perform the measurement at one measurement point (one pressure and temperature value), and then save the corresponding set of measurement values in a file. This mode is useful for testing purposes, before the automatic mode is initiated.

The automatic mode is initiated by using the control at the bottom-left corner. After that, the first temperature value from the predefined sequence is set. The application waits for the delay time to expire, in order for the temperature to settle. Then the first pressure value from the predefined sequence is set. The channel selector connects the sensors under test to the input of the signal acquisition unit, one at a time. For each sensor, R_{out} and R_{br} are measured, as well as the temperature, and the values are stored in the corresponding files. Measurements are then repeated in the same way for each of the pressure values. After that, the next temperature value is set. The measurements are repeated in the described way for all the sensors at all predefined pressure and temperature values. A flowchart of the sensor characterization experiment is shown in Fig. 3.

III. Results

After the realization of the software application described in the previous chapter, it was installed on a personal computer used to control the measurement setup for automatic pressure sensors characterization. Testing of the application showed that it performs as intended, and that it has all the functionality required for the sensor characterization experiment to be performed automatically.

Through the realization of the software application several significant objectives have been achieved, of which the main ones will be discussed in the following paragraphs.

Firstly, the sensor characterization process has been greatly improved in terms of efficiency. This was achieved by enabling multichannel measurements to be performed automatically, which is made possible by using the channel selector MPX-1. At this time, the measurement setup enables up to 5 piezoresistive pressure sensors to be characterized simultaneously. However, the hardware concept of the channel selector allows addition of new channels in the future. A practical limit of the number of channels will most likely be dictated by the total thermal mass of the sensors under test (together with the manifold and other objects in the chamber), as the increase in mass leads to longer temperature settling time, and eventually to an unacceptable experiment duration.

Another significant result is the reduction of operator actions to a minimum. The sensor characterization process is very tedious and time consuming when performed manually or even semi-automatic. Due to the inevitable operator fatigue, mistakes can be easily made at any step of the process, sometimes leading to unusable measurement results. Assuming there are no malfunctions during the process, the automation achieved in the described way leads to more reliable measurements in a shorter time. After the process is started, the role of the operator is reduced to monitoring. Further development of the software application may include remote monitoring, possibly based on Internet services.

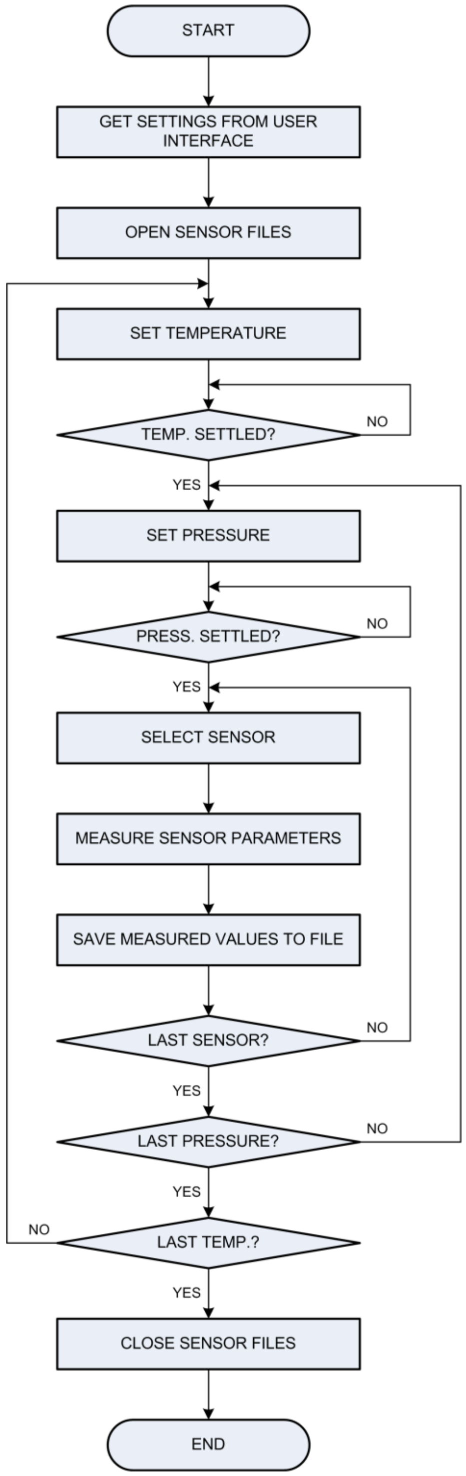

Fig. 3. Flowchart of the sensor characterization experiment.

Finally, the automation of the characterization process significantly reduces the use of resources. As all the sensors under test are simultaneously exposed to the same temperatures, the overall energy consumption during the experiment is greatly reduced. Because the same pressure is distributed to all the sensors under test, only one pressure setting sequence is required at each temperature, regardless of the number of tested sensors. Therefore, a smaller amount of gas is spent from the gas cylinder used as a pressure source, and the need for expensive calibrator maintenance is reduced.

IV. Conclusion

A novel software application is presented that enables automatic characterization of piezoresistive MEMS pressure sensors to be performed using the measurement setup developed at CMT.

The main objective of the work was to improve the efficiency of the characterization process as much as possible. Compared to the previous practice, the sensor characterization experiment has been greatly accelerated due to the ability to perform the measurement simultaneously on up to 5 sensors. Therefore, the effective characterization process duration per sensor can be reduced by more than 4 times.

The presented work has yielded some other important benefits. Required actions by the operator are reduced to a minimum during the sensor characterization process, which also means that the influence of human errors on the experiment is much less probable. Finally, the automation of the characterization process leads to a significant reduction of the used resources (electrical energy, gas supply, and equipment utilization).

The presented software application, although fully functional in its current form, can be improved in several ways. For example, the described approach provides a possibility for the number of sensors under test to be increased. Remote monitoring of the measurement process, even from very long distances, can be enabled by using Internet services. Further development of the software application and the whole measurement setup can include the support for additional and/or different pressure calibrators, climatic chambers and other equipment.

Although its main application is in small series production of pressure transmitters, the realized experimental setup is an important tool for research activities in the field of MEMS pressure sensors at CMT. Having that in mind, the developed software application has also been made suitable for research and development purposes. It will have a significant role in the development of new measurement methods intended for a new generation of pressure measurement instruments.

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