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A microcontroller-based interface circuit for data acquisition and control of a micromechanical thermal flow sensor

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Abstract. In the present work, a special microcontroller-based data acquisition and control system was designed and fabricated, for fast and accurate flow measurements with programmable modes of operation. The system can apply predetermined power to the heater and simultaneously is able of monitoring both the thermopile signal and the heater current. An RS232 connection was also implemented for the communication with the outside world. The interface circuit was adapted to the micromechanical flow sensor for evaluation. Various sensor parameters were extracted in both laminar and turbulent flow conditions. The sensor responses with three operation modes (constant voltage, power and temperature) were also obtained.

1. Introduction

Nowadays the research in the field of microsystems is progressively directed towards smart electronic interfacing [1,2], which provides the ability of performing complex operations. Specially designed interfacing electronics for specific applications improve the performances of the microsystem and provide a user-friendly environment for the control and the communication with it. In this work a microcontroller-based data acquisition and control system was designed and fabricated, for fast and accurate flow measurements with programmable modes of operation. The interface circuit was adapted to the micromechanical flow sensor for evaluation.

2. System Description

The thermal flow sensor that was used is described in detail elsewhere [3]. It consists of a polysilicon heating resistor and two thermopiles situated symmetrically on each side of the heater. The differential signal is directly available since the two thermopiles are connected in series. The heating resistance value is changing with temperature and consequently it induces a secondary signal to the sensor, which is interpreted by the thermopiles as additional flow signal. This effect can be compensated by means of different operation modes [4].

A block diagram of the interface circuit is shown in figure1. It consists of three sub-circuits: the data acquisition section, the control and supply section and the serial communication part. The interface is based on an 8-bit microcontroller (Atmel AVR) at 16 MHz, which handles all the different processes through the corresponding software. The specific microcontroller (μ C) was selected in order to produce a fast and low cost prototype.

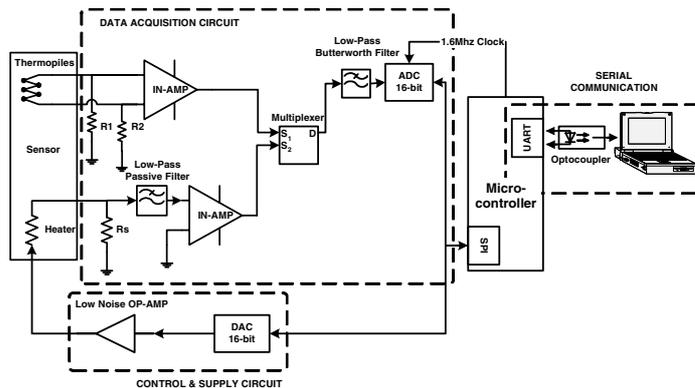


Figure 1. Block diagram of the interface circuit.

The circuit consists of an analog and digital part, which are realized in the same board. The interface circuit can perform high-speed measurements of both thermopile voltage and heater resistance. The thermopile voltage is in the range from μV to mV , thus particular consideration should be taken in order to minimize the external noise sources. Therefore, several noise reduction precautions were taken. A usual noise source is through the PC RS232 port, which uses a common ground with the electronic circuit. In order to prevent noise to penetrate to the circuit optocouplers were used. Moreover different ground planes were implemented for analog and digital part in addition with decoupling capacitors at all supply inputs. The data acquisition circuit can determine both the thermopile voltage and the heater resistance by the use of a multiplexer and it employs the SPI port to transfer the corresponding values at a frequency of 4 MHz. In both cases a 16-bit ADC is used. The ADC is capable of measuring bipolar signals in the range of $\pm 2.5\text{V}$ with resolution of $76.3 \mu\text{V}$. It can perform signal conversions with a rate up to 67000 samples per second (67 Ksps), thus the maximum signal frequency that can be represented correctly is 33.5 KHz. Due to aliasing effect, signals with higher frequency may appear as erroneous signals of lower frequency. To avoid this effect a specially designed low-pass Butterworth filter was implemented, which induces a 48.2 db degradation at 33.5 KHz. In order to determine the heater resistance, the value of the corresponding current is needed. The determination of the current is performed by measuring the voltage drop to a shunt resistant (R_s), which is connected in series with the heating resistance, as shown in figure 1. For more accurate measurements the signal was amplified 10 times with an instrumentation amplifier, so as to take advantage of the ADC full range. A low-pass passive filter (10KHz cut-off) was used to avoid electromagnetic noise, which may results to DC offset at the amplifier. The thermopile signal has no reference to the ground (floating), thus it can produce saturation effects to the amplifier. In order to avoid the specific effect two additional resistors (R_1 , R_2), were implemented. A 16-bit DAC, which can apply 2.5V with $38 \mu\text{V}$ resolution was used for the sensor power supply. The DAC was connected to μC through the SPI port at 4 MHz. With this configuration the selected output voltage can be applied within $4 \mu\text{s}$. The required sensor input voltage was $10\text{V} - 12\text{V}$, so the signal was amplified 6 times through a low noise amplifier.

3. Software Procedures

The general program flow is described schematically in figure 2. The main menu provides the operation mode of the sensor. It consists of three choices: Constant Voltage (CV), Constant Power (CP) and Constant Temperature (CT) mode. If CV mode is selected, a submenu appears with two options: Apply Voltage (AV) and Data acquisition (DA). Once AV is selected the user is asked about the preferred applied voltage value (in Volts) and subsequently the specific voltage value is applied to the heater. The DA option provides the ability of measuring the sensor response and the heater parameters once or periodically. If periodical measurements are chosen the system performs the required operations and returns the sensor signal (thermopile voltage), the heater power (mW) and resistance (Ω), constantly with the selected frequency. Obviously the CV mode provides two different functions. The voltage application to the heater and the data acquisition are implemented separately. In

this way, the sensor parameters can be measured either by the use of an external voltage (for calibration reasons) or without applying power, which is very useful in the case that the sensors is used as reference for the determination of the environmental temperature variations.

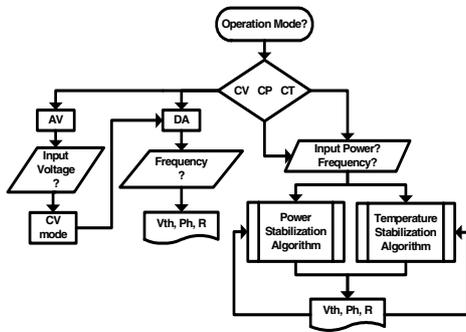


Figure 2. Block diagram of the μC program flow.

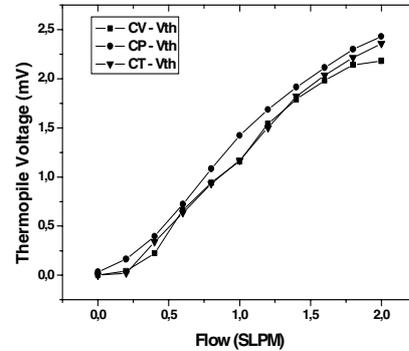


Figure 3. Thermopile signal as a function of flow for the three different operation modes.

In the CP mode an algorithm for the heater power stabilization is implemented. Two parameters should be inserted: the preferred input power (mW) and the frequency in which the measurements should be taken. Consequently the input power is stabilized to the preferred value with an accuracy of about $\pm 25 \mu\text{W}$. First, a small current in the order of μA is applied to the heater in order to determine the heater resistance value at room temperature. Then the first estimation of the applied voltage is made and the specific voltage is applied to the heater. The heater current is extracted through the measurement of the voltage at the shunt resistor. Finally, the new voltage value is calculated so as to maintain the input power stable. The system provides (through RS232 port) the sensor signal, the heater power and resistor with the predefined frequency. In CT mode, the system adjust the voltage supply so as to maintain the heater at a constant temperature. Similar to CP mode, the sensor operation point (in mW) and the measurements frequency, have to be inserted. In this mode of operation the system initially applies a specific power to the heater and extracts the corresponding resistance without flow. Since the resistance changes with power, the system waits until a steady state condition is reached. The criterion for steady state condition establishment is the resistance variation to be less than 4%. When this criterion met the current value of the resistance stabilized with an accuracy of about $\pm 200\text{m}\Omega$. Afterwards the system is ready to perform flow measurements. The specific implementation does not require for the user to know the heating resistance value that needs to be stabilized. The user defines only the sensor operation point (in mW) and the system performs the necessary operations in order to obtain and stabilize the corresponding resistance value. As in CP mode, the system supplies the sensor signal, the heater power and resistor with the predefined frequency. We have to underline the fact that in both CP and CT modes the frequency that is selected by the user is only determine the rate of the data display. The system constantly estimates and re-calculates the value of the power (or the resistance respectively), at the maximum rate (67 Ksps), regardless the value of the frequency that was selected by the user. The data acquisition process in both CP and CT modes acquires the values of the thermopile voltage and the heater resistance alternatively by changing the channel of the multiplexer. This operation induces a $350 \mu\text{s}$ delay since the presence of the filters in the circuit adds a lag to the final value of the measured voltage. In order to reduce the noise due to the fast measurement rate, an averaging of 20 values were applied. The duration of each data acquisition cycle is 1.3 ms.

4. Measurement Results

The interface circuit was used for the evaluation of the thermal flow sensor in the three different modes of operation. The experimental set-up is described in detail elsewhere [4]. The sensor was wall-mounted at the bottom of a semi-cylindrical tube. The length and the effective diameter of the tube

were 6 cm and 1.71 mm respectively. The specific configuration allows laminar flow conditions until about 3 SLPM. Above this value the flow inside the specific housing goes into the turbulent region [5]. The specific housing parameters were selected so as to allow inspection of the sensor responses in both laminar and turbulent flow regions. Pure nitrogen was used in all the experiments.

Figure 3 illustrates the thermopile signal as a function of flow for the three different modes of operation, in the flow range 0-2 SLPM. No considerable variations are observed as expected, since the flow values are particularly low. A sensitivity of 1.46 mV/SLPM is extracted for every one of the three operation modes. Above 2.5 SLPM the flow is entering the turbulent region, so the thermopile signal was extremely noisy to be determined with sufficient accuracy. Different sensor parameters were investigated in order to examine the functionality of the sensor in turbulent flows. Figure 4 and figure 5 represent respectively the heating power and the heating resistance variations in the flow range 0-10 SLPM for the three different operation modes. Obviously, the flow can be determined accurately throughout the whole flow range by obtaining the heater power in CT mode, or the heater resistance in CP mode. The CV mode appears to be less sensitive in both cases. In this way, the system has the ability to operate under various flow conditions by changing the reference parameter. This operation may be performed automatically by the interfacing circuit, which can determine the flow conditions and adapt the measurement process accordingly.

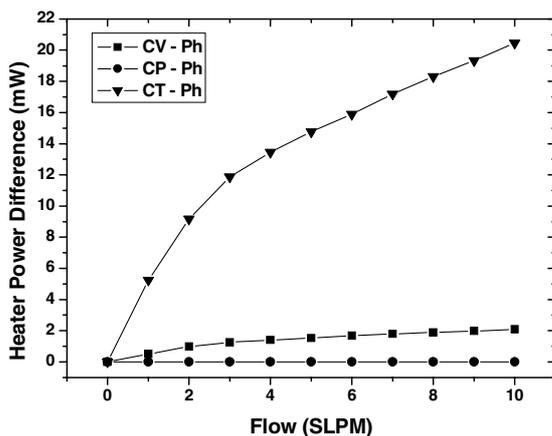


Figure 4. Heater power as a function of flow for the three different operation modes.

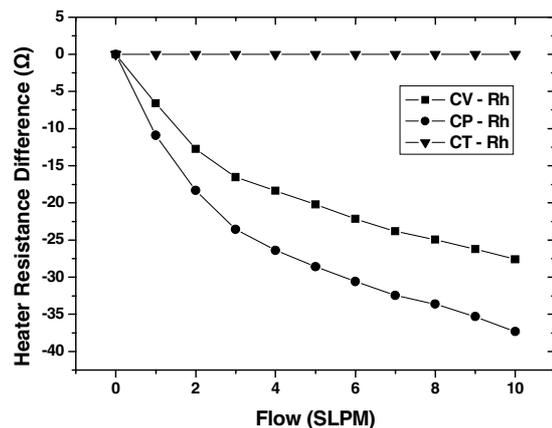


Figure 5. Heating resistance as a function of flow for the three different operation modes.

5. Conclusions

A microcontroller based interface circuit for data acquisition and control of a thermal flow sensor was designed and fabricated. The system performs very fast and accurate measurements of all the sensor parameters. It provides three different modes of operation (CV, CP, CT) through a user-friendly environment. The circuit can stabilize the power and the resistance of the heater with an accuracy of $\pm 25 \mu\text{W}$ and $\pm 200 \Omega$ respectively. The interface was used in the evaluation of the flow sensor in both laminar and turbulent regions. The thermopile signal can be extracted with a resolution of $0.15 \mu\text{V}$ and it is useful for the flow determination in laminar region. For turbulent flows, the changes of the heater resistance or power can be used for precise flow determination through CP or CT mode.

6. References

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